# JP2.5 An Implementation of a Double Fourier Series (DFS) Dynamic Core in a Global Numerical Weather Prediction Model.

[1]Hoon Park, [2]Hyeong-Bin Cheong, [1]Song-You Hong*

[1]Department of Atmospheric Sciences, Yonsei University, Seoul, Korea
[2]Department of Environmental Atmospheric Sciences, Pukyong National University, Busan, Korea

## 1. INTRODUCTION

The spectral method that incorporates the spherical harmonics (SPH) as an orthogonal basis function is widely used in the global atmospheric models. As the model resolution increases, however, the computational cost for the spectral transform becomes dominant over other parts of computation because Legendre transform requires O(N3) operations, with N being the truncation wave number. The Double Fourier Series (DFS) was proposed as basis function of global model to reduce computational cost characterized by O(N2log2N) (Cheong 2000; Cheong 2006). The suggested DFS retains most of the advantages available for the traditional spectral method and provides an efficient and simple high-order filtering method which is essential for the stable time integration of nonlinear partial-differential equations for the atmospheric flow without affecting the physics of the phenomenon (Cheong *et al*. 2004).

The DFS dynamic core is implemented in the YOnsei University Research Model System (YOURS) – global model, which was routed in a version of the NCEP global forecast model (Kanamitsu et al. 2002, BAMS) but with major differences in physics. The model with the DFS dynamic core is parallelized using Message Passing Interface (MPI) library routines.

The performance of the new global model is evaluated for heavy rain case and seasonal simulation, in comparison with the results with the SPH dynamic core. In section 2, the YOURS-DFS governing equations and implementation of DFS are described. An evaluation result and summary and concluding remarks are given in section 3 and section 4, respectively.

*Corresponding author address: Song-You Hong, Yonsei University, Department of Atmospheric Science, Yonsei University, Seoul, 120-749, Korea. E-mail: shong@yonsei.ac.kr

## 2. Implementation of the DFS

*a. governing equations*

The hydrostatic primitive equations with vertical sigma coordinate on the spherical domain of divergence, vorticity, virtual temperature, logarithm of surface pressure, and specific humidity are represented as follows (Cheong 2006).

$$\frac{\partial \xi}{\partial t} = -\frac{1}{a\cos^2\theta}\left(\frac{\partial}{\partial \lambda}F_u + \cos\theta\frac{\partial}{\partial\theta}F_v\right) - \nu\xi + S_\xi, \quad (1)$$

$$\frac{\partial D}{\partial t} = \frac{1}{a\cos^2\theta}\left(\frac{\partial}{\partial \lambda}F_v - \cos\theta\frac{\partial}{\partial\theta}F_u\right) - \nabla^2\left(a^2\frac{U^2+V^2}{2\cos^2\theta} + \Phi + R_d\bar{T}\ln P_s\right), \quad (2)$$
$$- \nu D + S_D$$

$$\frac{\partial T'}{\partial t} = -\frac{1}{a\cos^2\theta}\left(\frac{\partial}{\partial \lambda}UT' + \cos\theta\frac{\partial}{\partial\theta}VT'\right) + T'D - \sigma^{\chi}\dot{\sigma}\frac{\partial}{\partial\sigma}(T\sigma^{-\chi}) + \chi T\left(\frac{\partial \ln P_s}{\partial t} + V\cdot\nabla\ln P_s\right) - \alpha\left(T - T'\right) + S_{T'}, \quad (3)$$

$$\frac{\partial \ln P_s}{\partial t} = -V\cdot\nabla\ln P_s - D - \frac{\partial\dot{\sigma}}{\partial\sigma}, \quad (4)$$

$$\frac{\partial q}{\partial t} = -\frac{1}{a\cos^2\theta}\left(\frac{\partial}{\partial \lambda}Uq + \cos\theta\frac{\partial}{\partial\theta}Vq\right) + qD + S_q, \quad (5)$$

where the symbols of $F_u$, $F_v$, $T'$, $U$, $V$, and $\chi$ represent

$$F_u = U\left(f + \xi\right) + \dot{\sigma}\frac{\partial V}{\partial\sigma} + \frac{R_d T'}{a}\cos\theta\frac{\partial\ln P_s}{\partial\theta},$$

$$F_V = V\left(f + \xi\right) - \dot{\sigma}\frac{\partial U}{\partial \sigma} - \frac{R_d T'}{a}\frac{\partial \ln P_s}{\partial \lambda}\ , \quad T = \bar{T}(\sigma) + T'\ ,$$

$U = u\cos\theta$ , $V = v\cos\theta$ , and $\chi = \dfrac{R_d}{C_p}$ .

