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Solid Earth
Discussions

Interactive comment on "Effects of upper mantle heterogeneities on lithospheric stress field and dynamic topography" *by* Anthony Osei Tutu et al.

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This is an interesting and timely paper presenting results of modeling global topography and stress distribution based on a coupled numerical model of mantle convection and lithospheric dynamics. The upper 300 km shell of the model with free surface is modeled using realistic visco-elasto-plastic rheological model for the mantle and crust. The paper is of broad interest but I think the quality of presentation could be improved by addressing several discussion points listed below. Taras Gerya, Zurich, 15.01.2018

Specific points Page 1. We show that lateral density heterogeneities in the upper 300 km have a limited influence on the modeled horizontal stress field as opposed to the resulting dynamic topography that appears more sensitive to such heterogeneities. There

is hardly any difference between the stress orientation patterns predicted with and without consideration of the heterogeneities. . .". This low sensitivity in term of stresses seems unfortunate. Is the re any way to increase sensitivity? Changes in the dynamic topography should typically result in notable changes of bending stresses inside plates. Perhaps the method of comparing simulated and observed stresses should somehow try to isolate better the bending stress component?

Page 1. "After correction for the chemical depletion of continents, the TM2 model leads to a much better fit with the observed residual topography giving a correlation of 0.51 in continents, but this correction leads to no significant improvement in the resulting lithosphere stresses." Same as above. Would be good to understand better where major discrepancies for stresses are coming from – missing slabs? data inaccuracy?

Page 3. 2016). "The residual topography is here defined as the observed topography corrected for the variations in the crustal and lithosphere thickness and density variations and for subsidence of the sea floor with age." One could also mention here strong influence of the complex brittle–ductile rheology and stratification of the continental lithosphere result in short-wavelength modulation and localization of deformation induced by mantle flow (Burov & Guillou-Frottier, 2005).

Page 6. "A forward model is run for half a million years with a time step of 5kyr, 5 and at each time step tractions in the lower mantle due to density heterogeneities are computed using the spectral mantle code and then passed across the coupling dynamic boundary to the top component SLIM3D. Within the upper domain (SLIM3D), the flow velocities are then computed and passed back across the coupling boundary as an upper boundary condition to the spectral mantle code, with the method convergence estimated by comparing the velocity and traction norms of two successive iterations." This approach does not seem to account for continued slabs crossing 300 km depth level. It has been demonstrated by Stadler et al., (2010) that having such continued slabs is essential for properly reproducing surface plate motions.

Page 6. “Within the upper mantle, our crustal rheology is taken from Wilks (1990) and below the crust we have considered dry and wet olivine parameters in the lithosphere and sub-lithospheric mantle layers, respectively, modified after the axial compression experiments of Hirth and Kohlstedt (2004) (shown in the appendix, Table A1. Adopted from Osei Tutu et al. (2017) for studying the influence of both the driving and resisting forces that generate global plate velocities and lithospheric plate net rotation).” Reference to Osei Tutu et al. (2017) is for a paper in revision, which is not accessible.

Page 6. “Here the topographic signal induced by the layers below 300 km is assumed to be due to convection in the viscous mantle, although cold rigid subducting slabs (Zhong and Davies, 1999; Faccenna et al., 2007) and possibly also the deepest cratonic roots (Conrad and Lithgow-Bertelloni, 2006) extend deeper than 300 km.” Do you account for slabs at <300 km depths? Does not seem to be the case in Fig.2, but Fig. 3d shows some slab-like features along the western margin of South America. What moves plates in the absence of slabs and prescribed surface velocities (free surface boundary condition is used) – mantle drag only? How realistic is this approach for the global plate tectonics of modern Earth, which is assumed to be predominantly driven by the slab pull? Would be good to discuss this in some more details.

Page 10. “Since the focus of this study is to investigate the effect of the upper mantle lateral density variations on the horizontal stress field and dynamic topography, an assessment of the influence of the plate boundary friction and water content in the asthenosphere on plate velocities has been carried out in a separate study (Osei Tutu et al., 2017). Hence, in the present work, we constrain our resulting creep viscosity with a cutoff for extreme viscosity values in the upper mantle by setting permissible minimum and maximum viscosity values similar to Becker (2006) and (Osei Tutu et al., 2017), with this approach yielding a good fit between the observed and modeled geoid.” Would be good to give some summary of plate velocity modeling results since the referred paper (Osei Tutu et al., 2017) in review is not accessible. For example, Stadler et al. (2010) suggested that prescribing slabs in the upper mantle is essential

to reproduce global plate motions. Can you confirm this?

Page 15. “Cammarano et al. (2011) showed that correction for the depletion of the lithosphere increases the inferred temperature of a cratonic root by about 100K and decreases density by about 0.1 gcm−3, and fits observations well compared to models assuming pyrolitic composition.” Depletion-related density decrease of the cratonic mantle is age-dependent and increase from 30 to 80 kg/mˆ3 (i.e., 0.03-0.08 g/cmˆ3) with increasing the age from the Phanerozoic to the Archean (Djomani et al., 2001)

Page 17. “We predict normal faulting mostly in regions above upwellings (mostly extensional regions) such as the Icelandic swell, Eastern African rift, or along divergent plate boundaries, while thrust faults are mainly predicted in compressional regions such as subduction zones and some other tectonically active regions in continents. In continental areas, few regional variations occur in South America, West Africa and on the Eurasian cratons. In oceans we see variations in the North Atlantic around the Icelandic swell, at the east Pacific Rise and around the southern African plate region.” Strong compression seems to be predicted in the extensional backarc of the IBM subduction system (Fig. 6) – this seems problematic to me. Perhaps having continued deep and dense slabs in this region would change this?

References

Burov, E. & Guillou-Frottier, L. The plume head-lithosphere interaction using a tectonically realistic formulation for the lithosphere. Geophys. J. Int. 161, 469–490 (2005). Djomani, Y.H., O'Reilly, S.Y., Griffin, W.L., Morgan, P., 2001. The density structure of subcontinental lithosphere through time. Earth and Planet Science Letters 184, 605–621. Stadler, G., Gurnis, M., Burstedde, C., Wilcox, L.C., Alisic, L., Ghattas, O., 2010. The dynamics of plate tectonics and mantle flow: from local to global scales. Science 329, 1033–1038.

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