Recent developments of a new non-hydrostatic model at JMA

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1. Introduction

* Local Forecast Model (LFM) with dx=2km will be in operation on the next supercomputer system installed in 2012.
* LFM is currently in the stage of trial operation.
* The model used in LFM is JMA Nonhydrostatic model (JMA-NHM; Saito et al., 2006) which is used as the operational Meso-Scale Model (MSM) with dx=5km at JMA.
* A new dynamical core named "ASUCA" is under development to replace the current model, aiming at more computational stability and efficiency on the massive parallel computers.

2. Brief overview of "ASUCA"

2.1 Dynamical Core

* Governing equations ASUCA in generalized coordinate are as follows,

$$\frac{\partial}{\partial t}\left(\frac{\rho u^i}{J}\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{\rho u^i \hat{u}^n}{J}\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{1}{J}\frac{\partial \hat{x}^n}{\partial x^i}p'\right)-\frac{\rho'\delta^i_3 g}{J}=\frac{F^i}{J},$$

$$\frac{\partial}{\partial t}\left(\frac{\rho'}{J}\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{\rho \hat{u}^n}{J}\right)=\frac{F_\rho}{J},$$

$$\frac{\partial}{\partial t}\left(\frac{(\rho\theta_m)'}{J}\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{\rho\theta_m \hat{u}^n}{J}\right)=\frac{F_{\rho\theta m}}{J},$$

$$\frac{\partial}{\partial t}\left(\frac{\rho q_\alpha}{J}\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{\rho q_\alpha \hat{u}^n_\alpha}{J}\right)=\frac{F_{\rho q_{\alpha m}}}{J},\quad \alpha=v,c,r,i,s,g,h,$$

$$\pi=\left(\frac{p}{p_0}\right)^{\frac{R_d}{C_p}},\; p=R_d\pi(\rho\theta_m),\; \theta_m=\theta\left(1+(\varepsilon-1)q_v+\sum_{\alpha\neq v}q_\alpha\right),$$

$$p'=\frac{C_p}{C_v}R_d\pi(\rho\theta_m)'.$$

* RHS are terms of physical processes, Coriolis, Curvatures, and terms arising due to the change of density by precipitation and physical processes.
* The flux form is used for mass conservation.
* The flux limiter function suggested by Koren (1993) is employed for advection to keep monotonicity
* Vertical advection of q_α are calculated from sum of vertical velocity and sedimentation velocity.
* No explicit artificial diffusion.
* Specifications of ASUCA are shown in Table 1 in comparison with those of JMA-NHM.

2.2 System Design

* A kij-ordering (vertical index is set as the innermost suffix) is adopted for computational efficiency on the massive parallel multi core type computers.

2.3 Physical Processes

* The "Physics Library" project at JMA
  * Physical processes in the Physics Library are vertically one-dimensionalized.
  * Physics Library is designed to be used easily by any models. A schematic figure is shown in Fig.1.
  * Test cases including Gabls2/3 are provided in the Physics Library for the development of physical processes .They are also useful for implementation test by users, and detailed investigation when problem are found in real data experiments.
  * Physical processes equivalent to JMA-NHM have been already installed (some of them are even sophisticated) in the Physics Library.
  * Due to the improvement of readability by one-dimensionalized simple codes, it is easy to understand the details of the physical processes which is currently used in JMA-NHM. It helped us finding inappropriate parts in the codes.
  * It is very easy to implement Physics Library into models.
    * It was only a few days to plug in surface, pbl, radiation, and cloud microphysics schemes included in the Physics Library in case of ASUCA.
  * Having an affinity for kij-ordering of ASUCA.

3. Recent updates of ASUCA

* The physical processes of surface, pbl, radiation, and cloud microphysics included in the Physics Library have plugged in ASUCA.
  * Consistency of the total mass (due to lateral boundary flux, surface flux of water vapour, and precipitation flux) has been confirmed even with the inclusion of physical processes.
* Due to the implementation of Physics, ASUCA is in the stage to evaluate for the real data experiments compared with the results of JMA-NHM.
* We started daily experiment on 1 April 2011 with dx=2km and dt=20sec. We have no computationally unstable cases since the beginning of daily experiments.
* The simulation results are shown in Fig 2. comparing with the result of JMA-NHM and observation.

4. Spectrum analysis

* Spectra of horizontal velocity v at 850 hPa computed from the simulation results of ASUCA and JMA-NHM are shown in Fig.3.
* It has been confirmed that ASUCA is computationally stable without numerical diffusion while JMA-NHM needs a certain amount of numerical diffusion.

