Comment on "Long-term strain oscillations related to the hydrogeological interaction between aquifers in intra-mountain basins: A case study from Apennines chain (Italy)" by Devoti, Riguzzi, Cinti and Ventura

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The paper by Devoti et al. (2018) analyses the GPS time series from seventeen stations located inside and in the neighboring of the L'Aquila intermountain basin. The authors suggest that the observed movements are due to regional hydrological processes likely associated with multi-annual climatic variations.

After the presentation of the data and the interpretation based on the response of a tensile dislocation embedded in an elastic medium, the authors, at the end of the manuscript, assert that Moro et al. (2017) misinterpreted the InSAR displacement time series over the L'Aquila basin in terms of seismic precursor of the 2009 L'Aquila earthquake. Devoti et al. (2018) base this conclusion on the analysis presented in their Figure 10, where they compare the GPS displacements at one station only (out of seventeen available GPS stations) with the InSAR displacements shown in Figure 1 of Moro et al. (2017). Devoti and co-authors interpret the oscillations of both GPS and InSAR data as due to the climatic cause. This conclusion is in contrast with that of Moro et al. (2017), who ascribe the observed InSAR deformation to a preseismic phase.

The analysis performed by Devoti et al. (2018) contains an issue in the GPS-InSar comparison that invalidates their conclusions. Moreover, the model contains geological and hydrogeological inconsistencies that make the analysis not robust. In the following, we describe these two points and show that the data do not support the conclusions of hydrological response instead of preseismic behavior.

It is common knowledge that InSAR data measure deformations relative to a point (reference point) within the SAR image frame, assumed stable over the time. On the contrary, GPS data are referred to a different reference system (i.e., the ITRF 2008 in Devoti et al. (2018)) in which any point can be considered fixed. In Devoti et al. (2018), the authors arbitrarily shift the InSAR time series shown in Moro et al. (2017)'s figure 1a of approximately 10 mm to supposedly demonstrate the fit with the INGP displacements. Such a shift is misleading since the SAR time series commonly start from a zero deformation condition, as shown in Moro et al., (2017). Moreover, the InSAR displacements in Moro et al. (2017) represent the geometric average of all of the coherent points (several hundred) falling within an area of some squared kilometers corresponding with the Quaternary basin of Preturo, while the INGP GPS station shows the displacement of a single point within the same basin. Therefore, the two datasets are not directly comparable in the way they did.

To compare InSAR and GPS time series, the regional deformation affecting the SAR reference point must be considered in a rigorous scientific approach. To comply with this approach, we performed the following steps. First, we projected the East, North and Up components of GPS data along the Line Of Sight (LOS) of the RADARSAT-2 sensor by using the exact direction cosines (ascending orbit: -0.0928 north, -0.5220 east, 0.8479 up; descending orbit: -0.1194 north, 0.5835 east, 0.8033 up). It must be noted that in Devoti et al. (2018) there is no information about the way they re-project the data along the LOS. Second, we selected some InSAR points within a circular area of approximately 100 m radius from each selected GPS station, and the corresponding time series of deformation have been averaged. Third, for rigorously comparing GPS and InSAR data, we calculated the time series differences between pairs of GPS stations and corresponding InSAR averaged measurements. The differences allow removing both the regional deformation affecting the SAR reference point and the different reference systems used by the two geodetic techniques. Figure 1a shows some plots related to the calculated differences. It is evident that GPS and SAR datasets appear as not comparable. Therefore we can state that for such very small (millimeter-scale) deformations the two techniques cannot be used to validate/invalidate each other. Therefore, the GPS-Insar data cannot be compared by just graphically juxtaposing the two datasets as in Figure 10 of Devoti et al. (2018).

The study presented in Devoti et al. (2018) is based mainly on the correlation between GPS horizontal deformations and rainfall excess (i.e., the climatic factor). Even the model proposed to fit the climatic forcing of the deformation is based on horizontal displacements mainly. Whereas, it is worth noticing that, from a technical point of view, InSAR measurements are much more sensitive to vertical displacement (about 80% of the actual vertical motions is captured by RADARSAT-2 SAR data) than the horizontal one (about 50% and 10% of east and north, respectively).

