



Thermodynamic analysis of ocean circulation

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Calculating a stream function as function of depth and density is proposed as a new way of analysing the thermodynamic character of the overturning circulation in the global ocean. Since depth is linearly related to pressure, and density is the inverse of specific volume, the circulation is in effect displayed in a classical thermodynamic pV -diagramme. The sign of an overturning cell in this diagramme directly shows whether it is driven mechanically by large-scale wind stress, or "thermally" by heat conduction and small scale mixing. It is shown that the integral of the stream function in depth-density coordinates gives the thermodynamic work performed by the fluid. The analysis is also valid for the Boussinesq equations, although the thermodynamic work formally vanishes for an incompressible fluid.

The proposed method is applied both to an idealized coarse-resolution three-dimensional numerical ocean model, and to the realistic high-resolution OCCAM model. It is shown that the overturning circulation in OCCAM between 200 m and 1000 m depth is dominated by a thermally indirect cell of 24 Sv, forced by large scale wind stress via Ekman pumping. In the densest and deepest waters there is a thermally direct cell of 16 Sv, requiring around 50 GW forcing by parameterized small-scale mixing. There is also another thermally direct cell in the warm waters shallower than 200 m, with a magnitude of 62 Sv.