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Double-Diffusive Magnetic Layering

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Double-diffusive convection, in which the density depends on two components that diffuse at different rates, is an important phenomenon in geophysical and astrophysical fluid dynamics [1, 2]. In the oceans, the two components are heat and salt, and the phenomenon is referred to as thermohaline convection. In stellar interiors, the two components may be temperature and a compositional component (such as helium in a hydrogen rich plasma). The onset of double-diffusive convection can either be steady (which occurs in what is known as the “fingering” regime) or oscillatory (known as the “diffusive” regime in thermohaline convection or as “semi-convection” in an astrophysical context).

One of the most striking aspects of double-diffusive convection is its tendency to form layers or “staircases”. Such states are identified, for thermohaline convection, say, by their stepped salinity, temperature and density profiles with height; well-mixed convective layers are separated by steep-gradient interfaces. The formation of layers occurs in both the fingering and diffusive regimes, although there are differences in the two, particularly in the interface dynamics. Understanding the physics of the layering process is important, not only for the intrinsic interest of what is a counter-intuitive anti-diffusive process, but because, in a layered state, turbulent transport of the competing components is greatly enhanced compared to its non-layered counterpart. Thus, it is crucial that for an accurate parameterization of turbulent transport in the oceans or in stellar interiors, the physics of layering (when and how it occurs) needs to be fully understood.

In this talk, I shall consider the double-diffusive layering that arises when the two components are entropy and magnetic field [3]. This may be of importance for mixing in stellar interiors. If a horizontal magnetic field increases in strength with depth, then the atmosphere is “puffed up” by the field and instabilities can ensue – a process known as *magnetic buoyancy* instability. In the presence of diffusion and under certain restrictions, the equations describing magnetic buoyancy may be transformed into those of thermohaline convection [4, 5]. Although the transformation maps salt into magnetic pressure (with a change of sign), temperature in the thermohaline problem is mapped into a combination of specific entropy and magnetic field. This leads to different stability considerations between the two problems and the interesting possibility of instability in what may be thought of the “stable-stable” regime, in which the fluid is sub-adiabatic and in which the field increases with height.

Here I show, via numerical simulations, how layering can occur in the diffusive regime of the magnetic buoyancy problem and how it relates to the thermohaline problem. An example is shown in the figure below. Most strikingly, layering can occur even when both magnetic and entropy gradients may be thought of as stable. Turbulent transport is enhanced as a result of layer formation, thus implying that this effect needs to be considered in discussions of turbulent transport in stellar radiative zones.

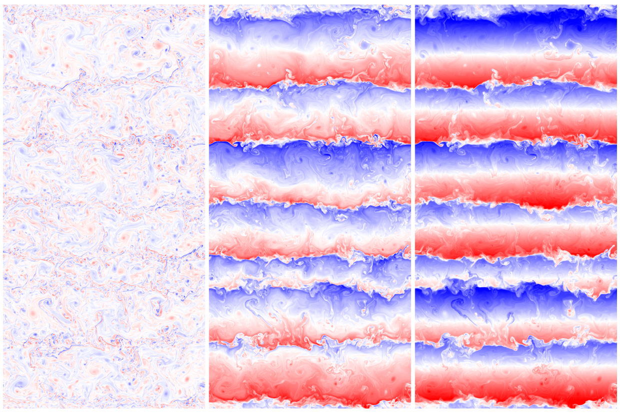

Figure: snapshots of the vorticity (left), entropy perturbation (centre) and magnetic pressure perturbation (right) in a simulation of layering in magnetic buoyancy. The flow is two-dimensional, and the field is pointing into the page.

References:

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