Inner Time Loop Application for Vertical Turbulent Diffusion Processes

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1. INTRODUCTION

In operational numerical prediction models, efforts have been made to use a longer time-step as a way of reducing the computational cost. However, detailed investigation of the Global Spectral Model (GSM) in an idealized experiment revealed that numerical instability could be occurred in tendencies due to vertical turbulent diffusion with the over-implicit scheme in certain situations over land, where surface turbulent fluxes increased rapidly after sunrise and became large. These results suggest that a shorter time-step should potentially be used in the operational system (JMA 2013). Accordingly, an inner time loop was applied in the GSM for the calculation of vertical turbulent diffusion processes with a shorter time-step to alleviate numerical instability. This reduces the computational cost in operational use as compared to that incurred in the application of a shorter time-step for all processes in the model.

2. INNER TIME LOOP APPLICATION

Using an inner time loop, processes can be calculated with a shorter time-step, $\Delta t'$, than the normal time-step, Δt, depending on the number of the time loops N: $\Delta t' = \Delta t / N$. Accordingly, doubling N will halve the time-step in a process. In this study, an inner time loop was introduced after calculation of fluxes and tendencies due to short and long waves, thereby enabling skin temperature updating before calling of the vertical turbulent diffusion scheme (VDF). To maintain interaction between the lowest model level and the surface via vertical turbulent transport at each inner time-step, calculation of surface turbulent fluxes (SURF) was also included in the inner time loop. The tendencies of the forecast variable ϕ_N in each inner time loop were added to update the variable in the previous loop ϕ_{N-1}, where ϕ_1 is identical to the forecast variable ϕ, in the normal time-step. All estimated tendencies in the inner time loops were summed up and added to tendencies due to radiation (RAD), convection (CONV), cloud (CLD), and both orographic and non-orographic gravity wave drags (GWD) as part of physics processes (PHY) at every normal time-step as follows:

$$\left(\frac{\partial\phi}{\partial t}\right)_{PHY} = \left(\frac{\partial\phi}{\partial t}\right)_{RAD} + \left(\frac{\partial\phi}{\partial t}\right)_{CONV} + \left(\frac{\partial\phi}{\partial t}\right)_{CLD} + \left(\frac{\partial\phi}{\partial t}\right)_{GWD} + \frac{1}{N}\sum_{1}^{N}\left(\frac{\partial\phi_N}{\partial t'}\right)_{VDF+SURF}$$

3. EVALUATION

Two experiments (CNTL and TEST) were conducted to evaluate the impact of the inner time loop in 84-hour forecasts. The CNTL experiment was based on the GSM. In the TEST experiment, an inner time loop with a halved time-step (N = 2) was applied to vertical turbulent diffusion and surface processes. Figures 1 and 2 respectively show the simulated temperature and moisture tendencies due to physical processes in pressure-time cross sections at the ARM (Atmospheric Radiation Measurement) SGP (Southern Great Plains) site. As a general characteristic, no significant difference was seen between CNTL and TEST around the site. The model-level output in CNTL at each time-step up to the 84-hour forecast with an initial time of 00 UTC on 4 August 2013 exhibited numerical oscillation with changes in the tendency of the positive/negative characteristic in turn with each time step in certain situations. Conversely, no numerical oscillation was observed in TEST, which was characterized by smoothed and increased tendencies. Performance was verified against wind-profiler observation data distributed via WMO’s global telecommunication system from near the ARM SGP site. Figure 3 shows pressure-time cross sections of wind speeds as simulated in the CNTL and TEST experiments, as well as wind-profiler observation data. During this period, the nocturnal low level jet (NLLJ) was observed over the Great Plains every night. The wind speeds in TEST were enhanced in association with the potential temperature profiles with decoupling of the nocturnal stable boundary layer (not shown). This makes the NLLJ representation closer to the observation in comparison with CNTL, though there is still room for improvement. Accordingly, as well has helping to alleviate instability, the results of this study also represent a useful step toward better atmospheric representation. Further investigation is needed to explore the sensitivity of land-atmosphere coupling.

REFERENCE

JMA, 2013: Outline of the operational numerical weather prediction at the Japan Meteorological Agency. Appendix to WMO technical progress report on the global data-processing and forecasting system and numerical weather prediction research. 188pp. Available online: http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2013-nwp/index.htm

