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Interactive comment on "Numerical models for ground deformation and gravity changes during volcanic unrest: simulating the hydrothermal system dynamics of an active caldera" *by* A. Coco et al.

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Anonymous referee #2

Comment

As effectively stated in the Abstract, this paper "presents a numerical model to evaluate the thermo-poroelastic response of the hydrothermal system in a caldera setting by simulating pore pressure and thermal expansion associated with deep injection of hot fluids (water and carbon dioxide)." I found it a good technical methodological paper,

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worth to be published in SE. However, the applicability of the model to Campi Flegrei is not obvious and should be discussed in more detail by the authors. Although my requests do not involve technical issues, I think that, for final publication, the manuscript should be reconsidered after major revision because in my opinion the results are not discussed in an appropriate and balanced way.

General comments. 1. The Introduction creates the impression that there is a ten-year general consensus about the hydrothermal origin of Campi Flegrei deformation. However, several recent papers attribute Campi Flegrei unrests to magma (e. g., Amoruso et al, EPSL 2008; Woo and Kilburn, JGR 2010; Trasatti et al., EPSL 2011; Amoruso et al. GRL 2014) and the authors should at least mention that the two interpretations (magma and hydrothermal system) are still under debate.

Reply

We did not want to give to impression that the hydrothermal system is now recognized as the only reason for the unrests at Campi Flegrei, but that this interpretation has been recently proposed and must be considered for a more exhaustive investigation, sometimes together with (and not in place of) the magma emplacement interpretation. We thought that this could be inferred from "More recently, models also consider the perturbation of hydrothermal systems [...] as sources of spatio-temporal variations in deformation and gravity signals". Thank to the referee's comment we figured out that probably this was not clear in the introduction. In addition, the introduction aims to explain possible causes of unrests in active calderas, without even mention the Campi Flegrei, which is introduced in Sec. 2 Background and Motivation. Finally, we revised the introduction by adding/reformulating relevant parts: - "Beside this interpretation, more recently models also consider the perturbation of hydrothermal systems..." - "The origin of unrest activities is still under debate in many active calderas (such as in Campi Flegrei, Italy), although for pre-eruptive hazard assessment it is fundamental to disentangle the signals generated by hydrothermal perturbations (e.g., Todesco and Berrino, 2005; Hurwitz et al., 2007; Hutnak et al., 2009; Todesco et al., 2010; Rouwet et

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al., 2014) from those related to magma movement towards the surface (e.g., Amoruso et al., 2008; Woo and Kilburn, 2010; Trasatti et al., 2011; Amoruso et al., 2014b)."

Comment 2. Ground deformation: although computed ground deformation looks alike that from a Mogi source during the first years of unrest for Scenario I, still some time evolution of the deformation pattern is clearly visible in Figure 5. The deformation pattern is even more variable over time for Scenarios II and III. The authors should discuss those time evolutions versus the constancy of the deformation pattern at Campi Flegrei claimed e. g. by De Natale et al. (J. Geodyn. 2001), Manconi et al. (JGR 2010), Amoruso et al. (JGR 2014), Amoruso et al. (GRL 2014). Moreover, no abnormal deformation close to the ring faults has been observed e. g. by Trasatti et al. (GRL 2008), Manconi et al. (JGR 2010), Amoruso et al. (JGR 2014), Amoruso et al. (GRL 2014), Trasatti et al. (GRL 2015). I suspect that the time evolution of the computed ground deformation pattern may be more noticeable after the injection ends. In case of multiple injection episodes, ground deformation from the different episodes would combine, originating an even more noticeable time evolution. Reply Thanks for this comment. Although the model parameterization is set up based on the Campi Flegrei, the aim of the paper is to provide a general numerical model to simulate hydrothermal activities in general active calderas, therefore we are not trying to fit any particular data set or unrest period at Campi Flegrei. Following this comment we realized that this point was not properly clarified through the paper. Therefore, we modified the relevant sections. In particular, in Sec. 2 we shortened the description of the Campi Flegrei, removing the details that are not strictly necessary for the scope of the paper. We added a sentence at the end of the section to clarify the target of the paper: "It is important to note that, while models are informed by data on the solid and fluid mechanics of the CF, we do not attempt to replicate or fit observations made during the ongoing unrest at CF." Sec 4.1.1 – Injection rates. We shortened the description of the different molar ratios chosen in the literature, confining the paragraph to the injection rates and molar ratios selected for the simulations of this paper. Sec. 5 – Discussion. We added the two following sentences: "Although the deformation profile observed in Scenario I reflects

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the solution of a Mogi-type source (Mogi, 1958) in the first years of the unrest, over time it develops into a more complex pattern that cannot be explained by a simple deformation source (Fig. 7). In the long-time scale the ground deformation is therefore mainly driven by the thermo-poroelastic response of the hydrothermal system." and "Although the simulations performed in this paper provide a qualitative assessment of the contribution of hydrothermal fluid circulation at restless calderas, a more quantitative study and comparison with observed data from a particular caldera (such as the CF) is beyond the scope of this study." Sec. 6 – Conclusion. The argument about the multiple short-lived injections has been removed, since we believe it is both not sufficiently reasoned and beyond the scope of this paper. Comment Minor comments 1. Somewhat differently from what stated at p. 2059, Amoruso et al. (GRL 2014, and more specifically, JGR 2014) found a single small deformation anomaly, restricted to La Solfatara. Reply We have removed the citation to Amoruso et al. (GRL 2014) from this part of the paper. Please observe that this paragraph has now been shorten. In addition, we realized that, in the Conclusion section, the paragraph about the comparison with gravity changes observed by Gottsmann et al. (2003) was misleading and then removed to avoid confusion. Comment

2. The authors should compare computed gravity residuals with those measured during the major 1982-84 unrest. To my best knowledge, 1982-84 gravity measurements show the best S/N ratio. Reply We appreciate the request by the the referee to the comment on a particular episode of unrest. However, as now clearly stated in the motivation and discussion sections, the main target of the paper is not to provide a quantitative/qualitative assessment of the unrest periods. Comment 3. Although I am aware that taking into account the feedbacks between ground deformation and rock permeability and porosity is a very difficult task, the authors might discuss the expected effects qualitatively Reply We added a qualitative discussion at the end of Sec. 5. Comment 5. By convention, fault dip is the angle between the fault and a horizontal plane. I suggest to follow this practice throughout the paper. Reply We modified Fig. 1 and the text accordingly (caption of Fig.1; page 2060 – line 8; page 2072 – line

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13). Comment 6. The coordinate system used in the paper is not clear to me. Maybe the authors use the adjective "Cartesian" instead of "cylindrical". Reply We now either removed the adjective “Cartesian” where not necessary or replaced it with the adjective “cylindrical”. Comment 7. Figs. 5 and 6 - I suggest to use the same depth units (m or km) for initial conditions and changes. Reply Thank you for detecting them. We now use the same units (km).

Interactive comment on Solid Earth Discuss., 7, 2055, 2015.