Space-time evolution of crustal deformation from GPS data: Principal Component Analysis (PCA), Independent Component Analysis (ICA) and the L’Aquila earthquake (Central Italy)

ABSTRACT

Geodetic time series data are usually studied through classical statistical techniques, that is decomposing them into different deterministic signals. Recently, new techniques have been developed and applied to geodetic data in order to extract much more information than from them. An example is the Principal Component Analysis (PCA), used both to detect network errors in GPS data (such as the Common Mode Error, CME, see Dong et al., 2006), and to identify local signals coming from a certain region. The latter approach is particularly useful for understanding geophysical processes, and the PCA-based Inversion Method (PCAIM, see Kositsky and Avouac, 2010) is a good realization of this concept. We used this method to analyze the GPS data of the 2009 L’Aquila earthquake (central Italy). A strong limitation of the PCA is that it is not able to separate multiple mixed sources. In other words, the PCA technique is not effective in treating the so-called Blind Source Separation (BSS) problem. For this goal, it is necessary to be efficient techniques such as the Independent Component Analysis (ICA). The objective of my project is to modify the decomposition step of the PCAIM code. In particular, I want to introduce the possibility to perform an ICA decomposition, with the goal to detect and separate multiple sources of signal.

3 - RESULTS

We reproduce the original data adopting one principal component for the coseismic deformation and two for the postseismic (see Fig. 3). We invert for both coseismic and postseismic slips using the Okada (1985) formulation. We assume a shear modulus of 30 GPa and a Poisson ratio of 0.25. In both cases we estimate the regularization parameter $\gamma$ using the L-curve method considering the roughness of the model and the reduced $\chi^2$.

We find $\gamma$-values in the range $10^{-2}$-$10^{-5}$, with the most frequent value of the order of $10^{-3}$, in agreement with studies of fault rocks typical of these regions at elevated temperatures and under fluid-saturated conditions (Souder et al., 2013). Small $\gamma$-values, such as $10^{-4}$ (Marone et al., 1991), characterize fault regions where transitions between velocity-strengthening ($\sigma > 0$) and velocity-strengthening ($\sigma < 0$) occur. These regions may undergo both afterslip and afterslips during the post-seismic phase (Borosiand Coceo, 1996). The M 4.4 aftershock occurred 77 days after the mainshock (see Figures 4 and 5) in a seismic event located on the Campotosto fault below the region undergoing afterseismic activity where the aftershock occurred was affected by a negligible coseismic ground acceleration due to the L’Aquila mainshock (ACCF=$0.01$ MPa). Instead, it experienced a Coulomb stress increase of 0.06 MPa due to afterslip on the Campotosto fault, and it was slightly unloaded by afterslip on the Paganica fault, resulting in a net increase of stress on the mainshock of post-seismic stage of 0.05 MPa.

1 - THE L’AQUILA EARTHQUAKE

The mainshock of the 2009 L’Aquila earthquake occurred on a NE-trending, SW-dip fault with a normal faulting, activated a complex system of SW-dipping segments. The most relevant are the Paganica and Campotosto faults (see Fig. 2). We used the relocated aftershocks catalogue of Chiaraluce et al. (2011) to define a suite of fault geometries for the Paganica and Campotosto faults to be used in the coseismic and postseismic slip inversions, and to test the sensitivity of GPS data to the use of increasingly complex fault geometries, using as a benchmark for the Paganica fault its geodetic solution. We also consider the possibility that rake constraints affect the slip distributions, since published results did not investigate this aspect.

2 - GPS DATA

The input GPS time-series have been obtained by analysing raw data with the GMAT/GLOBK software, as described in Sarna-Wojcik et al. (2012). We use a PCA method to estimate spatially constrained deformation errors (CME) for a wider area in the Euro-Mediterranean, using a set of 640 cGPS stations, while excluding those in the epicentral area and its surroundings. Filtering the time-series provides a significant gain in the signal-to-noise ratio, which is particularly important for studying moderate earthquakes. For the coseismic slip distribution we use 67 GPS stations; to study the postseismic we use 27 GPS stations that recorded continuously after the mainshock.

REFERENCES

