Forward-time-weighted semi-implicit adjustment with NDSL dynamics in RSM

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Background

- RSM is nested into CWBGFS for dynamical downscaling.
  - through MPMD (Multiple Program – Multiple Data)
  - for short-term climate forecast (9 months):
    $$\mathrm{CWBGFS}\ \mathrm{T_L}359\ (50\mathrm{km}) + \mathrm{MOM3} + \mathrm{RSM12km}$$
  - for extended-weather forecast (45 days):
    $$\mathrm{CWBGFS}\ \mathrm{T_{Co}}383(25\mathrm{km}) + \mathrm{SIT} + \mathrm{RSM8km}$$

- As CWBGFS proceed to Semi-Lagrangian (SL) version with NDSL (**N**on-iteration **D**imensional-split **S**emi-**L**agrangian) scheme, this scheme was also implemented into RSM for efficiency.

Motivation

- NDSL (**N**on-iteration **D**imensional-split **S**emi-**L**agrangian) was applied to the dycore of RSM in 2019
  - Larger Δt (3 to 4 times) was used.
  - Some noises showed up near jet regions possibly leading to unstable results.
  - Increasing the horizontal diffusion didn't help too much.
  - The uncentered forward-time-weighted semi-implicit (FWSI) adjustment (Juang, 2000) was then introduced to deal with these noises.

Introduction of Semi-implicit

- semi-implicit scheme
  - pioneered by Kwizak and Robert (1971) and Robert et al. (1972) and has become widely used in the atmospheric model.
  - linear parts are calculated implicit and non-linear terms are calculated explicit.
  - stabilizes the model by slowing down high frequency gravity waves which lead to numerical instability but have little impact on meteorological phenomena.

Semi-implicit in RSM

APPENDIX B of Juang and Kanamitsu (1994)

The equations of the perturbation of the semi-implicit associated linear terms in form of sine-cosine series:

$$\delta_t Q'_{<cc>} + S\overline{D^{*\prime}_{j<cc>}}^{t} = Z'^{n}_{<cc>},$$

$$\delta_t T'_{<cc>} + B\overline{D^{*\prime}_{j<cc>}}^{t} = Y'^{n}_{<cc>},$$

$$\delta_t D^{*}_{<cc>}{}' + \boldsymbol{A}\nabla^2\overline{T'_{j<cc>}}^{t} + RT_0\nabla^2\overline{Q'_{<cc>}}^{t} = X'^{n}_{<cc>},$$

where

$Q' = \ln(p_s{}')$ logarithm of surface pressure,

T' temperature,

$D^{*\prime} = \frac{\partial u^{*\prime}}{\partial x} + \frac{\partial v^{*\prime}}{\partial y}$ divergence,

$$X'^{n}_{<cc>} = \left(\frac{\partial D^{*\prime}}{\partial t} + \boldsymbol{A}\nabla^2\boldsymbol{T}'_{j<cc>} + RT_0\nabla^2 Q_{<cc>}{}'\right)^{n}_{<cc>},$$

$$Y'^{n}_{<cc>} = \left(\frac{\partial T'}{\partial t} + BD^{*\prime}_{j<cc>}\right)^{n}_{<cc>},$$

$$Z'^{n}_{<cc>} = \left(\frac{\partial Q'}{\partial t} + SD^{*\prime}_{j}\right)^{n}_{<cc>},$$

$$\bar{a}^{t} = \frac{a^{n+1}+a^{n-1}}{2},$$

$$\delta_t a = \frac{(a^{n+1}-a^{n-1})}{2\Delta t}, \qquad \text{(leap-frog)}$$

and other symbols are defined the same as those in APPENDIX B of Juang and Kanamitsu (1994).

Forward-time-weighted semi-implicit (FWSI)

