THE NEXT GENERATION OF NCEP ATMOSPHERIC MODEL DYNAMICS

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1. Introduction

NCEP (National Centers for Environmental Prediction) has two streams of dynamic core in its operational suite. One is based on spectral method in GFS and RSM, another one is grid-point method in Eta and WRF. In terms of major model, GFS is for global climate and weather forecasts, and WRF is for mesoscale weather forecast. Even though spectral method is used in GFS and RSM, the vertical is still finite difference as grid-point model. Recently, NCEP is under developing for possible next generation of atmospheric dynamics for all scales from global, mesoscale, and local scale, to couple with ocean, land, ice and even ionsphere and space models. Also, two main streams are under development, one is growing from GFS, and the other is from WRF-NMM.

In this extended abstract, we will emphasize on the possible next generation of atmospheric dynamics from the spectral model side. Based on the incremental changes to the GFS dynamics, several new features to meet on the requirement such as all scale and even covering space weather have been implemented, and they have been presented one by one during the past CWB annual meetings, such as the reduced spherical transform for efficiency (Juang 2004), the generalized hybrid vertical coordinates to have combination of sigma, pressure, and isentropic surfaces with completed conservations for accuracy and flexibility (Juang 2005, Juang 2006), the enthalpy as thermodynamic variable to consider all gases to internal energy for coupling with space model and chemistry models (Juang 2007), and the mass conserving positive definite semi-Lagrangian tracer advection (Juang 2008, Juang and Hong 2009). This extended abstract will emphasize on the further development of non-iteration dimensional-split semi-Lagrangian (NDSL) with accurate treatment for deformation in section 2, and introduce Riemann invariant characteristic equation (RICE) method with NDSL for accurate resolving gravity and sound waves in section 3. Some results based on section 2 and section 3 will be presented in section 4. Some concerns and future works are discussed in section 5.

2. Continue Non-iteration dimensional-split semi-Lagrangian (NDSL) development

The NDSL can be paraphrased here starting from continuity equation in one dimension, which can be ended up as

$$\frac{dA\Delta x}{dt} = 0 \qquad (1)$$

so the mass is local conservation because the departure mass is equal to the arrival mass from the above equation as

$$A_a \Delta x_a = A_d \Delta x_d \qquad (2)$$

However, the departure cell size may not be the arrival cell size. This is deformation from the mass conservation. Thus, the combining multi-dimension by this method will result further deformation on deformed mass from last deformation. To avoid this, summation of changes in each direction with one deformation is used, such as in Lin and Rood (1997).

Since NDSL is using the concept of central scheme to avoid iteration, but the dimensional split forcing will be work on the different location from the same location forcing. To make further accurate to avoid this bias, the deformation forcing from middle cell has be modified to similar to arrival cell. It works like advection with central scheme but deformation forcing is backward scheme. Thus the formula for the final NDSL with corrections can be summarize here. Let's start from deformation or divergence in one direction as

$$\frac{\partial u}{\partial x} \approx \frac{\dfrac{x_a^+ - x_d^+}{\Delta t} - \dfrac{x_a^- - x_d^-}{\Delta t}}{\Delta x} = \frac{1}{\Delta t}\frac{\Delta x_a}{\Delta x}\left(1 - \frac{\Delta x_d}{\Delta x_a}\right) \qquad (3)$$

For the same forcing in the same location, let $\Delta x_a = \Delta x$ in Eq. (3), then put into the Eq. (2), so we have

$$A_a = A_d\left(1 - \frac{\partial u}{\partial x}\Delta t\right) \qquad (4)$$

This modification avoids the bias and makes the accuracy based on the computational accuracy from the deformation. Some results to compare between bias corrected and un-corrected methods will be shown in section 4.

3. Apply Riemann invariant characteristic equation (RICE) with NDSL

Most of the semi-Lagrangian scheme used in atmospheric modeling is accompanied with semi-implicit scheme to have stable integration with large time step. The effectiveness of semi-implicit scheme is very promising, however, it retards high frequency waves, such as gravity modes and acoustic modes. Thus these high frequency waves will slow down with erroneous phase. The Riemann method with characteristic equation of Riemann invariant provides a hint to reduce this error by combining gravitational and acoustic mode into advection form, so that they can be solved by semi-Lagrangian advection.

The concept can be illustrated by one dimension shallow wave equation set as

$$\begin{aligned}\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+g\frac{\partial h}{\partial x}=0\\ \frac{\partial h}{\partial t}+u\frac{\partial h}{\partial \lambda}+h\frac{\partial u}{\partial x}=0\end{aligned} \qquad (5)$$

which can be combined all x derivative into advection form as

$$\frac{\partial}{\partial t}\begin{pmatrix}u\\ h\end{pmatrix}+\begin{pmatrix}u & g\\ h & u\end{pmatrix}\frac{\partial}{\partial x}\begin{pmatrix}u\\ h\end{pmatrix}=0 \qquad (6)$$

