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Quantification of error sources in the 2D mountain flow numerical test case and convergence studies with the limited area model COSMO-CLM

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We investigated the absolute discretisation errors and the convergence properties of the schemes implemented in the limited area model COSMO by application of the 2D mountain flow test case. For standard linear hydrostatic configurations (10m height of the hill and 10km half width) a complex error convergence was found for the horizontal and the vertical velocity by comparison with high resolution reference case. This cannot be explained by the formal order of convergence of the vertical and/or horizontal discretisation implemented in the model. A theoretical analysis of the error sources was conducted for different configurations of the damping at the model boundaries and for different mountain profiles. It revealed maximum errors due to damping at the lateral and/or upper boundaries and/or linearization for configurations known from literature ($U = 10m/s$, damping configuration as used for operational applications). It is found that keeping the error sources named above sufficiently small for a convergence study (relative error below 10^-3) leads to small hills ($h = 1m$) and velocities ($U \leq 10m/s$) and thus to high accuracy requirements ($\Delta w < 10^-6$) for the simulation. Ín linear regime the convergence can be investigated with respect to the analytical solution. In weakly linear to nonlinear regime the convergence with respect to a high resolution reference simulation can be investigated only. The analysis of the discretisation errors of the test case shows that different configurations are recommended for the investigation of the horizontal and vertical discretisation error convergence. In non-hydrostatic regime the relative horizontal discretisation error is increased in comparison with the hydrostatic regime. Thus, the horizontal schemes can be investigated best in the non-hydrostatic regime, at vertical resolution of approx. 100m or higher (due to first order accuracy of the vertical discretisation). The vertical discretisation convergence can be investigated best in linear hydrostatic regime at a horizontal resolution of approx. 250m or higher. We analysed the discretisation errors for uniform horizontal and stretched vertical grids and identified the model resolutions at which the unavoidable linear error term (resulting from grid stretching) is dominating and those where the second order error term of vertical discretisation is dominating. Furthermore the corresponding horizontal and vertical resolutions have been identified for which the discretisation errors have same order of magnitude. The results of the theoretical analysis will be presented together with test case results for different configurations exhibiting the theoretical findings for the schemes implemented in the COSMO model.