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On the suitability of two-layer energy-balance models for representing deep ocean heat uptake

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Over 90% of the excess heat energy due to global warming is taken up by the oceans. Because of this, ocean heat uptake and planetary heat uptake can be considered equivalent. This heat energy is readily taken up by the oceanic mixed-layer on decadal timescales and subsequently transferred to the thermocline and deep ocean below on longer, centennial timescales by different ventilation mechanisms. The ventilation rate is affected by many things including the mixed-layer depth, the strength of the overturning, and mode-water formation. In current two-layer energy-balance models (EBMs), all ventilation mechanisms are reduced and parameterised by a simple linear vertical heat-exchange term that depends on the temperature difference between the upper and lower layers (representing the mixed-layer and deep ocean, respectively).

Two-layer EBMs have been used successfully to reproduce the global mean surface temperature responses for CMIP5 models in abrupt CO_2-quadrupling experiments. Little attention has been paid to the EBM-predicted deep ocean response, however. We perform an abrupt CO_2-doubling experiment using an idealised aquaplanet model with a simple geometry that splits the ocean into small, large, and southern ocean basins. By fitting a two-layer EBM regionally to each basin's deep temperature response, we find that it provides a good fit only for the small basin. We suggest this is due to the small basin exhibiting a deep overturning circulation — not seen in the other model basins — which connects the ocean surface to its interior; only this ventilation mechanism can be successfully parameterised by a linear vertical heat-exchange. By considering the wind-driven circulation theory of Rhines and Young, we suggest a new parameterisation for the two-layer EBM deep ocean heat uptake that may be more suitable for basins without deep overturning.