Using eigen value and eigen vector methods, we can have above equation into

$$\frac{\partial R}{\partial t}+c\frac{\partial R}{\partial x}=0 \qquad (7)$$

where R is Riemann invariant and c is the characteristic advection speed as following

$$\begin{aligned}R=\sqrt{gh}\pm u/2\\ c=u\pm\sqrt{gh}\end{aligned} \qquad (8)$$

as two equations. Equation (7) is a pure advection form, thus NDSL can be used to solve R by speed c. Using this Riemann invariant characteristic equation (RICE) to solve momentum equation can take advantage of large time step by semi-Lagrangian method. Since semi-Lagrangian advection is stable with large time step, the gravitational mode in the above equation will be solved with large time step. The gravitational mode is not retarded and phase of the gravitational mode should be accurate. Some results from two-dimensional shallow water equation solved by RICE with NDSL will be shown in the next section.

4. Case results

There is a standard method to check whether the bias correction as mentioned in section 2. For a non-divergence flow, the constant field of density should be always constant. Table 1 show the maxima and minima values of a unit field integrated in a non-divergence flow for 100 steps. The NDSL-MCPD1 is the mass advection by NDSL without any correction in two-dimensional advection, which is mass conservation and positive definite interpolation (MCPD). NDSL-MCPD2 is the same as NDSL-MCPD1 without the multi-deformation bias. Another two with DV in Table 1 is the same as the mentioned methods with divergence correction in deformation by Eq. (4). We can see from Table 1 that MCPD2 (avoid multi-deformation) improves the result to have maxima and minima to be close to unit, and divergence correction has the best results.

For the RICE method, we are using case 6 in (7.2) Williamson et al (1992) to test. Case 6 is a not-so-stable 4-wave-number of Rossby-Haurwitz wave. The purpose of it is to maintain its wave number without growing. Figure 1 shows the h fields in initial condition in color and after about 8 days later. We can see the wave number and shape of the waves are very much maintained. We integrated it up to 30 days without any problem. Figure 2 show v field in hemispheric view to see how the wave pattern are maintained after 25 days. More figures will be presented in meeting.

5. Discussion

Although the next generation of NCEP atmospheric dynamic core has been finalized, the approach we proposed here has been very much theoretical basis and very practical. NDSL has efficient way to do semi-Lagrangian without guess and iteration error. Since it is dimensional splitting, there is no need to form halo for massively parallel programming. Furthermore, it can be used in reduced grid by one direction first then reassign grid for another direction. The modified mass conservation of NDSL with no deformation bias and high accurate deformation should result better forecast and favorable for climate integration.

The RICE method with NDSL is a new approach, there is still not finalized for this new method. The pole area has been shown noises as seen in Fig. 2, which has to be investigated and fixed.

However, the preliminary result shows a hope of successful method to avoid erroneous gravitational wave propogation. The further investigation with multiply gravitational mode as well as acoustic mode under nonhydrostatic modeling is under testing.

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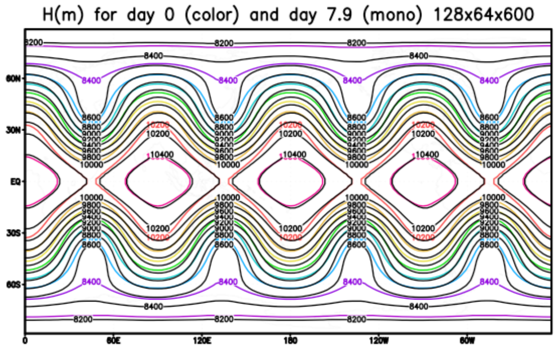

Fig. 1 h field in meter from Rossby-Haurwitz wave by NDSL RICE method, color is initial condition and black is after about 8 days later.

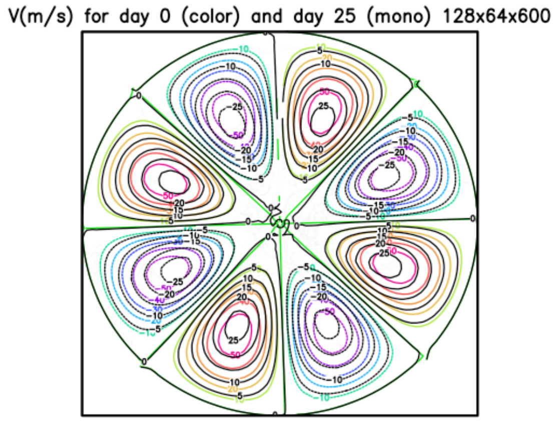

Fig. 2 v (m/s) fields on a north hemisphere, color is initial condition, black is after 25 days later by NDSL RICE method.

Table 1. A constant unit density over sphere is integrated with different methods in NDSL after 100 steps with non-divergence wind field.

scheme	max	min
NDSL-MCPD1	2.26547828958353081	0.772062367788112880
NDSL-MCPD2	1.73489277362112437	0.773492632734020913
NDSL-MCPD1_DV	1.03412223797833835	0.767735424272042666
NDSL-MCPD2_DV	1.00000000000000266	0.999999999999990119