Focus Earth

The Izmit Earthquake: A Quick Post-Seismic Analysis with Satellite Observations

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Buildings were razed to the ground and electric and telephone lines cut in Izmit, in northwest Turkey, by the strong earthquake that shook the region on 17 August 1999. The National Earthquake Information Centre reported a quake of magnitude 7.8, almost as strong as the 7.9-magnitude San Francisco quake that claimed 700 victims in 1906. In Turkey, four days after the event, the death toll had risen to more than l0 000, with 45 000 reported injured and thousands of people still missing.

The earthquake's epicentre was identified as being between Izmit and Bursa (Fig. 1), about 100 km east of Istanbul. High casualty figures were reported not only in Golcuk, but also in the towns of Derince and Darica, both situated to the west of Izmit. The large town of Adapazari, northeast of Sapanca Lake, was also severely damaged by the quake.

Since this devastating first shock, there has been a second series of tremors further east, but along the same fault line, peaking on 12 November and bringing death and destruction to the towns of Kaynashli and nearby Duzce.

Geological setting of the area

Turkey's North Anatolian Fault Zone (NAFZ) is the most active in the country. Historically, it is here that most of the biggest earthquakes have originated. The NAFZ zone splays out into three strands at about 30.5 deg E. The northern strand crosses the Bay of Izmit and the Marmara Sea, and reappears in the Gulf of Saros. Many researchers believe that the Marmara Sea region is a depression that is slowly widening, due to two fault systems running in parallel.

The tectonic activity in the area is basically explained by movements of the Eurasian, Arabic and African plates activating different portions of the Anatolian fault system (Fig. 2). The NAFZ is a close analogue of the San Andreas fault in California. Both structures are active, have similar slip rates, lengths and straightnesses, but earthquakes occur five times more frequently in the NAFZ (M > 6.7!).

