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A new covariant form of the equations of geophysical fluid dynamics and its discretization using discrete exterior calculus

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I introduce a new formulation of the equations of geophysical fluid dynamics (GFD) consisting of sets of topological and metric covariant equations, which allows a systematic discretization by applying the tools of discrete exterior calculus (DEC).

Within the covariant equations, where the form of the equations is invariant under coordinate transformation, the prognostic variables describing the evolution of the fluid are represented by differential forms. By introducing additional auxiliary prognostic variables, I split the geophysical fluid equations in a topological and in a metric part. The resulting set of equations has similar form to the covariant linear Maxwell's equations and allows to use concepts of electrodynamics also within fluid dynamics. Moreover, such formulation enables a systematic discretization according to DEC by using chains and cochains to approximate manifolds and differential forms, respectively. The discrete scheme follows from the choice of the topological meshes (chains) for the momentum and continuity equations and from the discrete representation of the metric equations (discrete Hodge-star operator, discrete interior product). I illustrate that this formulation incorporates several finite difference schemes, for instance, the triangular and the hexagonal C-grid discretization of the non-rotating linear shallow-water equations, for which consistency and stability for uniform and non-uniform grids are shown.