Other symbols are used as its usual notations.

*b. Implementation*

The DFS dynamic core was implemented in YOURS framework as a dynamic core option that can replace the SPH core. All the boundary conditions and initial fields are reconstructed according to different grid system and wave number domain. The YOURS-DFS has meridional S-grid system (Cheong 2004), which differs from the Gaussian grids in the SPH core. The DFS grid system does not include the north and south poles to avoid singularity at the poles. The wave number domain is rectangular in zonal and meridional direction; differ from triangular truncation in the YOURS-SPH option.

The vertical distribution of sigma layer is defined as half of adjacent two interface levels in DFS option; as a result, formulation of vertical finite difference scheme is different between the two dynamic options. Also, we added specific humidity as a prognostic variable, which is absent in the original DFS dynamic core (Cheong 2006).

The YOURS-DFS was parallelized using MPI library to execute on distributed memory machine system. The grid and wave variable domain is decomposed in two directions. A transpose method which rearranges the prognostic variable matrix along with calculation direction was adopted for the purpose of parallelization of FFT. A parallel tri-diagonal matrix solver (Mattor *et. al* 1995) was selected to solve tri-diagonal matrix which is used to solve Laplacian operator. It is used to calculate horizontal diffusion, semi-implicit time integration and wind components from vorticity and divergence.

## 3. Evaluation of the implementation

For a real case test, a heavy rainfall event over the Korea peninsula on 14-15 July 2001 is selected. The SPH version and DFS version of YOURS are performed prediction for 24 hour with the same initial conditions.

The YOURS-DFS produces compatible results in comparison with the results from the YOURS-SPH dynamic core run (Figure 1). The YOURS-DFS increases precipitation over the Korea peninsula in terms of the 24 hour accumulated rainfall and produces smoother patterns for mean sea level pressure (MSLP), resulting in underestimation of high pressure area over Manchuria. The YOURS-DFS underestimates precipitation over south Japan Sea, as compared to that with the YOURS-SPH core.