Figure 1. Geographical map of the earthquake area

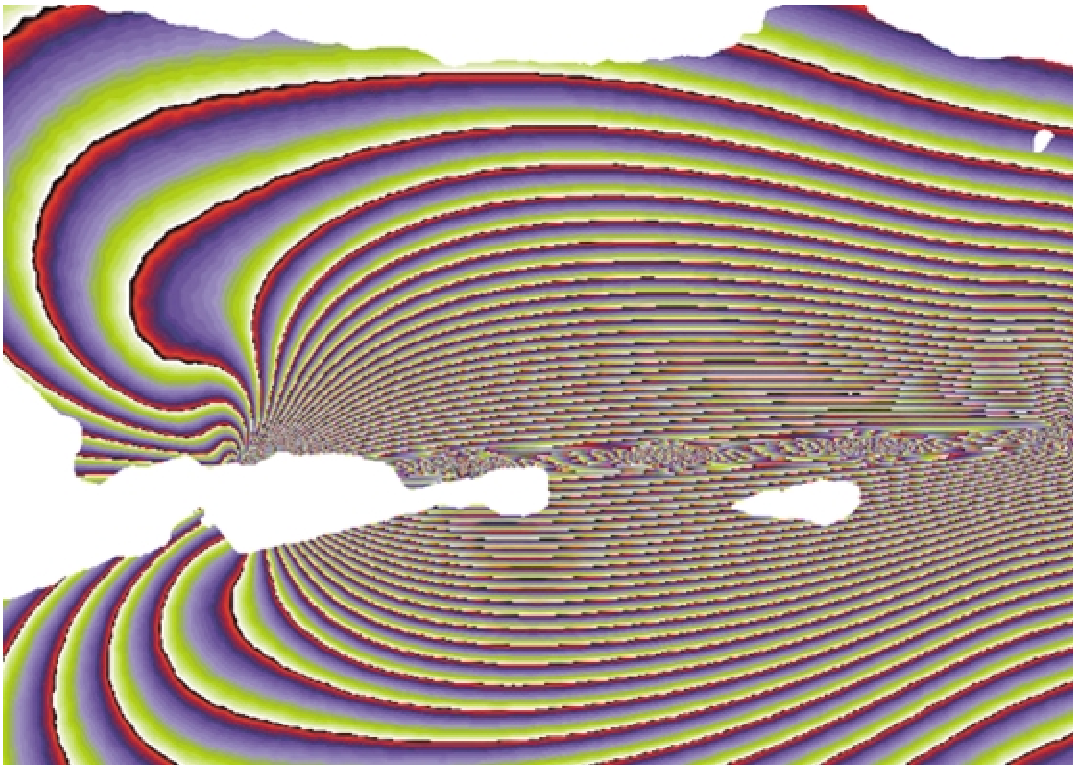


Figure 3. Theoretical surface deformation model based on geophysical data. The comparison with Figure 4 demonstrates the possibility to reconstruct the effects of a seismic event through the interpretation of ERS SAR interferometric fringes

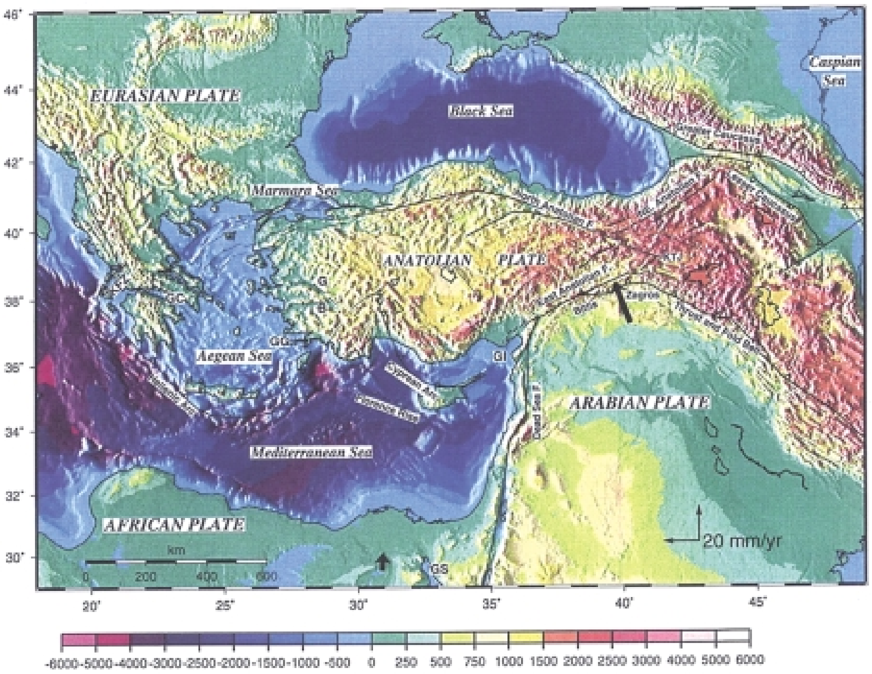


Figure 2. Overview of the main geological and morphological features evidencing the tectonic plate relationships in the eastern Mediterranean region

Seismic-event analysis

The 17 August earthquake originated at a depth of between 10 and 16 km along almost vertical ruptures. Four different fault segments became active during the two consecutive shocks: the first shock lasted 12 seconds and affected the western part, i.e. Golcuk, Izmit – Sapanca and Arifiye – Akyazi. Eighteen seconds later, the Earth shook again for 7 seconds, this time along the Golyaka rupture to the east-northeast of Sapanca. The surface displacement reached a maximum of 5 m near the town of Arifiye. The average offset along the active fault system was 2 to 4 m.

Earthquake effects as observed by ERS SAR

ERS-1 and 2 data were used to obtain a SAR differential interferogram showing the surface deformation in an area between Istanbul and the Lake of Sapanca. A theoretical deformation model (Fig. 3) derived from geophysical data was compared with the ERS SAR-derived phase interferogram (Fig. 4). The result of the modelled earthquake movement can be recomputed and displayed as fringes. The geophysical interpretation of the model is that the rupture occurred along an east-west fault, causing a predominantly horizontal movement (right-lateral strike).

