Seismic observations have revealed the existence of a stably-stratified layer 150 kilometres thick located above the inner core boundary (ICB). The density of this so-called ‘F-layer’ increases with depth, in contrast to the density jump expected for a well-mixed, adiabatic core. It is not known how the dynamics of maintaining such a layer can be explained. As a consequence, the aim of this project is to develop a self-consistent, fluid dynamical model of the convective process occurring in the F-layer that is able to explain the current observations.

The numerical model solves the vorticity-streamfunction formulation for Rayleigh-Bénard convection (ref. II) in a 2D box:

- The flow is subject to stress-free velocity conditions at the top and bottom boundaries.
- The top and bottom boundaries are assumed to be perfect conductors of heat.
- Two dimensionless numbers govern the dynamics of the flow: the Rayleigh number and the Prandtl number.
- If the Rayleigh number exceeds the critical value, then the theory says convection will occur.
- Simulations varying the Rayleigh number and Prandtl number were performed to verify the numerical model against the theory, an example of which is displayed in Figure 4 below.

Thermal Convection

Thermal convection alone cannot explain the dynamics of the F-layer:

- The temperature in the thermal boundary layer increases sharply with depth, since excess heat must be transported via conduction, so the density of the fluid must decrease with depth as a result.
- This is not consistent with seismic observations, i.e. density profile of stably-stratified F-layer.

Therefore the numerical model will be extended to simulate thermochemical convection:

- When iron freezes at the ICB, the lighter component of alloy remains in the ambient fluid.
- The thermochemical equations are similar to the thermal case, with one extra equation to be solved for the fraction of light material.

Thermochemical Convection containing a Slurry

Introducing a slurry (ref. IV) provides the source term that was absent from the thermochemical case:

- A slurry is a liquid phase containing a suspension of solid particles which have crystallised from the alloy.
- If the frozen solid is heavier than the residual liquid, then it will sink and displace the lighter component of the alloy upwards.

The slurry provides a mechanism for transporting buoyant, light material out without disturbing the stable stratification.

Thermal Convection containing a Slurry

The correct temperature gradient is achieved.

- The model is limited and does not explain the dynamics why there should be lighter material overlying denser fluid.

Method

A systematic approach will be used to investigate the problem:

- The numerical model starts with the simplest case in a plane layer.
- Limitations of each model lead to the consideration of a slurry layer.
- No source term corresponding with seismic evidence.

Thermochemical Convection containing a Slurry

Introducing a slurry (ref. IV) provides the source term that was absent from the thermochemical case:

- A slurry is a liquid phase containing a suspension of solid particles which have crystallised from the alloy.
- If the frozen solid is heavier than the residual liquid, then it will sink and displace the lighter component of the alloy upwards.

The slurry provides a mechanism for transporting buoyant, light material out without disturbing the stable stratification.

Seismic Observations

Seismic PPKp pressure waves, which sample the area above the inner core boundary, are used to probe the F-layer (fig. 1).

The wave velocity is slower than expected for a well-mixed, adiabatic core (ref. I).

By inverting the wave velocity for the density \( \rho \), it is found that the F-layer has a stable density stratification.

- The solid line in fig. 2 is the density profile for a well-mixed adiabatic core.
- The steeper, dashed line in fig. 2 is the density profile given by seismic observation – evidence of the stably-stratified layer.

A key issue is the presence of buoyant lighter material at the ICB that would disturb the stably-stratified layer. How is this compatible with the observations? The project aim is therefore:

‘To build a fluid dynamical, self-consistent model to explain the stable stratification of the F-layer observed by seismology.’