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Comparison of numerical and laboratory models of mantle plumes

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Plumes originating from point sources have been studied by analytical, numerical and experimental techniques to better understand mantle plume dynamics within fluid mechanical constraints. However, a detailed comparison is made difficult due to the widely different contexts (plumes growing from the injection of hot fluids or heating, use of different heating modes) and assumptions of fluid dynamical parameters. This has led to a wide range of different scaling laws, diverse ideas about plume shapes and sizes, and diverging thoughts about entrainment in the plume head and tail. It is essential to investigate how the technical differences and underlying assumptions influence our understanding of plume dynamics.

To facilitate this we compare laboratory experiments of a plume growing from a heated patch with numerical models that attempt to reproduce the laboratory conditions as closely as possible. For the fluids we use silicone oil with isoviscous behavior. A new method of visualization set up in the IPG laboratory allows us to visualize in situ the thermal and dynamical structures of the convection patterns on a 2-D section of the tank that is illuminated by a laser sheet. The fluids are seeded with thermo-liquid crystals that outline the thermal structure of the plume and that trace the motion in the fluid. This provides information about the temperature and the velocity without interfering with the flow. The heating patch consists of a small Peltier heater on top of which a thin copper disk is mounted.

The numerical simulations are axisymmetric finite element simulations of starting plumes where we use the measured properties of the laboratory fluids under the assumptions of infinite Prandtl number and laminar flow. We closely mimic the shape and heating mode of the heating assembly. We study the plume behavior with a range of power supplied to the heater patch.

We find excellent qualitative agreement between the numerical and laboratory models in both temperature and detailed velocity field. We find minor quantitative differences. This good agreement between two fully independent approaches suggests that the laboratory simulation can be accurately described by laminar Boussinesq flow at infinite Prandtl number. Iteratively, we show that the numerical method is capable of reproducing physical experiments and that the effects of common pitfalls and artefacts of numerical methods are minimized.