One of the critical aspects of the work in Moro et al. (2017) is the observation that the ground deformations are peculiar of the Quaternary lithologies infilling the Preturo and Pizzoli basins. Such displacements are opposed to those observed on the outcropping bedrock and inside the adjacent quaternary basins during both the preseismic and postseismic phase (compare Figure 1 and 2 of Moro et al., (2017) with Figure 10 of Devoti et al. (2018)). Instead, the multiannual GPS oscillations observed by Devoti and co-authors (and in the recent work of Silverii et al. (2019)) are in phase with each other, regardless of the lithological features at the GPS sites. Such differences are caused by the variable spatial resolutions and reference frames of the two datasets, i.e., the InSAR data identify spatially different, local displacements, while the GPS data identify regional displacements through punctual data.

Another critical point is related to the locations of the 17 GPS stations respect to the underlain lithologies. These are located on geological units with different hydrogeological responses. In detail, GNAL, MTRA, MTER, INGP, AQUI, AQRA, PAGA, SGRE and

SCRA GPS stations (Figure 1 of Devoti et al. (2018)) are located on hydrostratigraphic units characterized by low-middle effective infiltration (Plio-Quaternary and siliciclastic Cenozoic foredeep deposits) and porosity-related permeability. On the contrary, MTTO, CONI, ROPI, AQUN, CAOC, CDRA, BARS are located on the carbonate bedrock, characterized by high effective infiltration and high fracture-related permeability. Consequently, the displacements from all the GPS stations cannot be interpreted with a homogeneous hydrogeological or elastic dislocation model.

The estimated fault opening (2 cm on average) in Devoti et al. (2018) is calculated according to the piezometric data from the AVA11 and AVA13 wells. Since those wells, as reported in Devoti and co-authors, are cored inside the Quaternary stratigraphic sequence, it means that and they are not inherently representative of the piezometric level of the carbonate aquifer, because they intercept only the local multi-layered phreatic aquifer within the Quaternary stratigraphic sequence. Moreover, the formulation adopted by Devoti et al. (2018) (equation 1) to estimate the fault opening has been developed initially by Gudmundsson et al. (1999) for the estimation of vein opening, and fluid overpressure in basaltic lava flows during earthquakes, assuming undrained conditions for the fluid flow. The multiannual groundwater oscillation into the carbonate aquifer occurs in drained conditions, affecting the fault planes and the surrounding fractured rock isotropically. In drained condition, the fracture opening is inhibited or reduced mainly at least.

Finally, we further investigated the ground deformations affecting the Preturo and Pizzoli basins. We exploited the InSAR data from the ERS 1-2 SAR satellite constellation in the period 1995 - 2001, taken along the ascending orbit (Costantini et al. (2017), available at http://www.pcn.minambiente.it/mattm/en/project-pst-interferometric-products/). The InSAR time series have been scaled concerning the reference point of the RADARSAT ascending SAR dataset (Figure 1a in Moro et al. (2017)), for comparison purposes. The scaled displacement time series have been averaged over the Pizzoli and Preturo basin, following the procedure adopted in Moro et al. (2017). In Figure 1b, we show the mean displacement trend for both basins, together with the RADARSAT results. ERS data do not show significant trends or multiannual oscillations, but only annual variations are observed in the investigated time interval. Therefore the trend observed in the interval 2006 - 2009 (RADARSAT data) cannot be associated to a multiannual cyclic pattern that repeats periodically.

In conclusion, InSAR and GPS data identify different displacement patterns and therefore are not comparable in analyzing such millimetric deformations. Devoti and co-authors misinterpreted the correlation between the INGP station and InSAR data and, therefore, the approach they followed cannot be used to determine if the InSAR signal is due to hydrological or preseismic conditions and, consequently, they cannot rebut the conclusion made by Moro et al. (2017).

