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The performance of vertical turbulence models in the modeling of hydrodynamics in the Baltic Sea

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Vertical mixing plays an important role in the ecosystem processes in the oceans. Such processes in the Baltic Sea are complex and their throughout description requires still more process-oriented studies (Reissmann et al. 2009). The central basins of the Baltic Sea have strong salinity stratification with a permanent halocline and during the summer seasonal thermocline develops at depths of 10-30m. The complexity of the vertical mixing processes makes the Baltic Sea a good candidate for testing vertical turbulence models. It has been shown in a model-intercomparison study of six model in the Baltic (Myrberg et al. 2010) that although the 3D ocean models performed well, the prediction of the vertical structure of the water column in the Baltic Sea was not sufficiently represented by any of the six models.

The availability and number of measured temperature and salinity profiles usually makes a limitation for a comprehensive validation of vertical turbulence models. In 1996 in the Gulf of Finland, an elongated Gulf in the north-eastern extremity of the Baltic Sea, a measurement campaign was carried out jointly with Finnish and Russian research vessels including about 300 measured temperature and salinity profiles during the period from June to August. The high temporal and spatial distribution of the measurement profiles makes it an outstanding dataset for validation of the performance of various vertical turbulence models.

We used the 3D ocean model COHERENS (Luyten et al. 1999) implemented in the Baltic Sea with a 2 nautical mile resolution, with open boundary in the Danish Straits. Meteorological forcing was taken from Swedish Meteorological and Hydrological Institute's (SMHI) gridded 1° resolution m dataset, whereas in the Danish Straits the boundary conditions were taken from SMHI's 3D ocean model HIROMB. From the vertical turbulence models available in the COHERENS we run k-ε model, k-l model and algebraic formulations by Munk and Anderson (MA, 1948) and Pacanowski and Philander (PP, 1981). For the k- ε and k-l models we used both one and two equations models, together with different limiting conditions for the mixing length.

The model results were compared against the measured temperature and salinity profiles by calculating the bias and rms error for vertical levels at 2m intervals. Comparison against the measurements showed that salinity was quite accurately predicted by all the turbulence models. In the surface layer, up to 20m depth, the predicted salinities were slightly higher than measured and in the bottom layers (bellow 70m), the predicted salinities were lower than measured. The k-l model had highest bias and rms error in the surface layer and PP in the bottom layers. In the comparison of temperature the differences between the turbulence models were large. Most of the turbulence models produced too high surface temperature, except MA and k-l model with no limiting condition for mixing length, which underestimated the surface temperature. The differences between the predicted and measured temperatures were highest in the thermocline, where the rms error was up to 3°C. All of the turbulence models predicted too low depth for the mixed layer. The mixed layer depth was best represented by the k-l model with no limiting conditions for the mixing length. The best agreement with the measured temperatures was at depths below 50m.

None of the tested turbulence models succeeded in predicting accurately the vertical profile of temperature. In general, the k-l and k- ε models showed slightly better agreement with the measurements than the algebraic schemes. The k- ε and k-l models predicted mixed layer depth with better accuracy when no limiting conditions for the mixing length were used.