MODELING AND DETECTING THE (HIDDEN) EFFECTS OF POROELASTICITY IN INSAR AND GPS DATA, THE CASE OF THE EMILIA ROMAGNA EARTHQUAKES

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Introduction. The two mainshocks occurred in Emilia-Romagna in 2012 were close in time and space (Fig. 1a). We model the influence of fluids and pore-pressure changes on both surface displacements and on the Coulomb failure function (CFF). The poroelastic modeling was performed in a 3D half-space whose elastic and hydraulic parameters are depth dependent, in accordance with the stratified geology of the Emilia-Romagna subsoil. The model provides both the post-seismic poroelastic displacements and the coseismic and postseismic pore-pressure changes induced by the May 20 and May 29 mainshocks. The results are compared with postseismic InSAR and GPS displacement time series. We find that pore-pressure changes have the same magnitude in both the along-strike and along-dip directions. Although we cannot completely rule out that the slow fluid flow occurring at hypocentral depth could have played an active role in carrying on the Emilia-Romagna seismic sequence, we find small postseismic pore-pressure and CFF changes (~10 kPa), and we think that the triggering of the second mainshock is more due to stress variations related to the tectonic activity than to fluid migration.

GPS and InSAR data. We have considered the analysis of ground displacements using data from continuous GPS stations (May 2012–May 2014 time interval). The detrended and filtered displacement time series (GAMIT/GLOBK and QOCA software) are the input of an independent component analysis (ICA) performed adopting a variational Bayesian approach (vbICA, Chan et al., 2003; Gualandi et al., 2016). The vbICA performs a spatiotemporal separation of the geodetic data into a limited number of signals, interpreted as physical sources that generated the observed displacements. Each source has a spatial distribution (U) and follows a given temporal evolution not a priori imposed (V) (Fig. 1b and 1c). The original data can be reconstructed
with the weight coefficients $S$ (mm). Both temporal function and spatial distribution of the first independent component, IC1, agree with what we would expect from afterslip occurring on the two faults involved in the seismic sequence. The IC2 exhibits a large time scale, and it is probably related to a multiannual signal (e.g., Serpelloni et al., 2018; Silverii et al., 2016). The temporal function of IC3 shows a rapid increase in the early postseismic stage (first 10 days after the May 20 mainshock). Its spatial response is maximum at MO05, the closest station to the epicentral area and we interpret IC3 as the poroelastic response at the surface. The locations of the InSAR (SBAS) time series at points 1 and 2 [from Albano et al. (2017) and Cheloni et al. (2016)] are shown in Fig. 1a.

**Poroelastic model.** We use the software written by Wang and Kümpel (2003), which allows us to represent a horizontal-layered half-space with different elastic and hydraulic parameters.
It consists of two separate routines: PEGRN, which calculates the Green functions needed for the strain and stress computations, and PECMP, which computes the poroelastic variables (such as deformation, stress tensor, pore pressure, and Darcy flow) at receiver locations and at selected time steps. During the simulation, each fault can be activated, i.e. undergoing slip steps, at different time instants. In the postseismic stage, the faults are assumed as locked.

In our simulations for both the May 20 and May 29 events, we use the coseismic slip distribution models, the faults geometries, and the elastic layering proposed by Nespoli et al. (2017). The four layers of the poroelastic half-space have different diffusivity values representing a decrease of permeability over depth as proposed by Ingebritsen and Manning (2010).

**Results and Discussion.** At the surface, the modeled poroelastic, postseismic horizontal displacement reaches the maximum absolute value of 1 cm about 10 days after the May 20 mainshock. This duration is related to the draining time of the shallowest layers of our model, since at this time scale the deeper layers have a second-order influence on surface deformation. After 1 year, the modeled postseismic poroelastic displacement field is in accordance with the IC3 (Nespoli et al., 2018), so we interpreted this component as the poroelastic contribution to surface displacement, that is mainly confined in the near field. This interpretation is mainly supported by GPS data since InSAR time series can be temporally too sparse to sample the related transient displacement signal. In particular, at point 1, the modeled poroelastic Line Of Sight (LOS) displacement explains about 50% of the total measured displacement: here the afterslip significantly contributed to the total postseismic displacement. Positive postseismic poroelastic CFF changes, spatially correlated with the regions seismically activated, are estimated starting from the May 20 mainshock to 30 days of simulations, nonetheless, they are small (~10 kPa). Finally, we found an important fluid flow along the faults’ strike direction (Fig. 2), especially when assuming a heterogeneous slip distribution. This means that, in order to simulate the evolution of pore-pressure induced by earthquakes, a 3D fluid flow modeling can be very important.

**References**


Cheloni, D., Giuliani R., D’Agostino N., Mattone M., Bonano M., Fornaro G., Lanari R., Reale D. and Atzori S.; 2016: 
New insights into fault activation and stress transfer between en echelon thrusts: The 2012 Emilia, Northern Italy, 

Govoni A., Marchetti A., De Gori P., Di Bona M., Lucente F. P., Improta L., Chiarabba C., Nardi A., Margheriti L., 
Piana Agostinetti N., Di Giovambattista R., Latorre D., Anselmi M., Ciaccio M. G., Moretti M., Castellano C. 
and Piccinini D.; 2014: The 2012 Emilia seismic sequence (Northern Italy): imaging the thrust fault system by 
accurate aftershock location. Tectonophysics, 622, 44–55.


Ingebritsen S. E. and Manning C. E.; 2010: Permeability of the continental crust: Dynamic variations inferred from 

layered crust on the coseismic slip inversion and related CFF variations: Hints from the 2012 Emilia Romagna 

Nespoli M., Belardinelli M. E., Gualandi A., Serpelloni E. and Bonafede M; 2018: Poroelasticity and Fluid Flow 

Serpelloni E., Pintori F., Gualandi A. et al.; 2018: Hydrologically-induced karst deformation: Insights from GPS 

Silverii F., D’Agostino N., Métois M., Fiorillo F. and Ventafridda G.; 2016: Transient deformation of karst aquifers 
due to seasonal and multiyear groundwater variations observed by GPS in southern Apennines (Italy). J. Geophys. 

in a multilayered half-space. Geophysics, 68(2), 705-717.