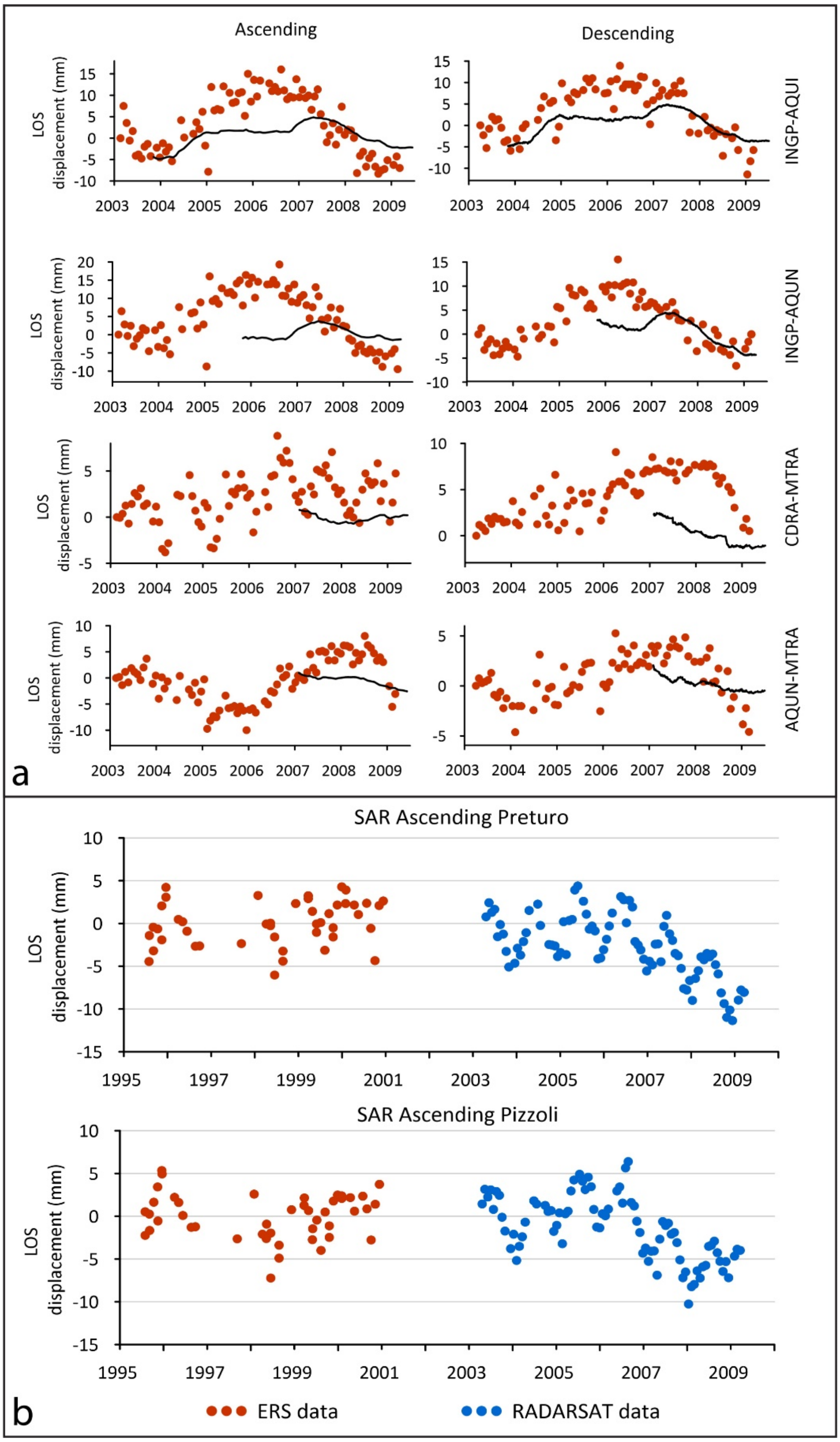

Figure 1: a) Differences between the displacements measured at some selected couples of GPS sites (black lines) and InSAR points (red dots) located close to each GPS station. b) Average LoS displacement time-series over the Preturo and Pizzoli basins, from ERS 1-2 and RADARSAT ascending SAR data.

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