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Dynamics-physics coupling in the context of the GEM dynamical core with height-based terrain-following vertical coordinate

The dynamical core of the Global Environment Multiscale (GEM) model—used operationally by Environment and Climate Change Canada (ECCC)—is based on a log-hydrostatic-pressure-type terrain-following coordinate (TFC) in the vertical. Recently, a new dynamical core for the GEM model has been developed that introduces the option of a height-based TFC. Hereinafter, the new core is referred to as GEM-H, whereas the pressure-based operational core is referred to as GEM-P. The principal motivation behind the development of GEM-H has been to improve upon the strong numerical instability of GEM-P for steep orography (terrain slopes larger than 45°) over complex terrain. Furthermore, the scalability limitation of the direct solver—employed in GEM-P for the different GEM-based operational prediction systems—is driving extensive research at ECCC aimed at developing optimized three-dimensional iterative solvers for future generations of massively parallel supercomputers. The height-based dynamical core is expected to be more amenable to such iterative solvers as the metric terms attributable to the vertical coordinate transformation appear explicitly in the discretized elliptic boundary value problem.

In the absence of subgrid-scale physics forcings, predictions by the two adiabatic and inviscid dynamical cores are found to be statistically equivalent. Efforts were then made to couple ECCC's Physics Package with the GEM-H core without any additional calibration. A number of dynamics-physics coupling approaches were considered during this stage. The operational GEM-P model utilizes the 'split method'for dynamics-physics coupling where the dynamical equations are resolved in the absence of any physical forcing and at the end of the dynamics sub-step the parameterized physics contributions are incorporated as adjustments to some of the prognostic variables in the so called 'split mode'. Another possible approach for dynamics-physics coupling is to directly incorporate the impact of the physics forcings as tendencies within the discretized dynamical equations, and hence is referred to as the 'tendency method'. Researchers in the past have demonstrated possible erroneous behavior of the split method, particularly for large time steps that are permissible with semi-Lagrangian semi-implicit (or iterative implicit) approach. Efforts to couple ECCC's Physics Package with the GEM-H dynamical core reaffirmed some of these issues pertaining to the split method.

Overall, the tendency method for dynamics-physics coupling is more consistent from a theoretical perspective, and it also leads to a very good agreement between the two dynamical cores. However, when compared against upper-air observations, the tendency method is found to suffer from deterioration in the objective scores. As a result, a split-tendency hybrid approach for GEM-H has also been developed that leads to objective forecast scores that are equivalent to GEM-P with the split method. Currently, research is ongoing to devise an optimal dynamics-physics coupling for the GEM model in general –which will be theoretically more consistent while producing equivalent or improved forecast scores compared to the split approach. The poster to be presented at the ECMWF Annual Seminar will include further information on this study along with the pertinent results.

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