Geodynamic models for the "uplift" and erosion of the Colorado Plateau

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Our aim is to test a range of geodynamic models that can explain the uplift of the Colorado Plateau, if uplift there was. Many mechanisms have been proposed and summarized in the literature [e.g. McGetchin 1980]. The main mechanisms fall in three different categories: (a) Late Cretaceous to early tertiary uplift related to Sevier-Laramide orogeny (80 to 40 Ma) [e.g. McQuarrie and Chase 2000]; (b) mid-Tertiary uplift related to removal of flat subduction (either through mechanical thinning of continental mantle lithosphere and subsequent removal of flat slab [Spencer 1996], release of negative dynamic topography [Mitrovica et al 1989, Gurnis 1992] or hydration of the lithosphere from volatiles derived from the Farralon slab [Humphries et al 2003]) and (c) Late-Tertiary uplift associated with regional extensional tectonism, either by large removal of instable lithosphere [Bird 1979] or heating from below. We propose to test these geodynamic models using the codes available through the Computational Infrastructure for Geodynamics framework.

We use a mantle convection model, so-called CitcomT [e.g. Billen et al 2003] CitcomT is a solving the equations of momentum, continuity and transport equations :

$$u_{i,i} = 0,$$

$$-P_{,i} + (\eta u_{i,j} + \eta u_{j,i})_{,j} + Ra\,\delta\rho\,\delta_{ir} = 0,$$

$$(\delta\rho)_{,t} + u_i(\delta\rho)_{,i} = (\delta\rho)_{,ii},$$

in 3D and in spherical coordinates.

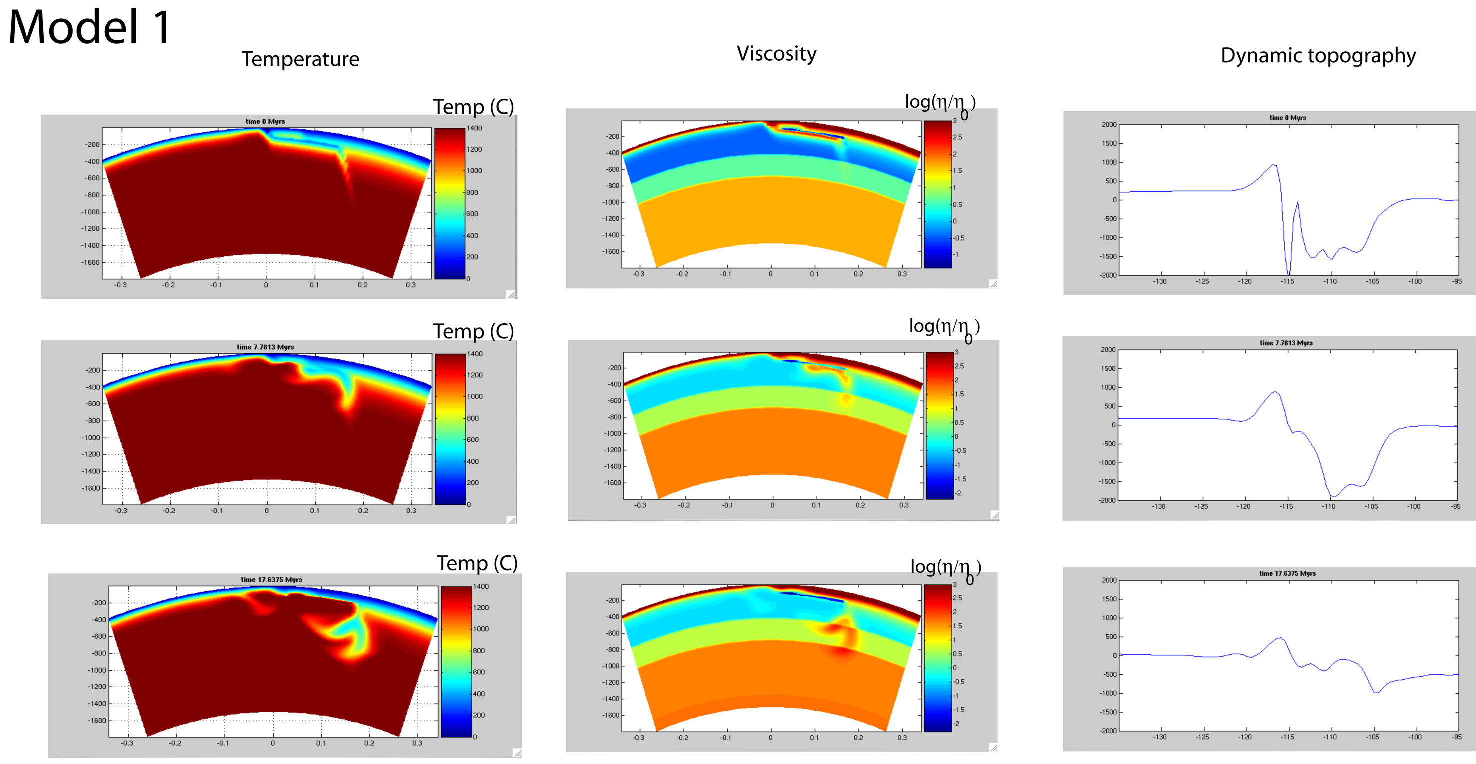
It computes dynamic topographies using the boundary flux method [Zhong et al 1993].