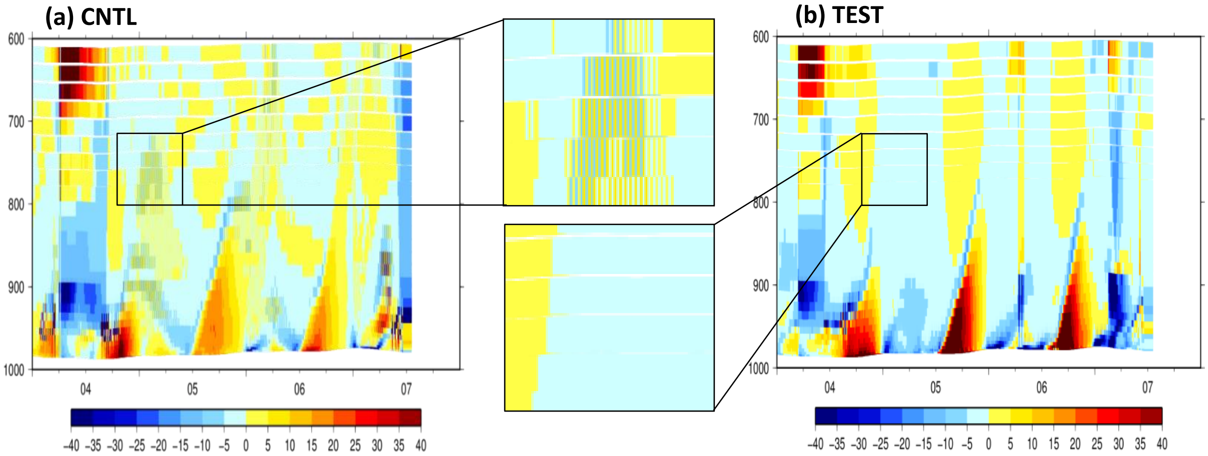

Figure 1. Pressure-time cross section of temperature tendency due to physical processes [K/day] for the (a) CNTL and (b) TEST experiments at the ARM SGP site. Model-level data were output at every time-step up to the 84-hour forecast with an initial time of 00 UTC on 4 August 2013.

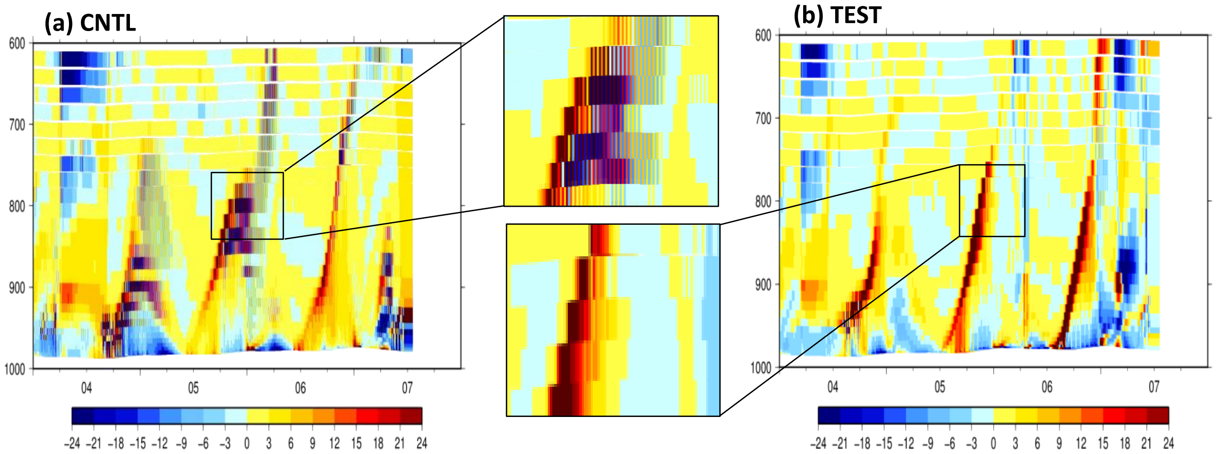

Figure 2. Same as Figure 1, but for moisture tendency due to physical processes [g/kg/day].

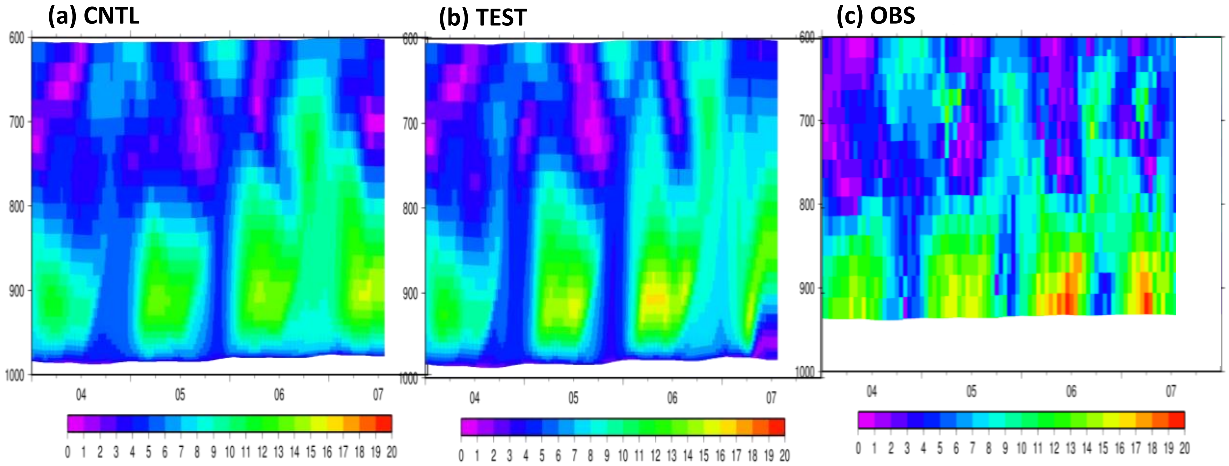

Figure 3. Pressure-time cross sections of wind speeds [m/s] for the (a) CNTL experiment, (b) TEST experiment and (c) wind-profiler observation near the ARM SGP site. In the experiments, model-level data were output hourly up to the 84-hour forecast with an initial time of 00 UTC on 4 August 2013.