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Understanding the interplays between Earth's shallow- and deep- rooted processes through global, quantitative model of the coupled brittle-lithosphere/viscous mantle system

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The volume of geophysical datasets has grown substantially, over recent decades. Our knowledge of continental evolution has increased due to advances in interpreting the records of orogeny and sedimentation. Ocean-floor observations now allow one to resolve past plate motions (e.g. in the North Atlantic and Indian Ocean over the past 20 Myr) at temporal resolutions of about 1 Myr. Altogether, these ever-growing datasets permit reconstructing the past evolution of Earth's lithospheric plates in greater detail. This is key to unravelling the dynamics of geological processes, because plate motions and their temporal changes are a powerful probe into the evolving force balance between shallow- and deep-rooted processes. However, such a progress is not yet matched by the ability to quantitatively model past plate-motion changes and, therefore, to test hypotheses on the dominant controls.

The main technical challenge is simulating the rheological behaviour of the lithosphere/mantle system, which varies significantly from viscous to brittle. Traditionally computer models for viscous mantle flow and on the one hand, and for the motions of the brittle lithosphere on the other hand, have been developed separately. Coupling of these two independent classes of models has been accomplished only for neo-tectonic scenarios and with some limitations as to accounting for the impact of time-evolving mantle-flow and lithospheric slabs. Here we present results in this direction that permit simulating the coupled plates/mantle system through geological time.

We build on previous work aimed at coupling two sophisticated codes for mantle flow and lithosphere dynamics: TERRA and SHELLS. TERRA is a global spherical finite-element code for mantle convection. It has been developed by Baumgardner (1985) and Bunge et al. (1996), and further advanced by Yang (1997; 2000) and Davies et al. (2013), among others. SHELLS is a thin-sheet finite-element code for lithosphere dynamics, developed by Bird (1998). In advancing the coupling between TERRA and SHELLS, our efforts are focused in particular on achieving the technical ability to: (i) simulate the impact of the time-evolving buoyancy-field of the mantle on lithospheric plates and (ii) to explore the dynamics of plates/mantle interactions by using the geological record as constraint. This permits focusing on regions that feature cratonic lithosphere, dynamic topography or high relief. Our results allow addressing the question of when and where the plates/mantle system featured top-down or bottom-up controls throughout the Cenozoic. This progress allows us to self-consistently simulate any tectonic scenario from the late Cretaceous – through the Cenozoic – to the present-day. As an example, the South Atlantic ocean-floor has recorded rapid changes in spreading rate since the Cretaceous, the reasons for which remain poorly understood. Our modelling advance provides the ability to quantitatively test hypotheses to explain this particular record, among others.