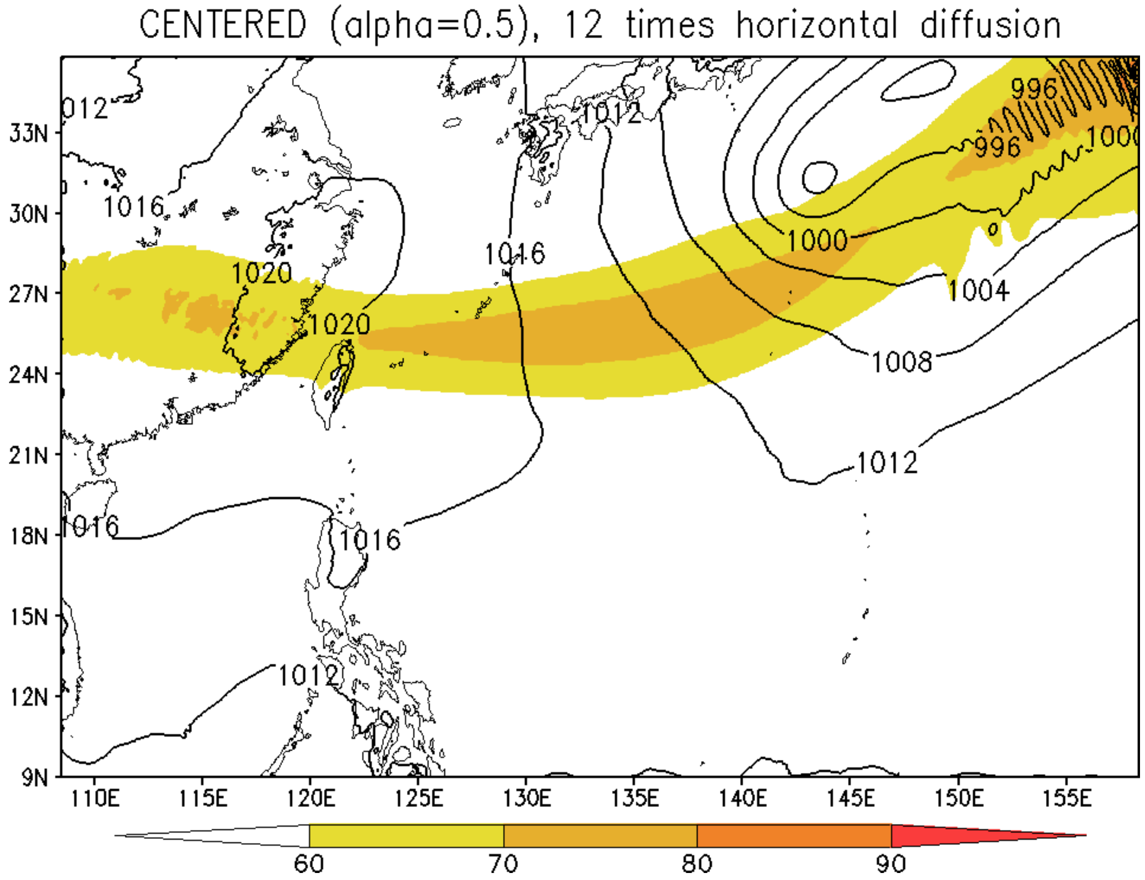
- from $\bar{a}^{\mathrm{t}} = \frac{a^{\mathrm{n+1}} + a^{\mathrm{n-1}}}{2}$,
- $\delta_{\mathrm{t}} a = \frac{\left(a^{\mathrm{n+1}} - a^{\mathrm{n-1}}\right)}{2\Delta \mathrm{t}} = \frac{\bar{a}^{\mathrm{t}} - a^{n-1}}{\Delta t}$

- **Forward-time-weighted semi-implicit (FWSI)**
  - replace the forcing at time n (F^{n}) by the forcing at time n+1 and n-1 with a forward-weighted coefficient α
  - that is, let $\bar{\boldsymbol{a}}^{\boldsymbol{t}} = \alpha a^{n+1} + (1-\alpha) a^{n-1}$.
  - Then, $\delta_{\mathrm{t}} a = \frac{\left(a^{\mathrm{n+1}} - a^{\mathrm{n-1}}\right)}{2\Delta \mathrm{t}} = \frac{\bar{\boldsymbol{a}}^{\boldsymbol{t}} - a^{n-1}}{2\alpha\Delta t}$
  - $\mathbf{0.5 < \boldsymbol{\alpha} \leq 1.0}$
  - **The larger α is, the more damping and slower phase speed of high frequency gravity wave are.**