In the interferogram (Fig. 4), each colour cycle from red to yellow corresponds to a ground displacement of 28 mm in the slant range direction (ERS satellite's viewing direction). By counting the number of fringes, one can calculate the co-seismic deformation. In the present case, 28 ± 2 fringes can be observed across the image. They suggest a deformation of about 81cm in the ERS viewing direction. The horizontal component of this measurement can be simply computed based on the viewing incidence angle (see Fig. 7).

With this approach, SAR interferometry can be used to quantify the dislocation produced by an earthquake. Basically, three measurements are needed to define the spatial displacement vector. Hence, three observations or interferograms from different viewing angles are required. In practice, the SAR data from ERS's ascending and descending passes would provide two of the three observations needed; the third might

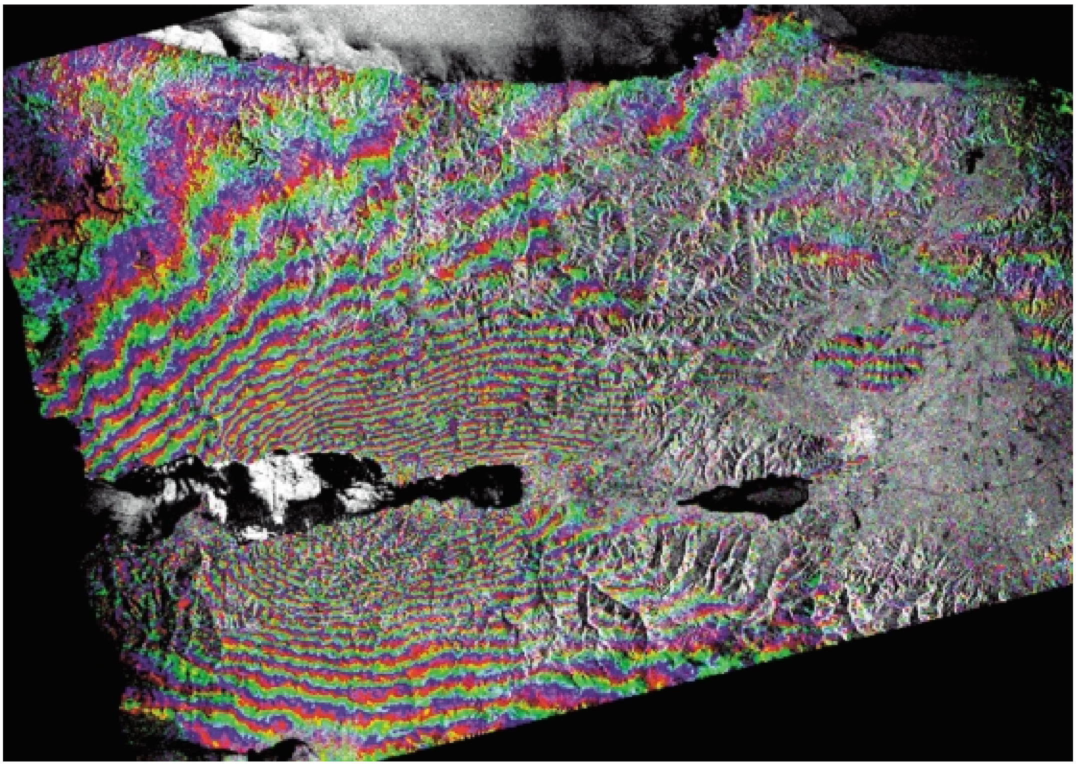


Figure 4. Interferometric fringes computed from an ERS-1/ERS-2 data pair acquired before and after the earthquake. The fringes are superimposed on a SAR amplitude image

be retrieved from historical data and from a tectonic analysis of the area.

