

Interpreting InSAR data: the 1995 Dinar earthquake

The aim of this exercise is to guide participants through the interpretation of Interferometric Synthetic Aperture Radar (InSAR) for a moderate-sized earthquake in Turkey, and to look at some of the implications for the recent tectonic history of the area in which the event occurred.

Introduction

On 1 October 1995, a M_w 6.4 earthquake caused extensive damage to the town of Dinar in western Turkey, a region of active tectonic extension, killing 92 people. The earthquake created a 10 km continuous surface rupture running along the base of the mapped Dinar-Civril fault with a maximum vertical offset of 25–30 cm, tailing off to around 15 cm to the SE. A Synthetic Aperture Radar interferogram has been generated from ERS-1/2 imagery spanning the event, and separated in time by 5 months.

You are provided with:

- A paper copy of the Dinar earthquake interferogram (Figure 1)
- A grid, for plotting a line-of-sight displacement profile across the center of the deformation pattern.
- A topographic profile drawn along the same profile line.

You can optionally download two kmz files – an image overlay, and a file containing some of the annotations shown in Figure 1 – for use in Google Earth. [Hints on how to make use of these files will be included after the questions.]

What does the interferogram tell us about the earthquake?

The interferogram (Figure 1) represents a map of the displacement of the ground surface during the earthquake. The pattern of interference fringes can be interpreted as a series of contours of equal surface displacement. When interpreting such a pattern it is important to know the sign convention used in plotting the interferogram. In this case, **each successive cycle of colors from blue to yellow to red indicates an increase in the distance between the ground and the satellite** (positive ‘range change’) **of 2.8 cm**. If we assume that the ‘far field’ of the interferogram (i.e. the areas far away from the fault) was not displaced in the earthquake, then we can estimate the amount of displacement in the earthquake by starting in the far field and counting the fringes inwards.

Such data can be used to give additional information about the earthquake that could not be determined by seismology or field investigation alone, such as the amounts and relative proportions of uplift and subsidence caused by the event over an area tens of kilometers wide. In combination with the digital elevation model of the same area, we can also examine the relationship between earthquakes and surface topography.

Examine the interferogram, either on paper or on Google Earth.

- Considering the location of the fault, the pattern of deformation, the sense of displacement, tectonic setting and/or the topography, determine what type of dip-slip fault the Dinar-Civril fault is, and hence the positions of the hangingwall and footwall with respect to the fault.

Next, count the fringes on either side of the fault, and estimate the maximum vertical displacements. Then use the sign convention of the color scheme to interpret these displacements as uplift and/or subsidence. **[Note that because the earthquake was a dip-slip event, most of the surface deformation was vertical and hence you can think of the fringes as contours of vertical displacement.]**

- How many hangingwall fringes are there? How much was the hangingwall displaced, and in which direction, during the earthquake?
- How many fringes are there on the footwall and how much was it displaced (and in which direction)?
- What was minimum total throw in the earthquake (i.e. uplift + subsidence)?
- Elastic modeling of the interferogram and information from seismology suggests that the fault dipped at ~40 degrees. Considering the minimum throw observed in the earthquake, what is the minimum amount of slip on the fault?

- Compare the total throw estimated above with the size of the measured surface rupture. Explain potential reasons for any discrepancy.

Asymmetry between uplift and subsidence, and long-term deformation

Using the grid provided, and starting in the far field, draw a vertical deformation profile for the Dinar earthquake along the section line X–X', converting the repeated fringe intervals into cumulative displacements. Do not continue the profile through areas that are incoherent (i.e. noisy), such as the area SW of the Dinar-Civril fault.

[Hints:

- (i) At 2.8 cm per fringe, $2\frac{1}{2}$ fringes = 0.07 m, and 5 fringes = 0.14 m.
- (ii) Where the fringe gradient is at its largest, counting every fifth fringe is reasonable.
- (iii) Rather than try to track displacement across the fault, consider displacements on the hangingwall and footwall separately, starting each time with zero displacement in the far field.]

Once your profile is complete, answer the following questions:

- What was the ratio of uplift to subsidence in the earthquake?
- How does this degree of (a)symmetry compare with that of the topography along the same profile?

These questions are optional for this short course!

- In the long term (over $10^5 - 10^6$ years) for similar fault systems, the uplift to subsidence ratio is somewhere between 1:1 and 1:4. How can you reconcile this discrepancy?
- If the topography were flat before the Dinar fault existed, and the relief observed today is equal to the cumulative throw of many earthquakes, how many earthquakes would it take to make the present topography? Comment on the likely accuracy of your estimate.
- Repeat the calculation, assuming that the observed topography was only the result of footwall uplift (use the long-term uplift:subsidence ratios provided above, and give minimum and maximum answers).

Google Earth hints and tricks

You can adjust the transparency of the image overlay, if you want to see some of the detail of the underlying imagery, by editing the overlay using 'Get Info' or 'Properties' (depending whether you are using the PC or Mac version). [About 30% transparency tends to be a good compromise.] Look in particular for the locations of mountains and lakes around the epicentral area, which are diagnostic of the tectonic setting and style of faulting.

Using the 'Path' tool, it is possible to draw a cross-section along a chosen line:

- First you must make a path. The Path tool is located in the toolbar, to the left of the 'Image Overlay' tool. You can click on the appropriate button or select 'Add Path' from the 'Add' menu. You can make a straight line with two mouse clicks, one at each end of the line. Whilst the 'Add Path' (or 'Edit Path') pop-up window is open, the line vertices can be edited by clicking on them.
- Add a name for the path if you feel like it. Click OK in the Add Path window.
- Right click on the newly-created path in the 'Temporary Places' list. Select 'Show Elevation Profile' from the pop-up menu.

Optional extension: elastic dislocation modeling

Visit earthquakes.aranzgeo.com to try the 'Visible Earthquakes' web-based tool for manual modeling of earthquake interferograms.

Readings and acknowledgements

This exercise was adapted by Gareth Funning (gareth@ucr.edu) from an exercise originally developed by Tim Wright of the University of Leeds.

For further information on the Dinar earthquake, the interferogram and its interpretation, you can read:

Wright, T. J., Parsons, B. E., Jackson, J. A., Haynes, M., Fielding, E. J., England, P. C. and Clarke, P. J. (1999) Source parameters of the 1 October 1995 Dinar (Turkey) earthquake from SAR interferometry and seismic bodywave modelling, *Earth Planet. Sci. Lett.*, 172, 23-37.