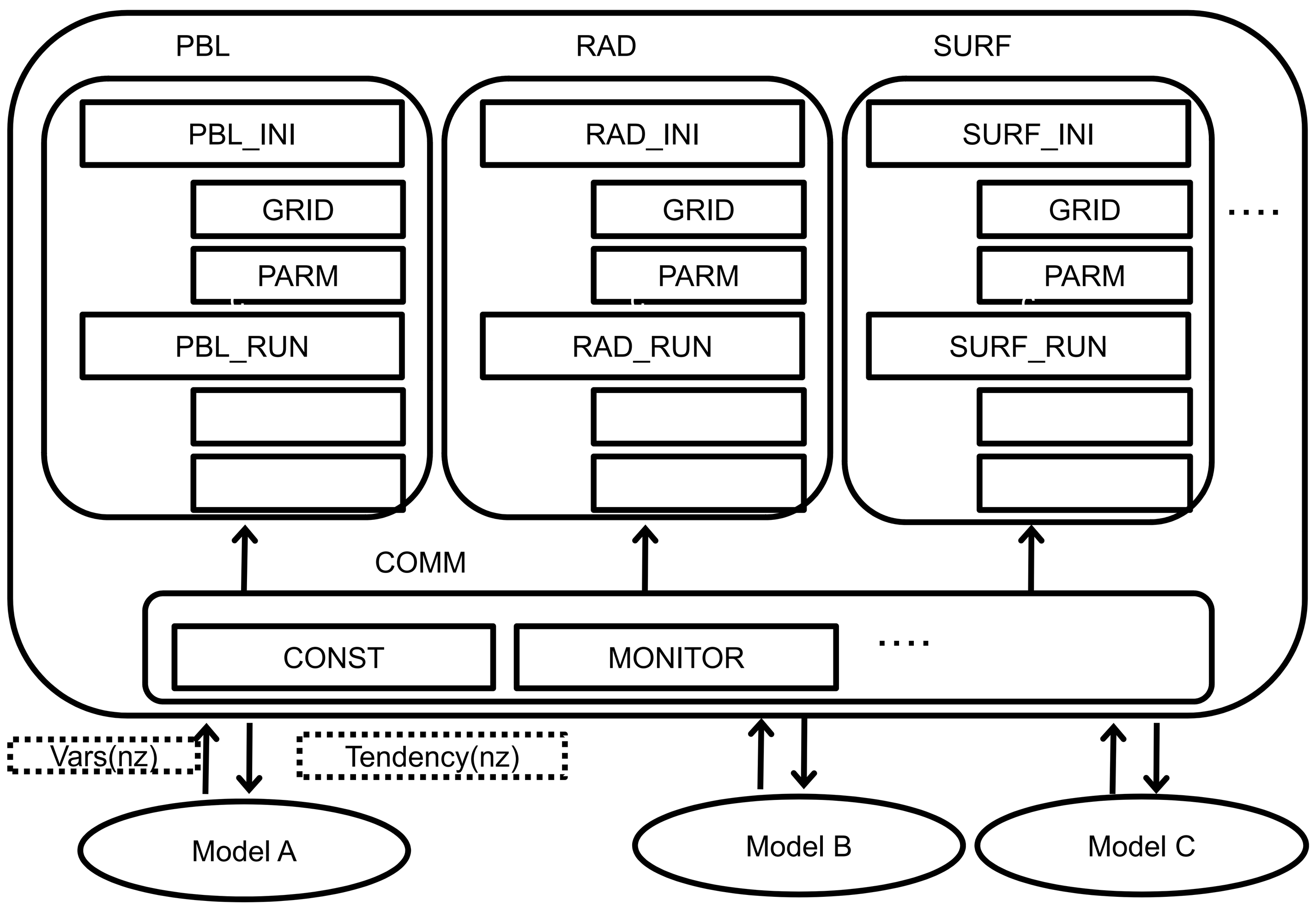

Fig.1 Schematic figure of the Physics Library.