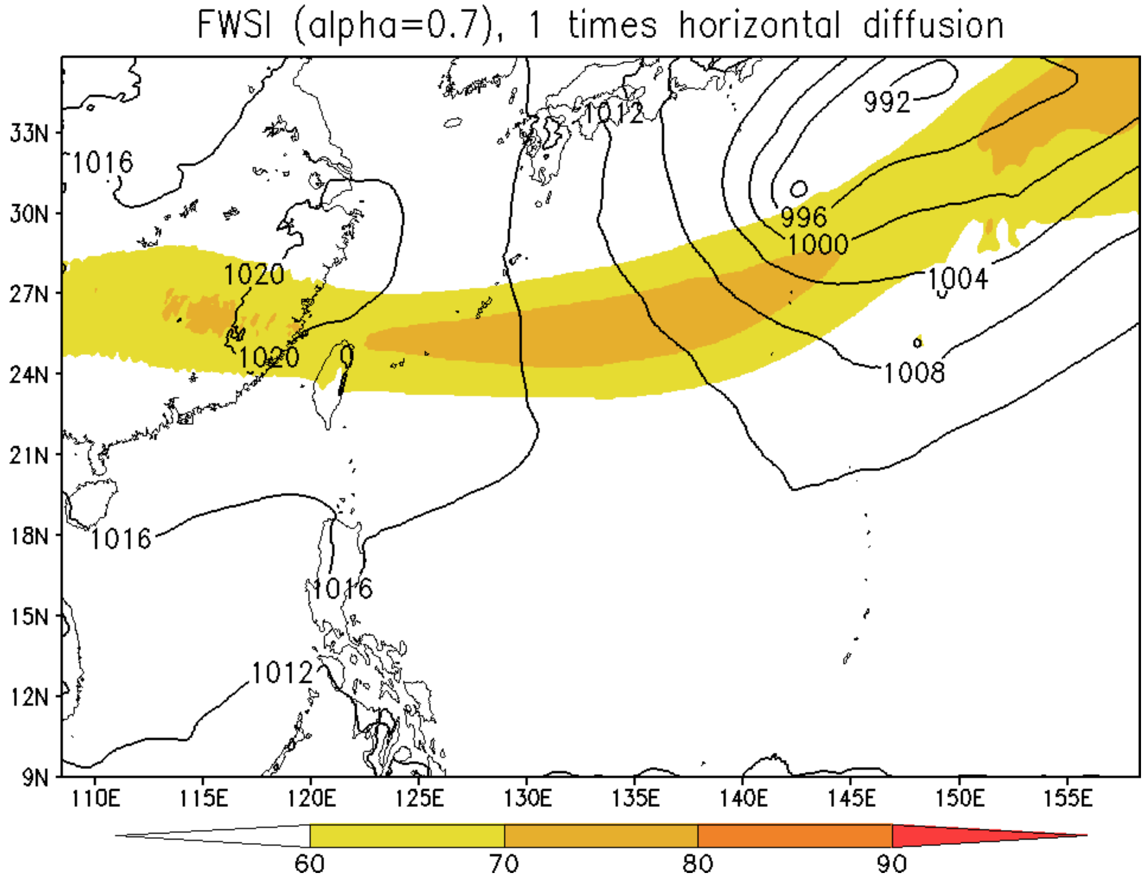
Results

initial: 2020 April 9_00 UTC
fcst. hr: 114 hr

Centered scheme



FWSI scheme



shaded: 200 hPa zonal wind [m/s]
contour: mean sea level pressure [hPa]

Results

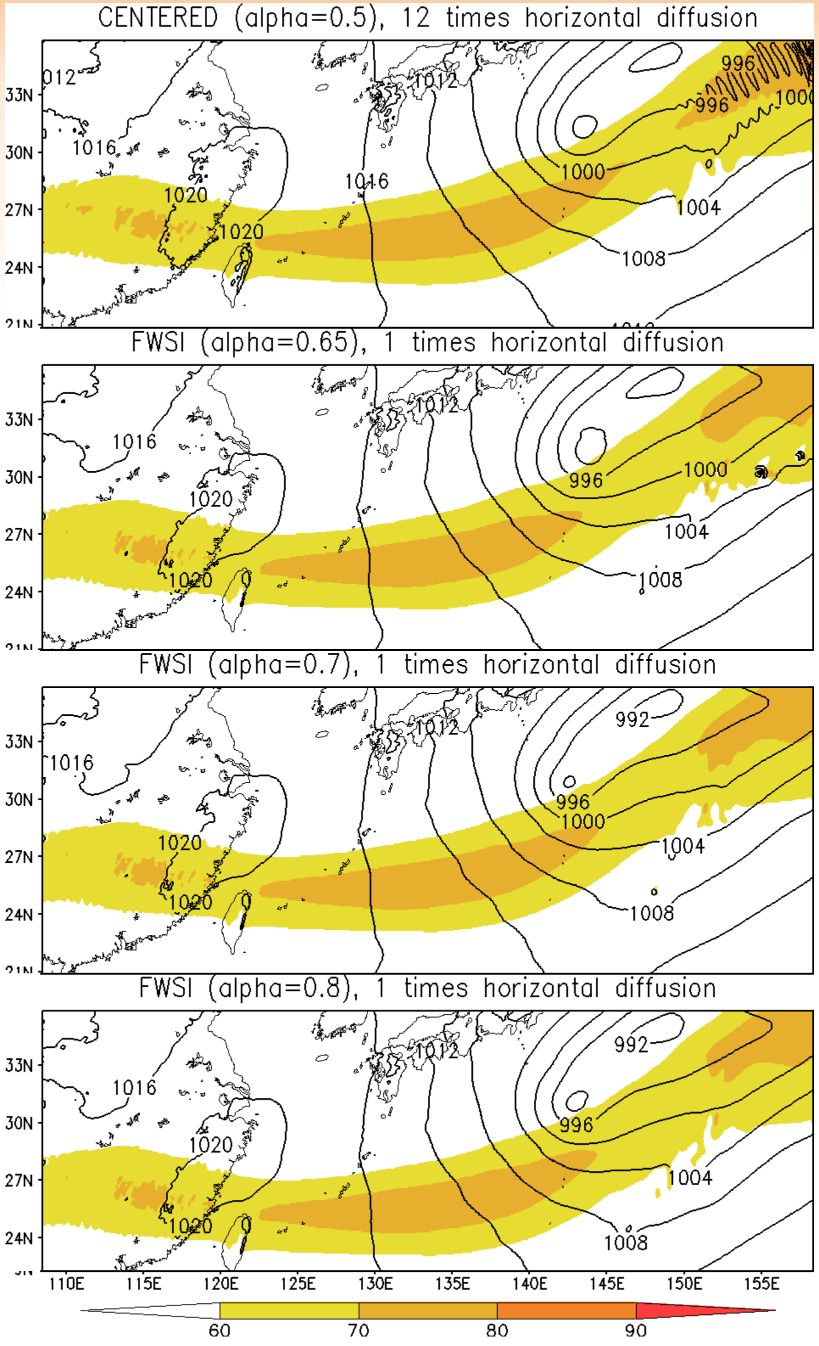
- The uncentered forward-weighted coefficients from 0.65 to 0.8 all reduce the noises significantly.
- However, 0.65 may not be sufficient for the whole 996 hours simulation, while 0.8 seems to be too smooth (not shown).
- Tuning of horizontal diffusion with different forward-weighted coefficients of FWSI depends on cases.

