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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.

Anonymous Referee #1

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General comments

This is a very interesting work concerning modelling of hydrothermal circulation in Campi Flegrei region. I see the core novelty of the paper in that the hydrothermal circulation is simulated with the presence of ring faults. One can learn from this paper how the faults influence the fluid flow in the hydrothermal system and associated surface uplift and gravity changes. The TOUGH2 code is used for modelling the fluid flow, whereas for deformations and gravity changes the authors apply their own programs. The simulations are done correctly, and their results are in line with literature.

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I have few critical comments (see below). One of them, concerning the influence of the faults on the conduit beneath La Solfatara, is the most critical one. This, general for the whole paper, comment concerns the core novelty of the work. Thus, I recommend the authors revise many formulations in the text thoroughly according to the points raised below.

I recommend publishing this work in Solid Earth journal.

Specific comments

1) According to the simulations done, it seems to me that the processes (hydrodynamics, deformations and gravity changes) in the primary permeable conduit beneath La Solfatara are not affected by the processes in the faults A and B. This can be concluded from (the list is incomplete): a. figure 5 – the pore pressure, temperature and saturation changes are similar in all considered scenarios both in spatial distribution and in maximum values; b. figure 7 – I believe if you calculate ground deformations for a model without faults, there will be only a minor changes in the distribution of the ground deformation; c. The authors make several remarks about that there is a minor influence of the conduit on faults and vice versa – page 2072, lines 18-20; page 2077, lines 9-14; page 2079, lines 8-10; page 2069, lines 11-13; d. The authors do not provide any concrete results showing how the faults influence processes at La Solfatara, and they do not provide any discussion on how this influence comes out, although the authors state many times that there is a strong influence on page 2076, lines 7-9; page 2078, lines 21-22; page 2079, line 3; page 2081, line 22,23,29.

It seems that since the processes in the conduit and in faults are running independently, the authors solve at once three separate problems, namely one for the conduit and two others for each fault. If the authors simulate separately the conduit and each fault and then sum the uplift and gravity from every simulation, will the result be different from the simulations done? The equations (5) for the deformations and equations (7) for the gravity variations are linear, thus a sum of two solutions is also a solution.

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Since the introduction of faults is a core novelty of the work, the effect attributed to faults should be discussed sharper. When reading the paper, an impression appears that the faults drastically change parameters beneath La Solfatara. If there is a strong influence of the conduit on the faults or vice versa (as you state on page 2076, lines 7-9; page 2078, lines 21-22; page 2079, line 3; page 2081, lines 22, 23 and 29) then please discuss it deeper making references to figures. If there is only a minor influence (as you state on page 2072, lines 18-20; page 2077, lines 9-14; page 2079, lines 8-10; page 2069, lines 11-13) then please make weaker the statements in other places.

Please state explicitly, whether there is a strong influence or there is only a minor influence for this particular model of CF, and align the text with this statement in all mentioned places and other places of the paper as well.

2) Page 2061, line 21 – For completeness I suggest to mention which TOUGH2 module you used in the simulations (EOS2 or another module).

3) Page 2062, lines 20-25 and page 2063, lines 1-3 – I doubt TOUGH2 is capable of flows in anisotropic permeability field when the primary directions of permeability tensor are not aligned with grid blocks. In this case special finite-difference numerical scheme (namely “nine-point” scheme) is required (e.g. see Yanosik et al. 1979 A Nine-point, finite-difference reservoir simulator for realistic prediction of adverse mobility ratio displacements// SPEJ. <http://dx.doi.org/10.2118/5734-PA>). I think you are neglecting k_{rz} term of the tensor when running TOUGH2. If you do not neglect this term, please provide an explanation of how you account for it. If you neglect it, then please discard most of this paragraph because you are just changing the vertical and horizontal permeability in the grid blocks which the fault penetrates. It is better to discuss here (or earlier) how you fit the rectilinear grid to inclined faults. Can a grid block comprise both the core and the damage zone?

When reading this paragraph, you create an impression that you take into account fluid flow in the vertical direction affected by the pressure change in the horizontal direction

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and vice versa (page 2062, lines 22-24). But if you neglect k_{rz} when applying in simulation the unnumbered formulas in the last line on page 2062, then you neglect the effect.

I also want to make a remark that with the maximum dip angle of 15 degrees for the fault $B \cos(15)^2=0.933$ is approximately equal to 1.0 and $\sin(15)^2=0.067$ is approximately equal to 0.0. Therefore, what you are discussing in this paragraph has a minor influence on the flow because k_r is approximately equal to k_{xi} and k_z is approximately equal to k_{eta} . I think this permeability alteration (related to multiplication of permeability by $\cos(15)^2$ and $\sin(15)^2$) is irrelevant for qualitative analysis, at least because you do not know the geological data with such a precision.

4) Page 2067, lines 5-9: When reading the article for the first time, it is not easy to understand the difference between Scenarios 2 and 3. Only analysis of units in Table 3 helps. One can measure the flux per square meter of cross section area or think of it as assigned to the total horizontal cross-section area associated with faults. Consider corrections like – “mass equal to” -> “total mass flow rate equal to” in line 6 and “flux rate equal to” -> “specific (per square meter) mass flow rate equal to” in line 8.

5) Page 2067, lines 25 and 26 – Not really, at the least the magnitude of the injection rate was discussed recently by Afanasyev et al. (2015).

6) Page 2076, line 17 – I suggest replacing “The radius of the plume reaches 500 m at the surface” by “The radius of the plume reaches 500 m in a shallow region close to the surface”. I believe if you use a good grid resolution for the shallowest part of the system you will not get the gas zone at the surface at 500 m from the centre (although some temperature alterations will be there).

7) Page 2077, line 14 – What do you mean by “Rock expansion due to heat conduction”? What about convective heat transfer, is it irrelevant? Possibly, you mean “Thermal expansion of rocks” or “Expansion of rocks due to temperature changes”.

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Technical corrections

- 1) Page 2061, lines 16 to 18 – Reformulate or discard “The 2D axisymmetric model extends 10 km in the radial direction in order to cover the entire CF volcanic area, the radius of which is estimated to be some 12 km”. The 10 km is still shorter than 12 km, thus you are not covering the entire CF.
- 2) Page 2068, lines 1 and 3 – “Although” is met twice what is not good for fluent reading. Consider replacing one of them.
- 3) Page 2069, lines 6 and 8 – Consider making the following corrections: “values decrease” -> “value decreases”; “hot fluids rise up” -> “hot fluid rises up”; “values continue” -> “value continues”;
- 4) Page 2069, line 11 – replace “close the surface” -> “close to the surface”;
- 5) Page 2071, line 21 – replace “importance increase” by “importance increases”;
- 6) Page 2076, line 10 – replace “La Solfara” by “La Solfatara”.
- 7) Figure 11 – make the symbols larger. It is hard to distinguish them. The difference can be seen only if zoom in.

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

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