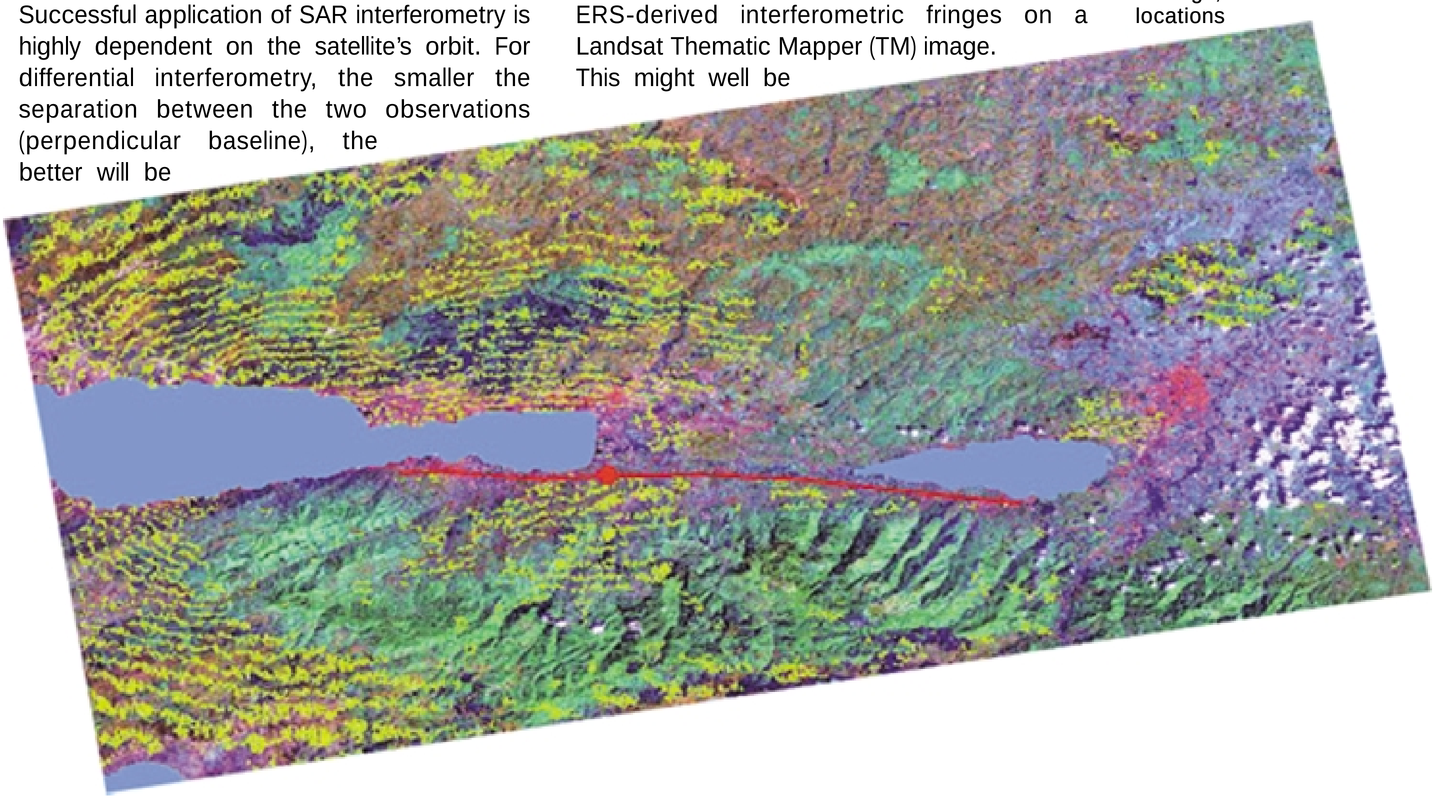
In the Turkish case, we find ourselves with an exceptional view of events in being able to observe a nearly horizontal movement, occurring in an east-west direction that is almost parallel to the sensor observation direction. In this particular case, one observation can be sufficient. In fact, the displacement so-derived (207 cm) is in good agreement with both ground measured and modelling results.

