A case study by using a global/regional unified MCV nonhydrostatic model

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1. Introduction

Currently CMA-GFS V4.0 in China Meteorological Administration(CMA) has been served as an operational medium-range global weather prediction [1]. With a new operational demand for regional hundred-meter scale, global kilometer resolution and the ability of the numerical model to adapt to exascale computing platforms, the regional/global unified nonhydrostatic Multi-moment Constrained finite Volume (MCV) model has been developed for the next generation atmospheric modeling in the CMA Earth System Modeling and prediction center (CESM). The multi-moment finite volume formulation is to define the unknowns as the values at the points located within each grid cell and to use the time evolution equations of different moments as the constraint conditions to derive the governing equations for updating the unknown point values. In the previous studies [2,3], based on the MCV method, we have developed global shallow water models and the nonhydrostatic atmospheric dynamics. For regional model, a 3D nonhydrostatic compressible atmospheric dynamics is built in the Cartesian coordinate [4]. More recently, a dry nonhydrostatic atmospheric dynamical core on cubed sphere using multi-moment finite-volume method has been developed [5]. For atmospheric tracers like water vapor, cloud water, O3 etc., a three-dimensional positivity-preserving and conservative multi-moment finite volume transport model is presented [6,7].

2. MCV nonhydrostatic model

Towards real NWP simulation, a global/regional unified next-generation NWP model has been built by coupling the scale-aware physical packages. For MCV dynamical core, the fully compressible flux-form governing equation is adopted and the prognostic variables are dry density ρ_d, the horizontal contravariant velocity (u^{ξ}, u^{η}) andd vertical velocity w, the moist potential temperature $\theta_m = \theta(1 + r_v/\epsilon)$, and mixing ratio r_χ $(\chi = v, c, i, r, \ldots)$ where ξ and η are the horizontal curvilinear coordinates and θ is potential temperature, and all the state variables are collocated. The horizontal numerical discretization is 4th order MCV scheme, and a second conservative finite difference scheme is used for the vertical discretization. The 3rd Runge-Kutta implicit-explicit time-stepping scheme is utilized for advancing the model. A generalized height-based terrain following coordinate is adopted to map the computational space to physical space. For tracer transport, the conservative MCV3_BGS-PRM advection scheme with flux correction transport (FCT) technique is given in the MCV NWP modelling. The global/regional unified model is cast in the curvilinear coordinate system and the regional LAT/LON grid and the global cubed sphere grid can be switched easily.

3. Numerical experiments

Heavy rainfall process in South China happened on April 24-25, 2024. Reviewing the weather process forecasting, CMA-GFS V4.0 actually underperformed the forecast of this heavy rainfall process. In the following numerical simulation of the global MCV model, the key physical configurations include the RRTMG scheme, Monin-Obukhov surface layer scheme, the Noah LSM scheme, the scale-aware TKE EDMF scheme, the scale-aware SAS cumulus shallow/deep convection, the GFDL cloud microphysics, unified gravity wave physics scheme, ozone photochemistry Scheme, stratospheric H2O Scheme etc.. Main model setups are as following: the horizontal grid DOF resolution is 0.125 degree that is approximately equivalent to 12.5km, model levels being 60 in the vertical, model top being 36km, the Rayleigh friction is imposed above 30km, and the initial field is the same as NCEP-GFS's and the start of the forecast is 2024042412 UTC. Overall, the ECMWF 24h precipitation forecast in the box is better than other operational models like Fig. 1 (b) and (c) in comparison with observational rainfall. Based on the same initial field, it is observed that the precipitation prediction of the MCV model shows the best performance among the CMA-GFS V4.0, NCEP-GFS and MCV model as shown in Fig. 1 (b), (d) and (f) and is competitive to ECMWF's. The preliminary case study of heavy rainfall indicates that a global/regional unified next-generation MCV model has great potential to the real weather prediction.

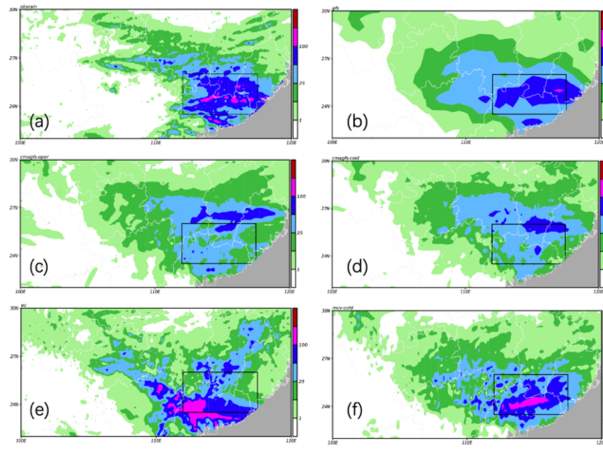

Figure 1: Observation rainfall and 24-hour precipitation forecasts in the southern China. (a) observation; (b) NCEP-GFS 13km operational forecast; (c) CMA-GFS V4.0 operational forecast (12.5km); (d) CMA-GFS V4.0 forecast using NCEP-GFS's initial field (12.5km); (e) ECMWF 9km operational forecast; (f) MCV model forecast using NCEP-GFS's initial field (12.5km).

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