The viscosity varies laterally and is temperature-pressure dependant. Lateral and radial viscosity variations can be included in the model, by setting the effective viscosity to the desire value in a given region.

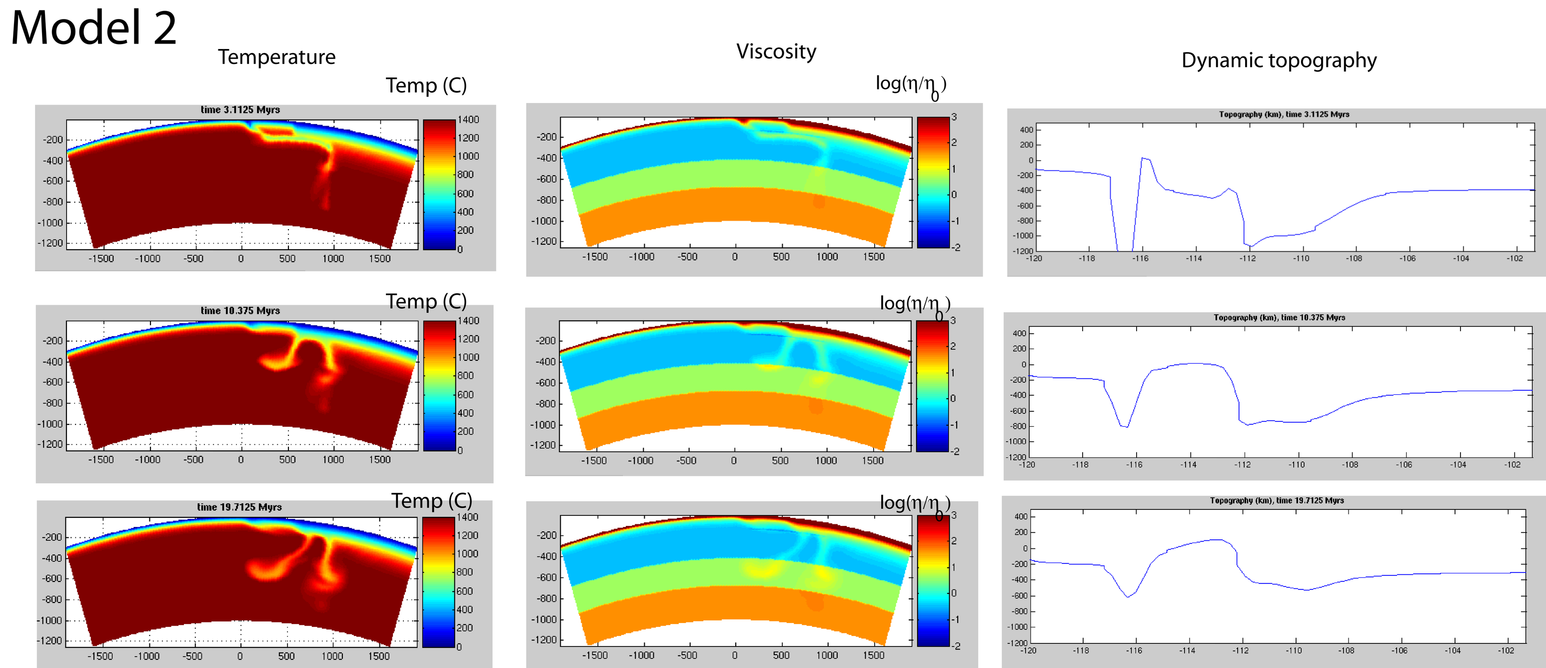
The code to account for regions that are chemically different [Moresi 1998] to simulate continental lithosphere/tectosphere. It is important to note that this implementation includes the computation of the advection of the chemically different layer.

