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Scaling and Performance Analysis of Underworld: Towards the One Billion Particle Target

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We investigate the scaling performance of Underworld, a geodynamic modeling framework, on high performance computing resources. These results inform the configuration and allocation of resources committed to study the complex geodynamic processes in and around subduction zones. We use a 3D thermal convection model that includes a temperature and stress dependent rheology as a proxy for the computational difficulty of the eventual subduction problems. This proxy model is designed with significant variation in viscosity, in conjunction with the non-linear temperature and stress dependent rheology this results in a computational problem that is significantly more challenging than the similar isoviscous convection problem.

"Using an allocation of 30000 service units on Texas Advanced Computing Center (TACC) cluster, Ranger, we ran a suite of models that exercised Underwold by solving problems with element subdomain sizes of 16×16×8 and 16×16×16 per core. For each of subdomain size we ran the models at several global resolutions, from what we call "tiny" models (32×32×32) to what we refer to as "huge" (192×192×192). The global resolutions selected require CPU core allocations from 100's to 1000's.

Underworld supports both a basic FEM solution method and Particle In a Cell (PIC). We solve the thermal convection problem using both methods to verify the equivalence of solutions. At the highest resolutions using the PIC method the number of particles approaches 1.5 million. We continue to explore this model with an eye towards systems populated by up to 1 billion particles.

Timing results are measured as the walltime per model timestep. A common steady-state model is first calculated over several thousand timesteps. This steady-state model is then restarted at the appropriate resolution whence the performance data is gathered.

Stress modeling in the Central Asia crust, importance of gravity stresses

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The Southern and Central Asia is a tectonically complex region which characterized by the great collision between the Asian and Indian plates. Its tectonic evolution is strongly related to the active subduction process along the Pacific border. Stress investigation in the continental crust is a very important problem not only for science but also for the practical purposes. There are four main factors which produce tectonic stresses: gravity anomalies of the crust, density inhomogeneities, deformation from area with intraplate collision, residual elastic deformations and underthrust stresses conditions from convective mantle. We present the stress model of the crust and lithosphere for the Central and Southern Asia on the basis of the finite element modeling. For the crust we take the elasto-plastic rheology with Drucker-Prager criterion. In the lithosphere the elasto-plastic model with von Mises criterion is assumed. We investigated stresses which are produced by the crustal density inhomogeneities and surface relief. The calculations are done using the U-WAY finite element code [Vlasov et al., 2004] developed at the Institute of Applied Mechanics Russian Academy of Sciences (similar to the Nastran program). Density inhomogeneities are based on the AsCRUST-08 crustal model [Baranov, 2010], which has resolution of 1×1 degree. AsCRUST-08 was built using the data of deep seismic reflection, refraction and receiver functions studies from published papers. The complex 3D crustal model consists of three layers: upper, middle, and lower crust. Besides depth of the boundaries, we provided average *P*-wave velocities in the upper, middle and lower parts of the crystalline crust and sediments. The seismic *P*-velocity data was also recalculated to the densities and the elastic moduli of the crustal layers using the rheological properties and geological constraints. Strength parameters of rocks strongly depend on temperature, tectonic and fluid pressure. Fluid pressure can reduce resistance forces in faulting rock, tectonic pressure increases these forces.

Results. Isotropic pressure in crustal layer is approximately equal to 0.6—0.8 from lithostatic values, for example 900 MPA on the 40 km depth (Poisson ration changes in the crustal layer from 0.25 to 0.32 in accordance to its mineral properties). In the mantle isotropic pressure practically equals to lithostatic values which corresponds to Poisson ratio 0.5. Lateral pressure variations in the crustal layer are limited by 10—15 % (negative pressure anomaly under Tibet orogen reaches 15 %).

Shear stresses gradually increase with depth and reach approximately 650 MPA in the lower crust under Tibet orogen and 300 MPA on the 30km depth. The models in this work are simplified in several aspects. However our purpose was to compare gravity stresses in the normal continental crust and under Tibet orogen with anomaly thick crustal layer.

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Main tectonic regularity in the structure of continental margins

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The lithosphere plate tectonics theory describes the process of oceanic crust opening and closure in geological history of the Earth using the Wilson cycle [Keary, Vine,1991]. Upon the end of the cycle the oceanic crust being formed at its early stages is almost completely destructed in the process of subduction. As for the continental margin it is modified during the cycle with formation of volcanic and non-volcanic islands arcs, back- and fore-arc sedimentary basins, and orogens. During the next