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A new approach to the formulation of energetically and thermodynamically consistent ocean models and parameterisations

Remi Tailleux
University of Reading, Meteorology, Reading, United Kingdom of Great Britain – England, Scotland, Wales
(r.g.j.tailleux@reading.ac.uk)

The momentum balance underlying most numerical ocean models is one in which the primary forces driving fluid motions are rotation, the pressure anomaly gradient, and vertical buoyancy forces. While this form of momentum balance has the advantage of simplicity, it does not in itself reveal much about the dynamical control exerted by the near material invariance of potential temperature and salinity, whereby oceanic motions are expected to be preferentially stirred along `neutral' directions, nor does it reveal much about the possible dynamical controls imposed by energetics constraints. The main aim of this work is to show that it is possible to rewrite the momentum balance in a way that is much more explicit about the role of the preferential directions for lateral stirring as well as about how energetics affect momentum. The new momentum balance is obtained by combining Crocco's theorem with the theory of available potential energy. Its main properties is that the forces that make it up (save for friction) are all perpendicular or nearly perpendicular to the 3D velocity field. One force is a new form of Nycander's P vector, which controls the local changes in available potential energy. The directions that it defines coincide with those defined by the standard neutral vector except in the Southern Ocean and Gulf Stream region, where it is hypothesised that neutral rotated diffusion must cause spurious diapycnal mixing. One another force is given by the gradient of a new form of Bernoulli function, which controls the local changes in total energy. As a result, both forces define two different set of neutral directions, one along which lateral stirring leaves the available potential energy unchanged, the other along which lateral stirring leaves the total energy unchanged. The newly obtained momentum balance can be Reynolds averaged, which reveals the role of the eddy kinetic energy, eddy available potential energy, as well as of the variances and co-variances of sub-grid scale variability of temperature and salinity on the momentum balance for resolved motions. More generally, a full energy cycle can be constructed, with exact equations describing the energy exchanges between resolved and unresolved energy reservoirs, that can form the basis for energetically and thermodynamically consistent parameterisations.