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A Two-Level Wind and Buoyancy Driven Thermocline Model

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ABSTRACT

A simple two-level model is designed to simulate the “thermocline equations,” applicable for large-scale steady oceanic flow. The model serves two functions. First, it replaces problems with the interpretation of slablike dynamics (e.g., Luyten *et al*., 1983) by using continuously horizontally varying buoyancy, but at the cost of reducing the vertical resolution drastically. The equations used are geostrophy (plus a small linear drag to close a Stommel-like western boundary layer), mass conservation, and buoyancy conservation with a small but necessary horizontal diffusion. (Inclusion of vertical diffusion has little effect). The ocean is driven by an Ekman layer, whose functions are to provide a given surface input of mass (through Ekman pumping) and buoyancy (through a specified buoyancy in the Ekman layer), i.e., to maintain the same boundary conditions as in classical thermocline studies. Sidewall conditions are not well understood and are almost certainly over-specified in this formulation. Second, the model works towards the development of a simple numerical model which can permit rapid, cheap evaluation of the ocean circulation on climatic timescales.

The depth integrated flow is known from the Ekman pumping, so that the only unknown flow is the (single) baroclinic mode, which may be derived from the thermal wind equations as the density field is advected and diffused. The time taken to a steady solution is a few hundred years for a two-gyre basin of side 4000 km.

Despite the apparent simplicity of the model, the solution is fairly realistic and quite complicated. The solution involves convective adjustment in the northern (cool) part of the basin. The area occupied by convection increases with the amplitudes of both buoyancy forcing and Ekman pumping. There is a strong western boundary current, that separates farther south of its equivalent North Atlantic latitude, and flows toward the northeast corner of the basin where there is strong downwelling as the flow is returned in the lower level. The average of the level densities serves as an approximate streamfunction for the baroclinic flow that spins up initially like a long Rossby wave response of a linear ocean to wind forcing. Transfer from the southern to the northern gyre is produced by diffusion and ageostrophic effects in midocean, and not at the western boundary.

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To examine the ventilation of the lower subtropical level of the ocean, trajectories were examined for water particles emitted from the downwelling Ekman layer. Those released in the southern half of the subtropics have quite complex tracks, with a tendency for anticyclone circulation for several years followed by a cross-gyre movement to the subpolar gyre and circuitous routes back to the subtropics. The net result seems to be little direct ventilation. Particles released nearer the gyre boundary also show little tendency to direct lower ventilation. Adding random walks to the particle tracks to simulate the horizontal diffusivity shows that diffusion made little qualitative difference apart from an expected smearing out of the tracks.

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