We present three models which test the hypothesis of uplift of the Colorado Plateau due to removal of the the flat subduction. In each model, we include a buoyant continental tectosphere that is shaved by the flat subduction. In each model, decoupling between the subducting plate and the overiding lithosphere is ensured by including a region of low viscosity between the two. Model 1 simulates an abnormally thick oceanic lithosphere below the plateau, Model 2 assumes a thinner oceanic plate and Model3 is equivalent to model 2 except that the zone of decoupling is made larger.

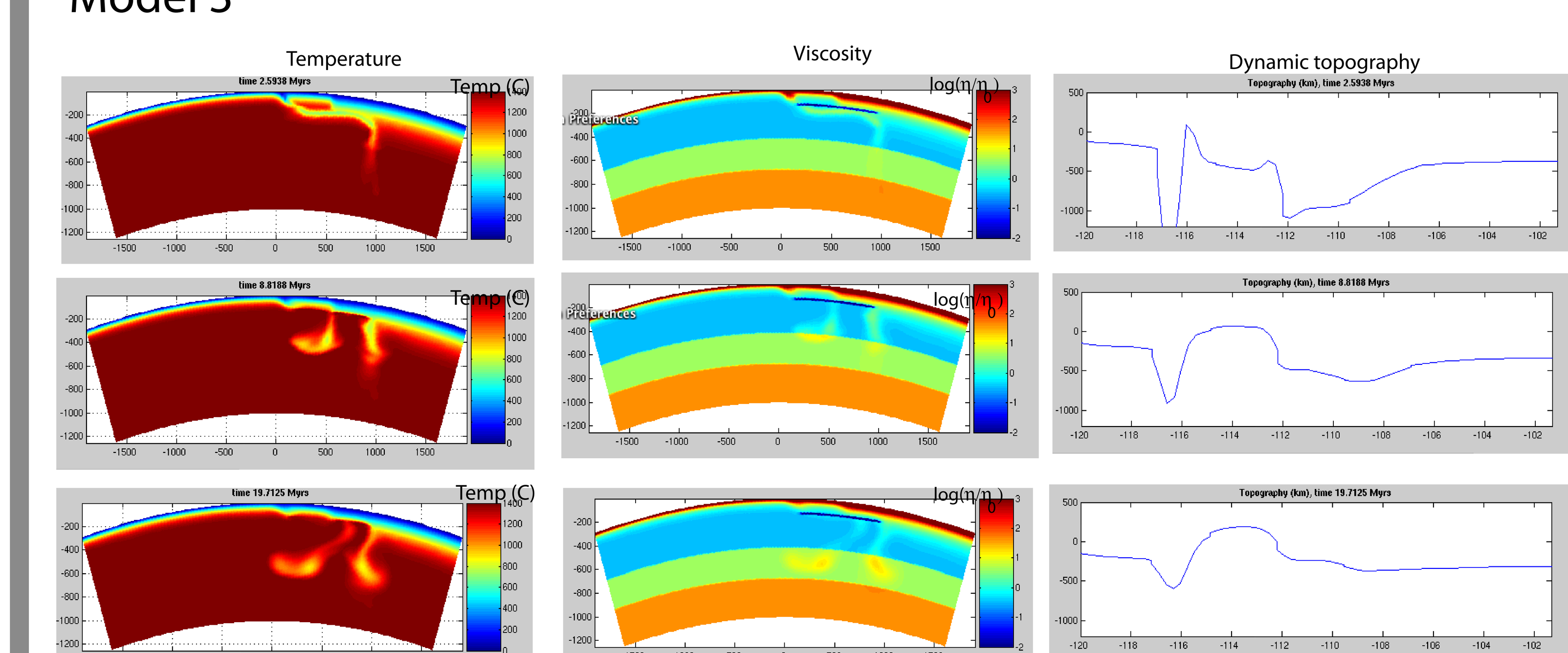
Model 1



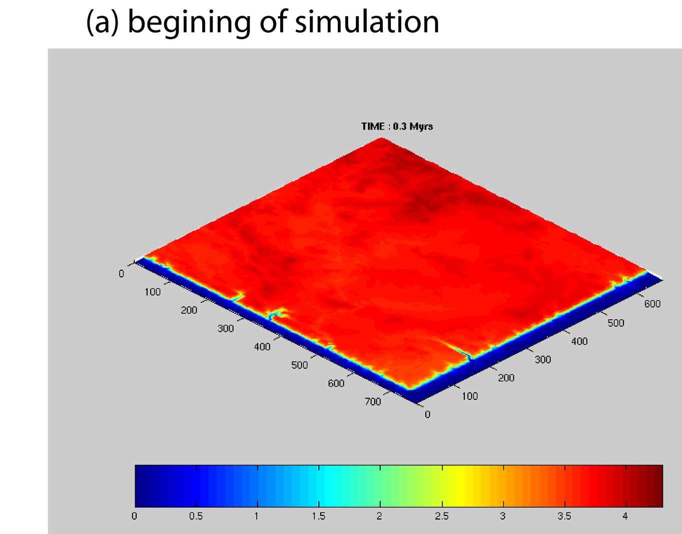
Model 2



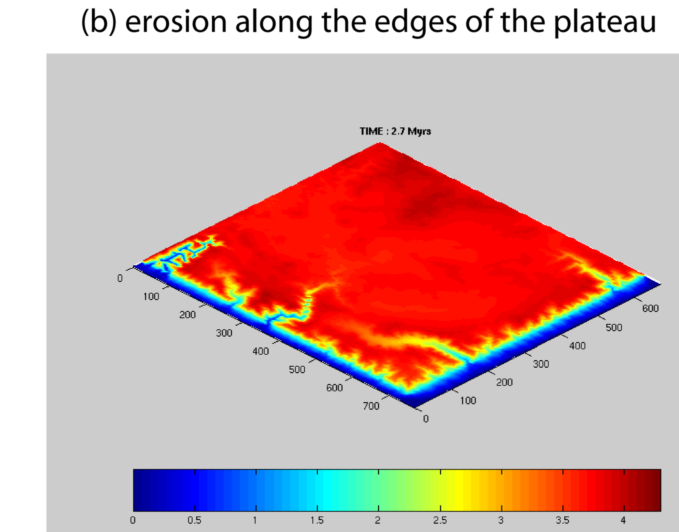
Model 3