Centered+12diff.

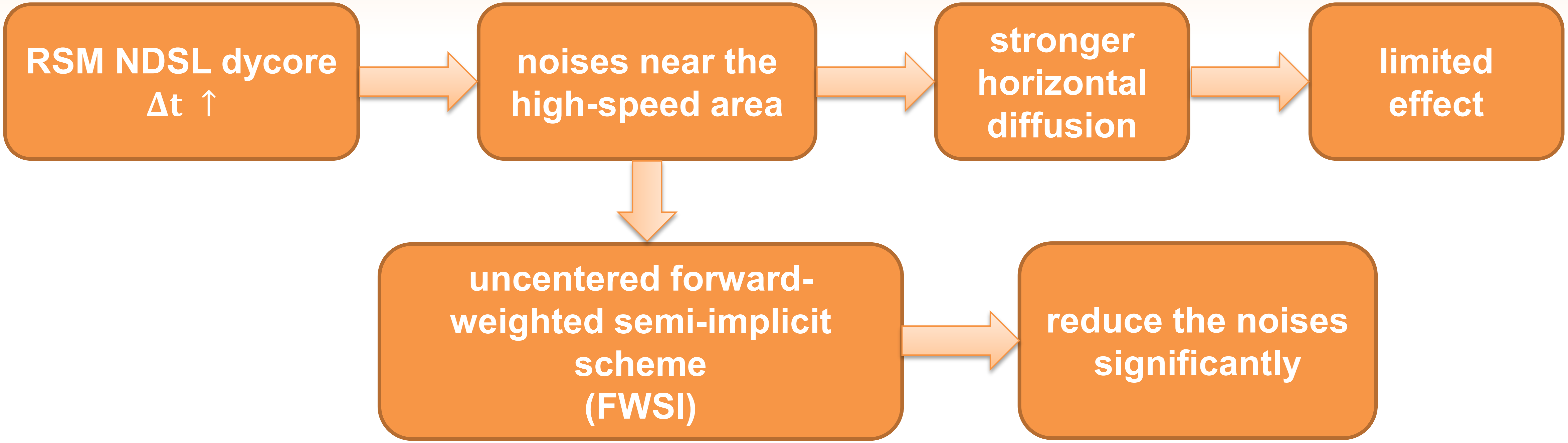
FWSI(0.65)+1diff.

FWSI(0.7)+1diff.

FWSI(0.8)+1diff.



Conclusions



1. This implement of FWSI is to help stabilize RSM with NDSL when the larger timestep is used.
2. Some other numerical methods along with this implement are undertesting for the development of NDSL dynamical core of RSM.

References

- Juang, H.-M. H., 2000: The NCEP mesoscale spectral model: A revised version of the nonhydrostatic regional spectral model. *Mon. Wea. Rev.*, **128,** 2329-2362.
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- Rober, A. J., J. Henderson, and C. Turnbull, 1972: An implicit time integration scheme for baroclinic modes of the atmosphere. *Mon. Wea. Rev.,* **100,** 329-335.

Q & A

THANK YOU!