Entrainment in 2-D and 3-D Numerical Models of Thermochemical Convection

Rebecca Farrington, Louis Moresi, Dave Stegman and David May

School of Mathematical Sciences
Monash University
Clayton, VIC 3800, Australia

Thermochemical convection problems frequently arise in geodynamics including, for example, the entrainment of the chemically dense D" layer at the base of the mantle. Understanding the behaviour of these processes through both experimental and numerical models is an ongoing area of interest with implications for geodynamics, geochemistry, and geomagnetism.

Laboratory experiments are often used to study thermochemcial convection. Experimental studies (Jellinek & Manga, 2002; Davaille, 1999; Gonnermann et al, 2002) which investigate mantle stratification with a dense layer atop the core-mantle boundary illustrate the importance of entrainment within these systems. Even small chemical variations may profoundly influence the dynamics of upwelling plumes including excess temperature (Farnetani, 1997), both stability and longevity (Jellinek & Manga, 2002) and possibly pulsations (Lin & van Keken, 2005). Many seismological observations point to such chemical heterogeneity existing in D". However the recent discovery of a post-perovskite phase transition (Oganov & Ono, 2004) which leads to destabilisation of the thermal boundary layer may require an increase in the negative buoyancy arising from compositional densities (Nakagawa & Tackley, 2004).

Thermochemical convection can be simulated numerically using many different techniques, including tracer, marker chain, tracer ratio, filter and field methods as discussed in (van Keken et al, 1997; Tackley & King, 2003; Lenardic & Kaula, 1993). These methods, while meeting the requirements of the established thermochemical benchmark outlined in (van Keken et al, 1997), produce wide ranging behaviour for entrainment. It is possible to calculate the entrainment rates in laboratory experiments and develop scaling relationships as outlined in (Jellinek & Manga, 2004). The question remains how well numerical models capture the entrainment observed and measured in the laboratory models published for example by (Jellinek & Manga, 2002; Davaille, 1999; Gonnermann et al, 2002).

Resolving the density interface and entrainment rates in numerical thermochemical convection therefore remains a major issue. The methods currently used either over- or under-estimate (Tackley & King, 2003; Lenardic & Kaula, 1993) the entrainment observed in the laboratory experiments, but the extent to which has not been examined in detail. These difficulties, in particular overestimation, may become amplified with the move from 2-D to 3-D geometry, leading to a growing need to quantify entrainment rates in numerical models.

We have studied the time evolution of the buoyancy number, density interface and entrainment for 2-D and 3-D numerical models of thermochemical convection. We have measured entrainment rates across a range of Rayleigh numbers. Continued study of these models will be pursued investigating effects such as model resolution, particle density, thickness of dense layer, viscosity contrast, aspect ratio and boundary conditions including lid-driven systems.

References:

A. Davaille. Simultaneous generation of hotspots and superwells by convection in a heterogeneous planetary mantle. Nature , 402:756-760 , 1999.

C.G. Farnetani. Excess temperature of mantle plumes: The role of chemical stratification across D". Geophys. Res. Lett. , 24(24) :1583-86, July 1997.

H.M. Gonnermann, A.M. Jellinek, M. Manga. Dynamics and longevity of an initially stratified mantle. Geophys. Res. Lett., 29:33-1-33-4 , 2002.

M.A Jellinek and M Manga. The influence of a chemical boundary layer on the fixity, spacing and lifetime of mantle plumes. Nature , 418:760-763 , 2002.

M.A. Jellinek and M Manga. Links between long-lived hot spots, mantle plumes, D", and plate tectonics. Rev. Geophys. , 42(3) , September 2004.

A. Lenardic and W.M. Kaula. A Numerical Treatment of Geodynamic Viscous Flow Problems Involving the Advection of Material Interfaces. Journal of Geophysical Research , 98(B5) pp 8243-8260, 1993.

S-C. Lin and P.E. van Keken. Multiple volcanic episodes of flood basalts caused by thermochemical mantle plumes. Nature , 436:250-2 , July 2005.

T. Nakagawa and P.J. Tackley. Effects of a perovskite-post perovskite phase change near core-mantle boundary in compressible mantle convection. Geophys. Res. Lett., 31 , 2004.

A.R. Oganov and S. Ono. Theoretical and experimental evidence for a post-perovskite phase of $MgSi0_3$ *in Earth's D". Nature , 430:445-48 , July 2004.*

P.J. Tackley and S.D. King., Testing the tracer ratio method for modeling active compositional fields in mantle convection simulations Geochem. Geophys. Geosys. , 4(4) , April 2003.

P. E. van Keken and S. D. King and H. Schmeling and U.R. Christensen and D. Neumeister and M.-P Doin, A comparison of methods for the modeling of thermochemical convection, Journal of Geophysical Research , 102 , October 1997, B10, pp 22477-22496