3D Strain Estimation and Velocity Analysis of Turkey from GPS data

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Abstract

All the large earthquakes that have occurred in Turkey are largely on the borders of the compressional/extensional strains. However, the nature and characteristics of strain patterns of seismic deformations in Turkey have not yet been reported. This study, for the first time, describes and maps the geographic distribution of the normal and shear strains using the Turkish Real Time Kinematics-Continuously Operating Reference Stations Network (RTK-CORS Network from 2009 to 2012). We analyze the strains with respect to the CORS network and estimate the horizontal/vertical components of strain tensors using GPS velocity data. We utilized the delaunay triangulation model and carried out biharmonic spline interpolation method to obtain the strain component maps. The normal and shear strain variations along the x, y, z-axes and the xy, xz, yz-planes, respectively, show that vertical displacements are quite effective on the tectonic processes. The normal strain in the vertical direction exhibits a structure in coherence with the topography and the extension stands out in the regions with high mountains. The main deformational component is the shear strain on the yz-plane that determines the faulting mechanisms in Turkey. The normal strain along the y-axis and horizontal shear strain on the xy-plane have a great importance in terms of the general movements of the Anatolian Block along the E-W direction. We conclude that the normal and shear strains appear to be a very subtle barometer for tectonic stress conditions within Turkey, and that strain analysis can be of great importance in understanding the nature and characteristics of seismicity of Turkey.

Introduction

A Continuously Operating Reference Station network, called RTK-CORS (TR) was established by General Command of Mapping (GCM) in Turkey between 2009 and 2012. The CORS-TR network consists of 147 GNSS reference stations with interstation discrepancies ranging from 70 to 100 km and was mainly designed to provide Real Time Kinematics (RTK) applications and to monitor crustal movements. In this study, we apply the biharmonic spline interpolation method and Delauney triangulation technique of GPS data processing to evaluate GPS data from the permanent 147 stations within the CORS-TR network.

CORS-TR data are analyzed via GAMIT/GLOBK V10.4 software in daily basis since the system was installed. GAMIT consists of programs to process phase data to estimate three-dimensional relative positions of ground stations and satellite orbits, atmospheric zenith delays and earth orientation parameters while GLOBK which combines geodetic solutions such as GPS, VLBI, and SLR experiments is a Kalman filter. Site coordinates, satellite coordinates, and covariance matrices are analyzed by Kalman filtering, without forcing, to obtain accurate velocities and coordinates. Local and global IGS solutions are edited by SOPAC and are evaluated to provide stabilization. The reference frame used in the computation is International Terrestrial Reference Frame 2008 (ITRF2008). The GPS files we used are from one day every three months for the period 2009-2012.

The velocities obtained by GPS data processing over repeated surveys provide useful information on strain state of crustal deformation. In this study, all data are involved in computation. Strain tensors are calculated from the GPS velocity field by MATLAB grid-strain estimation software. The problem is considered as three-dimensional. GPS velocity provides deformation rates on the crust’s surface in three directions (x, y, z-axes). Here we use a computationally cheap, easy and fast Delauney triangulation technique of gridded GPS data.

Results

The following figures illustrate the strain component maps. The warmer colors represent the positive strain resulting from compression or contraction while the cooler colors reveal the negative strain that expresses divergence or extension. The strain values used in the maps are expressed in parts per billion (ppb).

Normal strains

Fig. 1 shows the normal strain variation map along the x-axis, and indicates that the major part of the inland areas except for the Aegean Region (AR) extends along the x-axis. The AR, however, tends to compress in this direction. In general terms, East Anatolia Fault Zone (EAFZ) enveloped by the extensional zone, while the compressional and extensional zones alternately follow each other throughout North Anatolia Fault Zone (NAFZ). It is observed that a considerably large area in the midst of the Marmara Sea (MS) tends to expand along the x-axis in the western segments of NAFZ where large earthquakes are expected. The normal strain along the y-axis has special importance since the Anatolian block entrapped between NAFZ and EAFZ moves in the east-west direction. As depicted in Fig. 2, the compressional and extensional zones along the y-axis exhibit a more homogenous dissemination compared to those in the x-axis, and an alternating structure in the NS and EW directions. As a consequence of this pattern, the consecutive extensional and compressional zones exist in both NAFZ and EAFZ.