Successful application of SAR interferometry is highly dependent on the satellite's orbit. For differential interferometry, the smaller the separation between the two observations (perpendicular baseline), the better will be the result. Small baselines are optimal to preserve the coherence; at the same time, the influence of ground topography in the interferogram becomes negligible. In the case of the ERS SAR image pair used here, the perpendicular baseline was about 18 m over Izmit. This low figure was obtained thanks to the careful satellite orbital monitoring and manoeuvering performed by the ESA ground controllers at ESOC in Darmstadt (Germany).

Interferometric/optical image product

Figure 5 shows an attempt to superimpose the ERS-derived interferometric fringes on a Landsat Thematic Mapper (TM) image.
This might well be

Figure 5. The interferometric fringes shown in Figure 4 were superimposed on a Landsat Thematic Mapper (TM) image. Urban areas are shown in red/magenta. The intensity of the ground deformation is proportional to the fringe density. This image product enables a first assessment of damage, even for remote locations



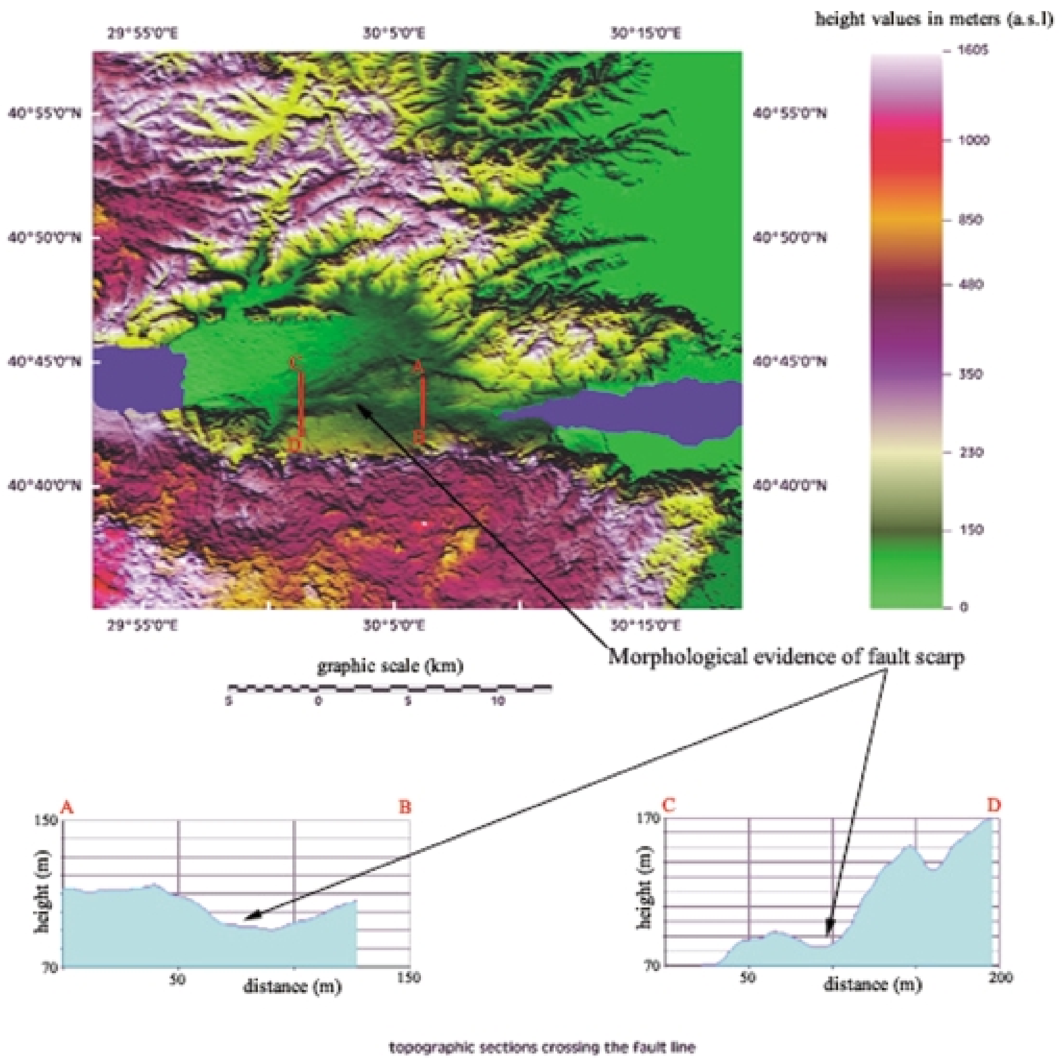


Figure 6. The shaded-relief image was obtained from an ERS SAR interferometric DEM. Height values are colour-coded. The image product can be used in studies relating to the recognition of tectonic and morphological lineaments

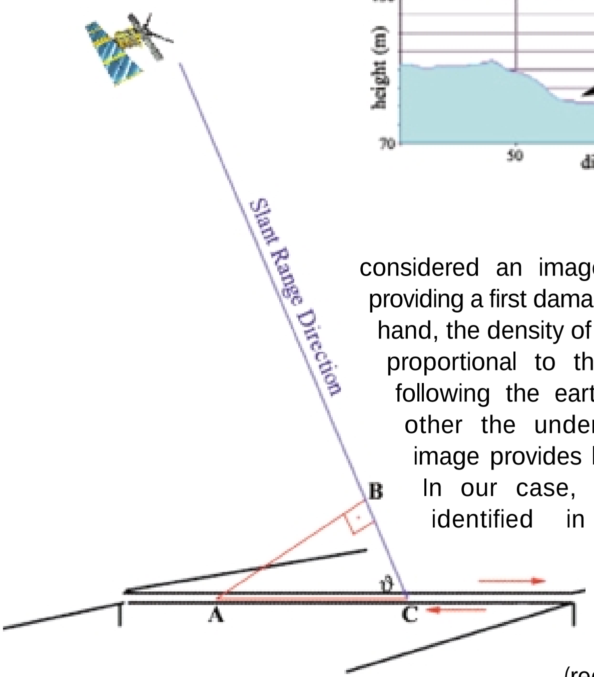


Figure 7. ERS SAR slant-range viewing with respect to the geological fault movement. A simple geometrical function can be used to determine the movements horizontal component.

BC = slant-range deformation of approx. 81cm
AC = fault-plane horizontal deformation of approx. 81/cos J = 207 cm (J = 67 deg)

