Diapycnal advection by nonlinear processes in the ocean*

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The nonlinear nature of the equation of state of seawater leads to numerous interesting processes in the ocean. Two of the more well-known processes caused by nonlinearities in the equation of state are cabling and thermobaricity. Other nonlinearities lead to difficulties in analysing water-mass transformation on continuous 'density' surfaces due to the ill-defined nature of neutral surfaces. This ill-defined nature of neutral surfaces describes the problem of not being able to globally connect neutral tangent planes, i.e. planes which describe the local mixing direction of fluid particles in the absence of diapycnal mixing, to form a well-defined surface in three-dimensional space. All these processes have been known to exist for quite some time but their impact on ocean circulation and its analysis remains elusive.

In this work an algorithm is introduced which improves existing density surfaces to ensure that the resulting surfaces are as close to approximating neutral tangent planes as possible. Because of the remaining slope errors between these continuous 'density' surfaces and the neutral tangent planes, even in the absence of diapycnal mixing processes fluid trajectories penetrate through any continuous 'density' surfaces. This leads to a fictitious diapycnal diffusivity and an extra physical mechanism that achieves mean vertical advection in the ocean through any continuous 'density' surface.

Using these accurate density surfaces, the effects of cabling, thermobaricity and the diapycnal advection due to the ill-defined nature of neutral surfaces are quantified. It is shown that these processes cause a significant downward diapycnal transport on the order of 6 Sv, concentrated in the Southern Ocean. This additional production of dense water has implications on the ocean’s energetics which is discussed in this work.

Another consequence of the ill-defined nature of neutral surface is the non-existence of a geostrophic streamfunction. New approximate expressions for the geostrophic streamfunction are also developed and are shown to be significantly more accurate than previously available expressions.

All the algorithms described and the additional code used to quantify the diapycnal velocities caused by nonlinearities in the equation of state are implemented in Matlab. This code including a user manual is part of this work.

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