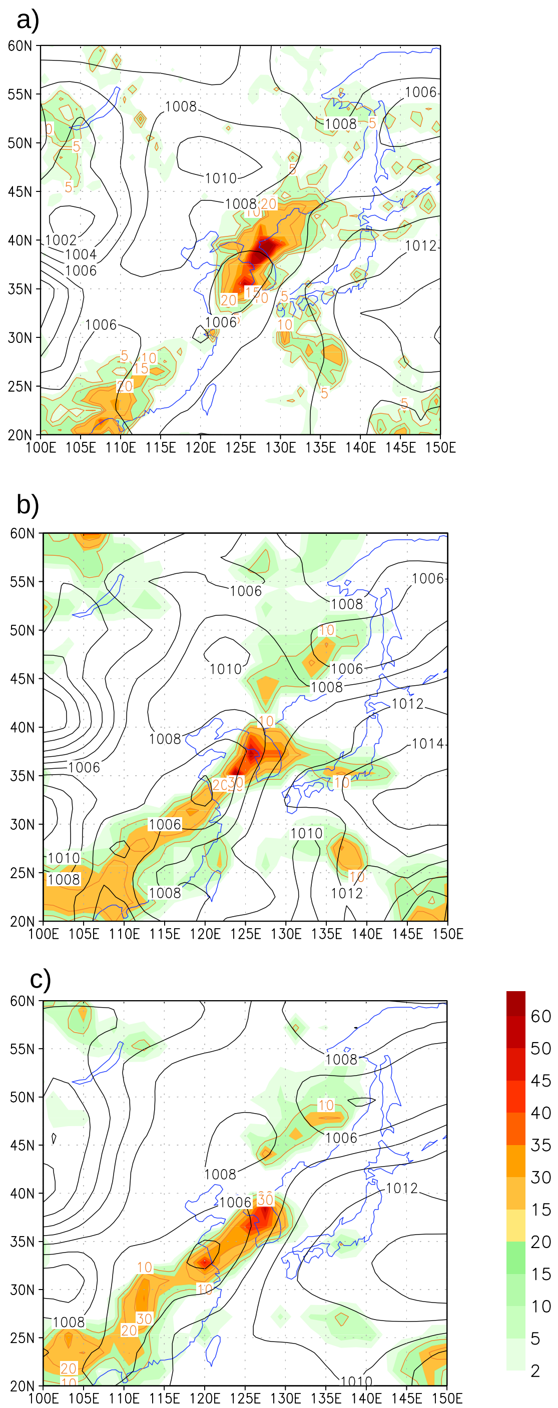

Fig. 1. (a) Analyzed Sea Level Pressure (hPa) (reanalysis) and GPCP rainfall (mm), and the corresponding results from b) the YOURS-SPH, and c) YOURS -DFS runs

The YOURS-DFS global model was evaluated for seasonal simulation from Dec. 1995 to Feb. 1997 in comparison with SPH core. Overall, the two results well reproduce zonal mean zonal wind in comparison with reanalysis data (Figure 2). The SPH core shows easterly bias in Tropical troposphere and westerly bias in southern hemisphere stratosphere together with weakens westerly in winter hemisphere stratosphere. The DFS alleviates easterly bias in tropic troposphere and westerly bias southern hemisphere stratosphere. The DFS run shows equator ward shift southern hemisphere jet stream causing from strong horizontal diffusion in DFS.

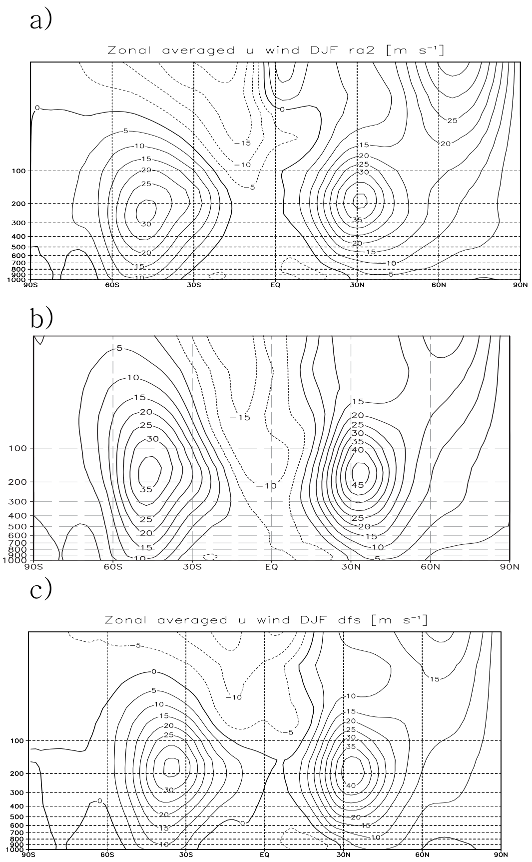


Figure 2. A zonal mean zonal wind from a) reanalysis, b) simulated from the SPH run, and c) simulated from the DFS dynamic core

The parallel calculation performance for 426 wave truncation (1280 grids in zonal and 640 grids in meridional) in DFS is shown in Figure 3. The speed up almost linearly increases up to 8 CPUs. But the speed up for 8 CPUs shows less than 3.5 in comparison with 2 CPUs showing more rooms for parallelization.

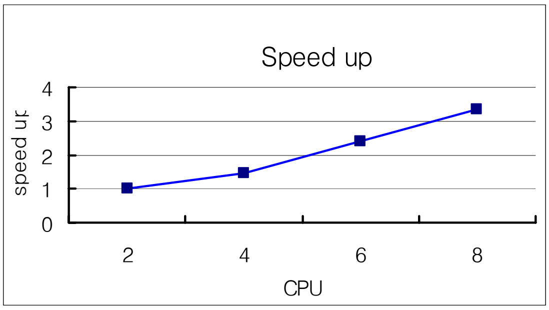


Figure 4. A parallel calculation performance of DFS dynamic core.

## 4. Summary and concluding remarks

The DFS dynamic core was implemented in YOURS GSM as a dynamic option. The dynamic core was parallelized can be executed on distributed memory system. In the evaluation run, the new global model shows comparable results compared with SPH dynamic core results. The parallel performance shows needs to be optimized.

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