Table 1. Specifications of ASUCA(left) and JMA-NHM(right)

	ASUCA	JMANHM
Governing equations	Flux form Fully compressible equations	Quasi flux form Fully compressible equations
Prognostic variables	ρu, ρv, ρw, ρθ, ρ	ρu, ρv, ρw, θ, p
Spatial discretization	Finite volume method	Finite difference Method
Time integration	Runge-Kutta 3rd (long and short)	Laepflog w/ time filter (long) Forward backward (short)
Treatment of sound	Conservative Split explicit (Klemp et al., 2007)	Split explicit
Advection	Flux limiter function by Koren (1993)	4th (hor.) and 2nd(ver.) order with advection correction
Numerical Diffusion	None	4th order linear and non-linear diffusion
Treatment of rain-drop	Time-split	Box-Lagrangian
Coordinate	Generalized coordinate or Conformal mapping +Hybrid-Z	Conformal mapping (hor.) Hybrid – Z (ver.)
Grid	Arakawa-C (hor.) Lorentz (ver.)	Arakawa-C (hor.) Lorentz (ver.)

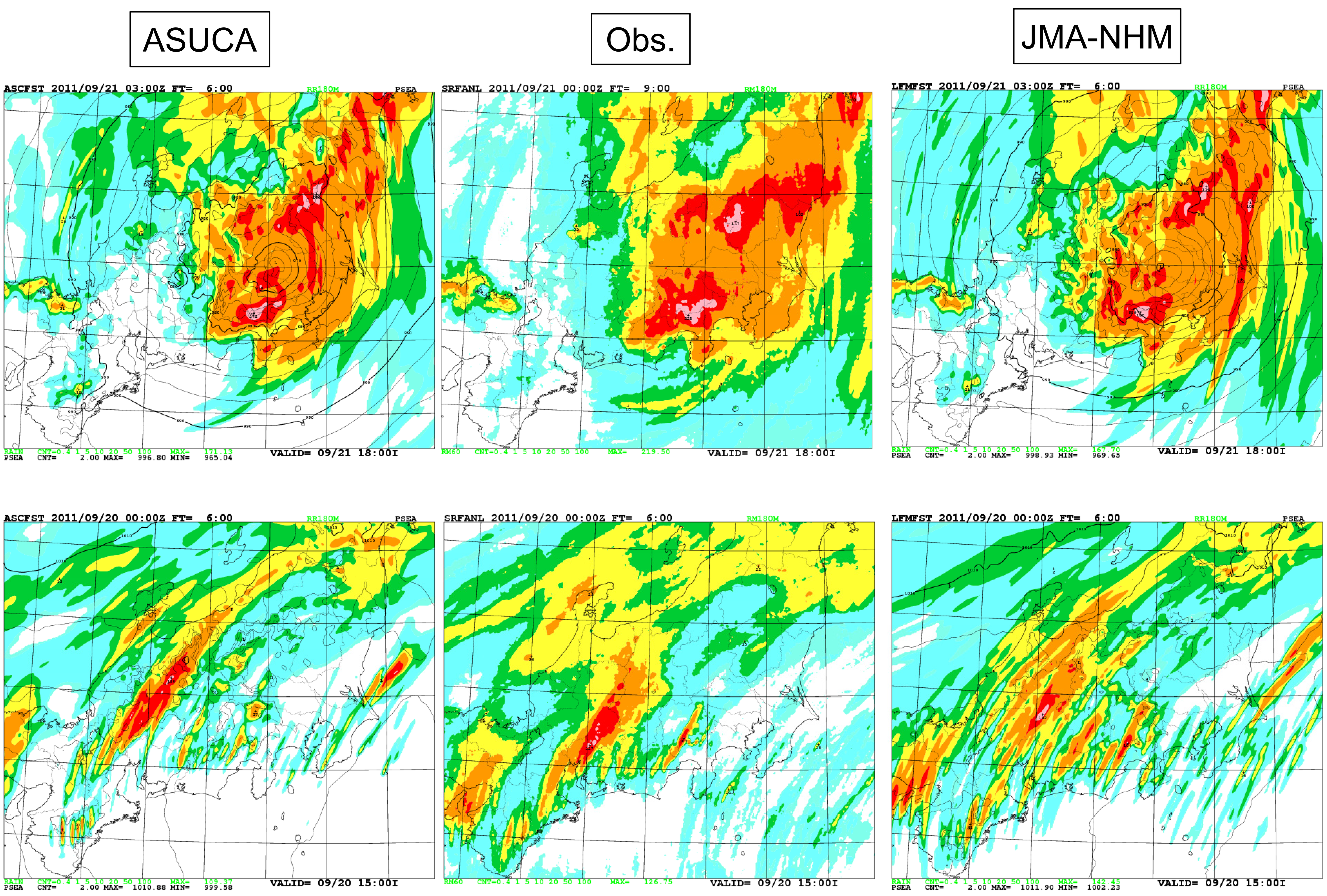

Fig.2 MSLP and 3-h accumulated rain for the cases initialized at 03 UTC 21 September 2011 (top) and 00 UTC 20 September 2011(bottom) . (Left: ASUCA, center: observation, right: JMA-NHM.).