considered an image product suitable for providing a first damage assessment. On one hand, the density of the fringes (in yellow) is proportional to the degree of damage following the earthquake, while on the other the underlying optical satellite image provides land-cover information. In our case, urban areas can be identified in magenta: relevant damage data are retrievable from the fringe density. The active fault location (red line) was performed by using conventional geological maps and was further refined with satellite image interpretation. The epicentre is marked with a solid red circle.

Geological analysis enhanced by ERS SAR interferometry

A altitude colour-coded and shaded Digital Elevation Map (DEM) generated from the ERS tandem pair of 12 - 13 August 1999 is shown in Figure 6. This image clearly shows the morphological and tectonic features in the area. In this particular case, the fault from which the 17 August 1999 earthquake originated could be easily identified by analysing the enhanced morphology shown by the DEM. This kind of ERS InSAR product can be used by specialists to study tectonically active areas not only in this region, but also elsewhere in the World. One of the most significant outputs from such an analysis is ‘risk maps’.

Conclusions

For the Izmit earthquake, as for previous similar events all over the World, ERS SAR interferometry has provided extremely useful results. A quantitative analysis was performed to assess the overall displacement on the surface. It is believed that an image pair from an ascending and a descending pass might be sufficient, together with tectonic information, to estimate the movement quantitatively. In this particular case, the favourable situation with respect to both satellite orbit and tectonics allowed the dislocation to be determined using a single interferometric pair, together with geological information. A SAR interferometric/optical image product has been worked out which might well meet the requirement of gaining immediate access to information on land cover and earthquake intensity whenever and wherever such natural disasters occur.