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NONLINEAR CONTROLS ON OCEAN CIRCULATION AND MIXING IN THE HIGH-LATITUDE OCEANS

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The uptake and vertical redistribution of heat and carbon is a crucial component of the ocean's role in regulating Earth's climate. Turbulent mixing, triggered by gravitational instability, enhances vertical transport of heat and carbon between the sea surface and deep ocean. The nonlinear nature of the thermodynamic relationship between seawater state variables – salinity, temperature and pressure – and seawater density results in a process known as cabbeling. Cabbeling is the gain in density that occurs when waters with equal density, but distinct salinity and temperature, mix. Therefore, in certain circumstances, nonlinearities in the equation of state for seawater density result in processes that can alter local gravitational stability, possibly leading to enhanced mixing. In this thesis, I explore the impact of these nonlinearities on the thermohaline structure and mixing in the high-latitude oceans.

In Chapter 2, I seek to establish if the gain in density upon mixing, known as cabbeling, is having an impact in high-latitude oceans. A hypothesis from [4] is extended to investigate if a gravitationally stable profile can become unstable after mixing due to cabbeling creating denser waters, that is, if a profile is unstable to cabbeling. In both observational data and output from a data-constrained global circulation model, profiles are rarely unstable to cabbeling suggesting cabbeling sets a limiting threshold for vertical profile stability. The results from this chapter are published in [2].

Cabbeling's effect on small-scale mixing is explored using direct numerical simulation (DNS) in Chapter 3. The simulations show that a cabbeling instability can trigger and drive convection from an initially gravitationally stable state. Further, cabbeling-driven convection is the same order of magnitude as convection driven by

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static instability, indicating parametrisations of convection in global ocean models may need updates to take into account cabbeling instability, particularly at the high-latitudes. The results from this chapter are published in [3].

In Chapter 4, the interaction between cabbeling and double diffusion is investigated using DNS. At high-latitudes, when turbulent mixing is weak, and salinity and temperature increase with depth, conditions are favourable for 'diffusive' convection. With a linear equation of state, this double diffusive instability forms equal density anomalies within layers either side of a 'diffusive' interface. With a nonlinear equation of state, our DNS results show that a larger density anomaly forms in the lower layer and the interface migrates upward, consistent with previous laboratory experiments. The temperature difference is found to be the main driver of the asymmetric density anomalies. The results from this chapter are published in the *Journal of Fluid Mechanics* [1].

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