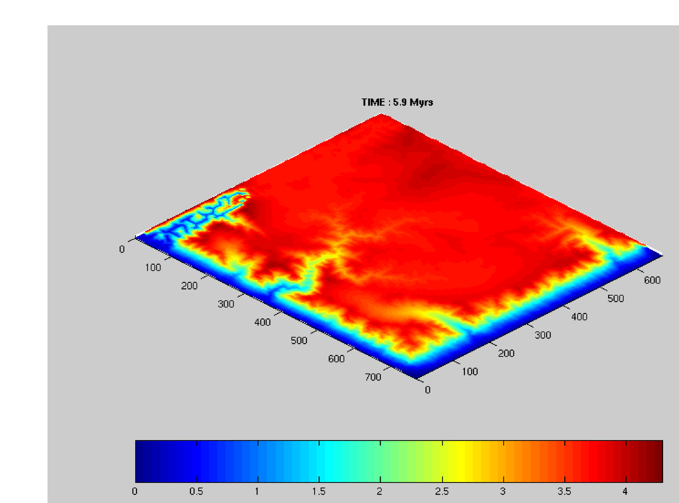
(a) begining of simulation



(b) erosion along the edges of the plateau



(c) begining of incision of the Grand Canyon



We here use a Surface Process Model, which simulates the evolution of hillslope and river incision. We present an example of a simulation.
The model starts with a base level drop. Consequently, erosion is induced at the edges of the plateau. This, in turn, causes isostatic uplift on the edges of the plateau, slowing down erosion along these scarps and forming an internally drained basin. Ultimately, the basin will overfill and lead to rapid erosion along the Grand Canyon.

Computations were perfomed on the Pangu facilities at the Geological and Planetary Sciences Division, California Institute of Technology