# Development of a New Dynamical Core for the Nonhydrostatic Model


**Junichi Ishida, Chiashi Muroi, and Yuri Aikawa**

*Numerical Prediction Division, Japan Meteorological Agency*

E-mail: j_ishida@naps.kishou.go.jp, cmuroi@naps.kishou.go.jp, aikawa@met.kishou.go.jp


## 1. Introduction

A new dynamical core for JMA's nonhydrostatic model is now under development for mesoscale numerical weather prediction. JMA presently operates the global spectral model (GSM) and a nonhydrostatic regional model (Mesoscale Model: MSM) within the current operational supercomputer system. The recent rapid increase in market share of scalar multi-core architecture machines and the spaghetti code of the current regional model have motivated us to renovate the model. This paper gives a brief outline of the new dynamical core of the revised nonhydrostatic model, called "ASUCA". The new version is intended for operation as a regional cloud-resolving model at JMA.

## 2. Outline of the new dynamical core

Flux-form fully compressible equations are applied as the governing equations for this model. The prognostic variables are $\rho u$, $\rho v$, $\rho w$, $\rho\theta$ and $\rho$, where u, v and w are the components of wind velocity, $\theta$ is potential temperature and $\rho$ is density. The equations are transformed using general coordinate transformations, which enable the new model to be extended to a global nonhydrostatic version. The only assumptions are that the transformed coordinates have flat lower boundaries regardless of topography and the axis of a transformed coordinate is parallel to the vector of gravity acceleration.

The finite volume method (FVM) is applied to the transformed equations. A structured quadrilateral grid is employed, which makes the data structure simple. A mass conservation equation is directly integrated using FVM and mass is conserved throughout the whole domain including lateral boundary inflow and outflow. No correction scheme is required for mass conservation. An accurate flux correction advection scheme is employed to avoid causing oscillations, and this scheme employs the flux limiter function proposed by Koren (1993). The correction scheme for conservation and avoidance of negative quantity can be simplified. These features reduce the computational cost and the amount of data communication required for numerical stability and conservative properties.

A third-order Runge-Kutta scheme (Wicker and Skamarock, 2002) is applied for time discretization. A split-explicit time integration scheme (Klemp and Wilhelmson, 1978) is used to avoid small time steps caused by sound waves. Pressure gradient terms and divergence terms are treated in the shorter time step, and other dynamical and physical processes are evaluated in the longer time step. In the short time step, horizontal velocities are integrated first in an explicit manner, and vertical velocity and density are solved implicitly.

## 3. Software design

The code of this new model is designed for parallel architecture machines including PC clusters. Fortran90 and MPI are used in the code, and OpenMP directives are inserted into it for multi-thread environments. Since the latency time of the data communication is not small, the code is also designed to reduce the number of calling of MPI subroutines. Three-dimensional arrays in space are stored sequentially in the order of z (k), x (i) and y (j). To avoid spaghetti code, style and coding rules are also prescribed.

## 4. Summary and future plan

We are currently testing the new dynamical core through a range of idealized experiments. We have also incorporated a number of simple physical processes, and are implementing trial runs of the model using real data.

There is also a need to develop more sophisticated software design. Since the source code for physical processes will be shared between the new model and the current nonhydrostatic regional model, it is necessary to develop efficient methods of code sharing.

The dynamics core also needs to be more sophisticated. For example, if water substances with a fast fall velocity (such as rain or graupel) are used as prognostic variables, another scheme to treat advection is necessary. We plan to introduce the piecewise rational method (Xiao and Peng, 2004) for this purpose.

## References

Klemp, J. B., and R. B. Wilhelmson, 1978: The simulation of three-dimensional convective storm dynamics. J. Atmos. Sci., 35, 1070-1096.

Koren, B., 1993: A Robust Upwind Discretization Method for Advection, Diffusion and Source Terms. CWI Report NM-R9308.

Wicker, L. J., and W. C. Skamarock, 2002: Time-splitting methods for elastic models using forward time schemes. Mon. Wea. Rev., 130, 2088–2097.

Xiao, F., and X. Peng, 2004: A convexity preserving scheme for conservative advection transport. J. Comp. Phys., 198, 389-402.