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Studying climate impacts on hydrophysical processes in Lake Constance by 3D hydrodynamic modelling

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A 3D hydrodynamic model was applied to investigate the implications of a change in climatic conditions for the hydrophysical behaviour of deep Upper Lake Constance. The model simulations covered the period from 1960 to 2011. Model adaptation and verification was based on 51 years of vertically resolved temperature recordings. Three different horizontal grid layouts were employed to test the sensitivity of the model to spatial grid resolution. Effective vertical turbulent diffusivities K_z in the stratified lake below 10 m were determined from simulation results and from vertically highly resolved CTD probe data over 16 years using the heat budget method. The K_z obtained from the simulated and measured water temperatures agreed rather well and ranged in the order of 10^{-5} to 10^{-4} m^2s^{-1}. In the deep water, where the lake basin is resolved only by few grid cells, the diffusivity values were overestimated by the model, whereby the deviation from the measurement data based estimates decreased with increasing grid resolution. The open water turbulent diffusivities in the model are substantially smaller than the basin wide effective diffusivities supporting that vertical transport in a stratified lake is largely dominated by turbulent mixing near the lake boundaries. The model was finally applied to investigate the impact of changed wind velocities and air temperatures on deep water renewal which is a key process for the vertical transport of nutrients and oxygen in deep Lake Constance. Numerical tracers were employed as indicators of the vertical transport and mixing of water. Increased air temperatures not only resulted in an overall increase in water temperatures but also in a change of the mixing dynamics. Deep-water renewal was most sensitive to changes in air temperatures during the winter season. Variations in wind velocity influenced water temperatures and mixing via changes in latent and sensible heat fluxes as well as by changes in the energy flux to turbulent motions.