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Modelling the vertical thermal stratification in the North Sea - advantages of using adaptive coordinates

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The seasonal stratification in the North Sea which is characterised by a sharp summer thermocline oscillating on semi-diurnal (tidal and inertial) timescales has been studied in a numerical model (GETM) of the coupled system North Sea / Baltic Sea. The setup includes three nested grids: a 4 nm one for the North Atlantic, a 1 nm grid for the North Sea / Baltic Sea and a 600 m grid for the southern North Sea.
The model results are analysed for the period 2003-2012. To validate the modelling system, point measurements but also vertical Scanfish-transect covering the entire North Sea are used.
To assess the impact of the vertical coordinate system, a twin experiment is started: a) a run with fixed sigma-coordinates and b) a run with adaptive coordinates with an adaptation towards stratification. The differences are quantified in terms of Potential Energy Anomaly, bottom and surface temperature differences and numerical mixing.

The results indicate that the adaptive coordinates show an excellent performance in reproducing the location of the thermocline and the temperature gradient across the thermocline. Whereas the sigma coordinates also match the thermocline-location, its vertical gradient is significantly underestimated. In the vicinity of the thermocline the adaptive coordinates allow for a vertical grid spacing of down to 5-10 cm, which is hardly feasible in classical vertical coordinate systems. Additionally, the minimum vertical viscosity/diffusivity at the thermocline is one order of magnitude lower than for sigma coordinates. Transforming the vertical gradient and diffusivity into a vertical flux gives higher values for sigma coordinates and allow for an higher exchange across the thermocline. Here the results for the adaptive coordinates show the expected blocking behaviour.
The better representation of vertical gradients by using adaptive coordinates reduces the numerical mixing and thus the artificial effects of the numerics. Since the adaptive coordinates are spatially and temporal varying, they allow for the oscillation of the coordinate lines with the moving thermocline due to internal waves or internal tides. This gives lower values of numerical mixing.

The total stratified area during the summer does not vary much between the two runs. Only in the southern part of the North Sea significant differences are visible.

Our results show that vertical adaptive coordinates are beneficial in modelling regions with spatial and temporal varying stratification. Although the adaptive coordinates introduce computational overhead of roughly 10% for hydrodynamic runs, this is compensated by the excellent performance in reproducing vertical gradients. Moreover, the overhead is negligible in biogeochemical applications where most of the computational time is spend in the advection routines.