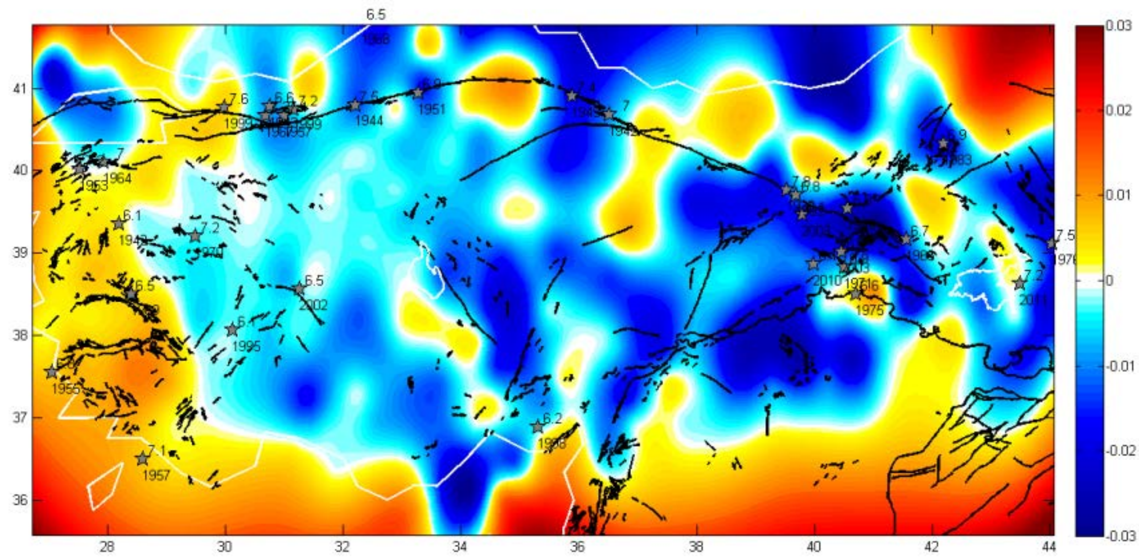

Figure 1. Normal strains along the x-axis (max rms = ± 2 x 10^{-5}ppb). Note the compressional strains in the Caucasus, Arabian plate and W-ends of AR and the extensional strains in the W-part of MS.

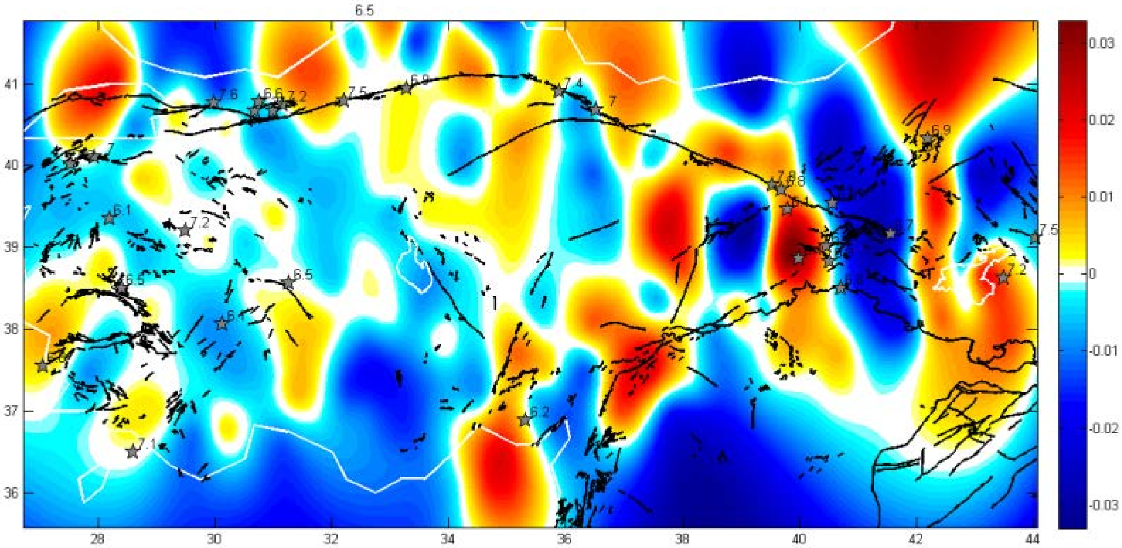

Figure 2. Normal strain in the y-axis (max rms = ± 2 x 10^{-5}ppb). Note the compressional strain in the ruptured zone of the 2011 Van earthquake (LV) consistent with its aftershock distribution (6000 events).

Shear Strains

In Fig. 3 the shear strain on the xy-plane demonstrates a circular closure with a very high extension in central Eastern Anatolia (EAAP) and Lake Van (LV). This closure area is, interestingly, where LV has become a morphological dome with minimum crustal thickness resulting from asthenospheric uplift due to a lithospheric split. The local compressional zone situated in the middle of this circular closure with a structural doming coincides with a fault line. Examining the shear strain on the xz-plane (Fig. 4) unfolds the typical tectonic regime of Turkey, particularly in EAAP, and validates our work. The southern sections of LV are distinctive with a large compression, hence forming the Bitlis-Pötürge Massif (BPM) stretching in the E-W direction, which ends at LV in the south. Further north of this massif is the EAAP which manifests compression with rather low values compared to its southern end (BPM). Fig. 3 clearly depicts the difference in shear strains between BPM and EAAP, standing out as zonal distinction. The Northeastern Mediterranean region, however, is explicit with its clearly low value compression while the further west is characterized by an extension uniting AR with the N-S extensional zone.

