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A perfectly balanced method for estimating the internal pressure gradients in sigma-coordinate ocean models

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The estimation of the internal pressure gradients in sigma-coordinate ocean models has been addressed both in text books and in many research papers.
In this paper a perfectly balanced method for estimating internal density and pressure gradients is suggested.
The method is perfect in the sense that for cases with rho = rho(z), where rho is density and z the vertical coordinate, the numerical estimates of the density and pressure gradients are zero. The method has in addition another important property: For continuous stratification, the estimates of the internal pressure gradients vary continuously with changes in the stratification.

The properties of the method are investigated using two very simple vertical column test cases, the seamount case, and two Nordic Seas test cases, one with rho = rho(z) and another more realistic case with rho = rho(x,y,z). For the seamount case and the simple Nordic Seas case, the errors are orders of magnitude smaller than the corresponding errors reported in earlier papers. For the simple vertical column case with non-zero density gradients, the estimates of the gradients produced with the new method converge quadratically towards the true values as the horizontal and vertical grid sizes both tend to zero.
The new method may be regarded as a modified second order method calibrated such that the errors are zero for rho = rho(z).