New climate models: A discontinuous/continuous low order finite element shallow water model on the sphere with grid refinement capability

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We evaluate a finite element for its application in the dynamical core of a shallow water model on the sphere. We combine a continuous representation of second order for the height field with a discontinuous representation of first order for the velocity field. The specific low order element has the rare property of being able to represent the geostrophic balance and to satisfy the Ladyzhenskaya-Babuska-Brezzi condition, which is a necessary condition for convergence. We introduce the spherical geometry via a stereographic projection, which can be introduced to the differential equations fairly easy and does not diverge at the poles. We apply the model to icosahedral geodesic grids. We evaluate our model with the standard suite of atmospheric test cases and a Stommel gyre test case for ocean applications. The error for the global energy decreases with increasing grid resolution. The model shows a convergence of second order for the L^1- and L^2-norms as one would expect, since we use a first order field representation for velocity. An energy spectra calculated for the isolated mountain test case shows a reasonable energy decay. The model is able to reproduce a decaying geostrophically balanced jet stream with perturbation. This test is rather challenging for gridpoint models with low order field representation. The model allows the use of grid refinement. Using h-refined grids we are able to decrease the numerical cost significantly for the representation of ocean boundary currents and atmospheric test cases. The results are equivalent to model runs with continuous grids and a higher number of degrees of freedoms. The results from this paper support the considered finite element for its use in the dynamical core of a global climate model.