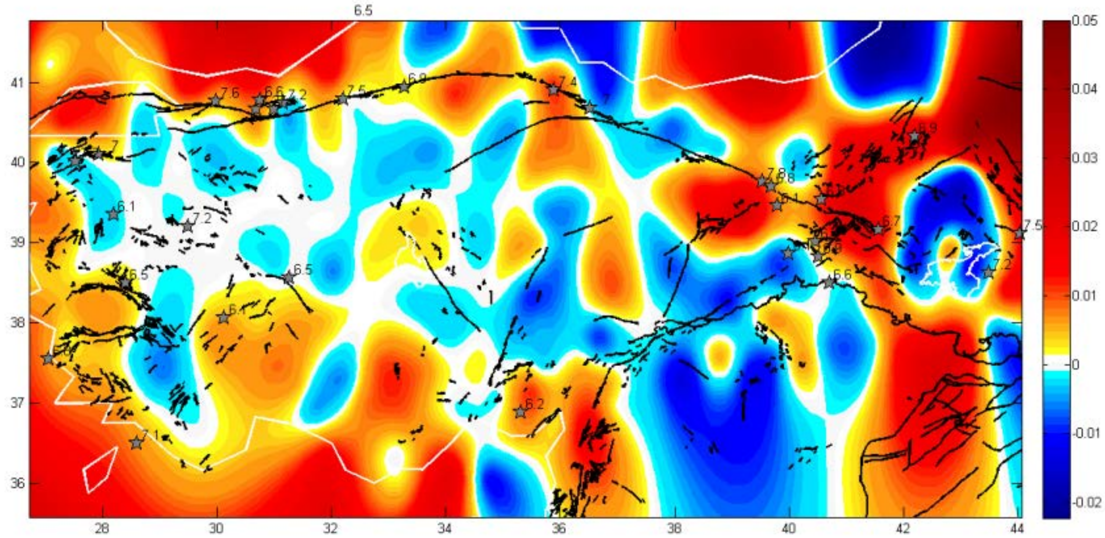

Figure 3. Shear strain in the xy-plane (max rms = ± 7.7 x 10^{-6} ppb). Note the anomalous circular closure of extensional shear strains in the center of EAAP, LV and the compressional shear strains in the W-part of MS.

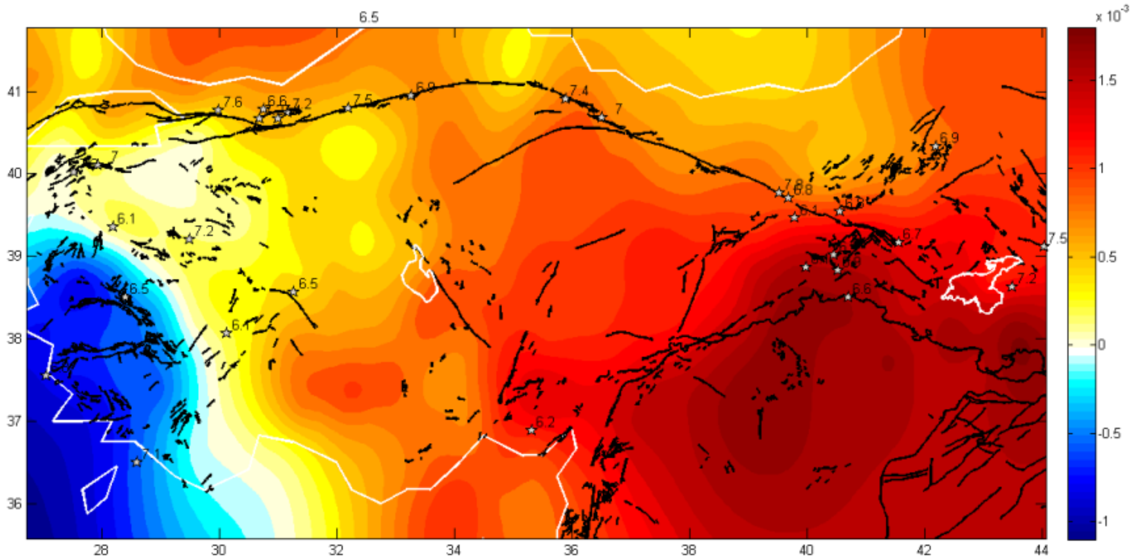

Figure 4. Shear strain on the xz-plane (max rms = ± 4.7 x 10^{-4} ppb). Note the high extensional shear strain in W-ends of the AR and the high compressional shear strain in the Arabian plate, S-ends of EAAP that form BPM.

Conclusion

This study provides an important implication for derivation of active strains at network stations and applying analytical surface deformation theory. This shows that the strain maps contribute to any seismic hazard assessment through the identification of regions of localized, continuous and active deformations in Turkey. The computational analysis of strain fields produces significant seismic and tectonic constraints necessary for a continuous strain modelling of the tectonic activity in Turkey. The normal and shear strains indicate that the obtained strain component maps provide important insights into the location of the seismic events. The observed deformations are related to continuous strain fields on the continuous displacement field.