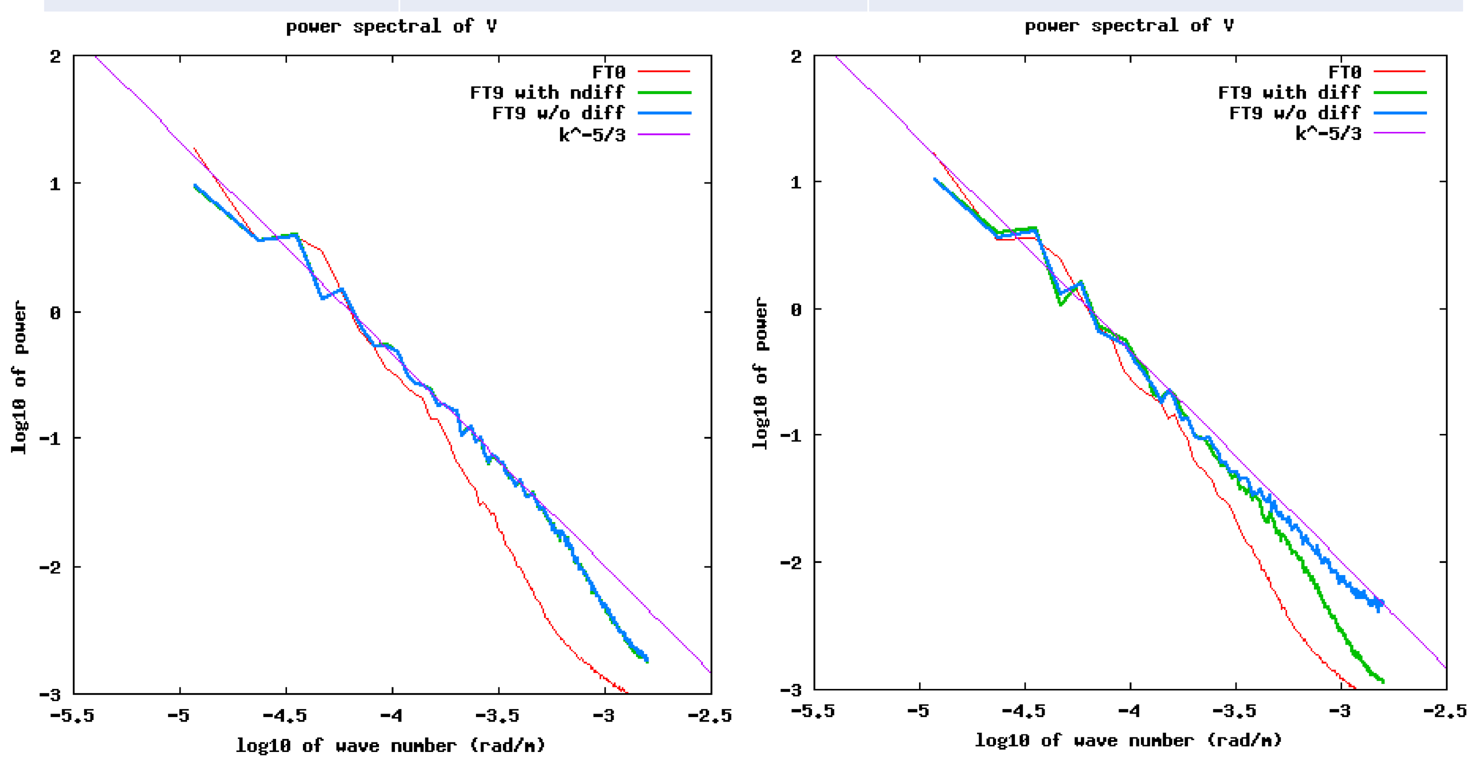

Fig.3 Spectra computed from ASUCA (left) and JMA-NHM(right). Spectrum at FT=0 (red), FT=9 w/o numerical diffusion (blue), FT=9 w/ numerical diffusion (green), and k^-5/3 lines are displayed.

5. Summary

* A new dynamical core is under developing.
* Physical processes have been plugged in, using the Physics Library.
* Real data experiments are conducted to evaluate the performance
* Spectral analysis shows that we need no artificial diffusion.

References

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