Necessity of parameterizations for convective initiation in high resolution cloud-permitting models

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1 Introduction

NWP centers around the world, including the Japan Meteorological Agency (JMA), have recently begun operating high resolution cloud-permitting models with horizontal grid spacing of around 2-km with no convective parameterizations. JMA's operational 2-km model, called the Local Forecast Model (LFM), has been in operation since August 2012, with the forecast domain expanded in May 2013 to cover Japan and the surrounding area. Its initial conditions are generated by three-hour data assimilation cycles combined with the three-dimensional variational assimilation method and one-hour forecasts from the forecasting model. Forecasts are updated every hour.

Higher resolution models are considered capable of resolving a significant part of vertical transportation of momentum, heat and moisture, which is the main feedback of convection, in the form of vertical advection with grid-mean vertical velocities, meaning that no convective parameterizations are required. However, verification to examine the performance of JMA's 2-km operational model revealed issues related to convection such as delays in convective initiation and excessive intensity of convective activities.

This report first outlines verification of the operational 2-km model with focus on convective initiation, then discusses possible reasons for the delays in convective initiation. Finally, an attempt to resolve the issues and its outcome are described.

2 Delay in convective initiation shown by verification of the operational model

Figure 1 shows a timeseries representation of the number of grids in which precipitation exceeding 1 mm/h is observed (red bars) and predicted by the operational model (purple line). The numbers of events are accumulated over several cases in which showers associated with unstably stratified layers occurred. The figure shows that while most events with precipitation exceeding 1 mm/h were observed at 16 JST (Japanese local time), the peak time of current operational predictions delayed by around two hours from the corresponding observation, which means that convection is not initiated at an appropriate time in the current 2-km operational model. Similar tendencies can be also seen in Figure 2 timeseries representation showing the observed and predicted frequencies of precipitation exceeding 10 mm/h.

3 Effects of enhancing the dynamical and boundary layer scheme

JMA replaced the old non-hydrostatic model (JMA-NHM; Saito et al. (2007)) with a new one called "ASUCA" at the end of January 2015 (Aranami et al. 2015). ASUCA has been developed as a new dynamical core with higher accuracy and better computational efficiency on massive parallel scalar supercomputers. Physical processes equivalent to or more enhanced than those of the JMA-NHM were implemented via use of the "Physics library" (Hara et al. 2012). In particular, the improved Mellor-Yamada-Nakanishi-Niino level 3 model (MYNN3; Nakanishi and Niino (2009)) used as a boundary layer turbulence scheme was refined so that turbulent fluxes and tendencies of prognostic variables in the turbulence scheme can be stably solved, removing temporarily fluctuated, noisy, and overestimated turbulent fluxes.

In the initial stage of ASUCA development, no convective parameterization was implemented (as with the operational model employing JMA-NHM at the time). For the delay in convective initiation described in the previous section, ASUCA improved the delay in precipitation peak as shown by the green line in Figure 1 (although the frequency shortage at the initiation stage remains unresolved). This implies that refinement of the dynamical and the boundary layer scheme is highly related to the timing of convective initiation. However, the delay still has room for improvement.

4 Possible cause of convective initiation delay

It is considered that the main feedback of convection such as vertical transport of momentum, heat and moisture can be represented by grid-mean vertical velocity in models with a horizontal resolution of a few kilometers or less. However, this does not necessarily mean that all phenomena (especially initiating and controlling convection) can be resolved in high resolution models. For example, the forced lifting necessary to initiate convection would often be induced by small scale convergence and small scale topography variance, but some cases may not be resolved even if vertical transport is represented. The lack of smaller phenomena related to convective initiation in the models explains the delay in convective precipitation peaks predicted by the 2-km operational model and even the newer model in comparison with observations.

5 Parameterization for convective initiation

As an attempt, a parameterization to represent convective initiation was implemented in ASUCA. The parameterization is based on the existing convective parameterization suggested by Kain and Fritsch (1990) (known as KF scheme), but it has been modified assuming slower convective stabilization, implying that tendency from convective processes is much smaller than for the original convective parameterization.

The KF convection scheme, which is employed in the 5-km operational meso scale model at JMA, diagnoses a final state in which a certain ratio r of the initial convective available potential energy (CAPE) is removed for a certain life time of convection τ:

$$\frac{d\mathrm{CAPE}}{dt} = -(1-r)\frac{\mathrm{CAPE}_{\mathrm{initial}}}{\tau}. \qquad (1)$$

Tendencies of prognostic variables ϕ are calculated using the difference between the initial and final states

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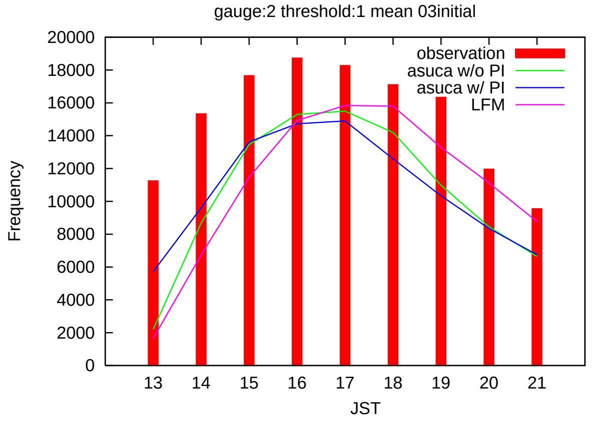

Fig. 1: Timeseries representation of the number of grids at which precipitation exceeding 1 mm/h is observed (red bars) and predicted by models (lines). Purple line: the operational model, green and blue lines: ASUCA without / with the parameterization of initiation, respectively

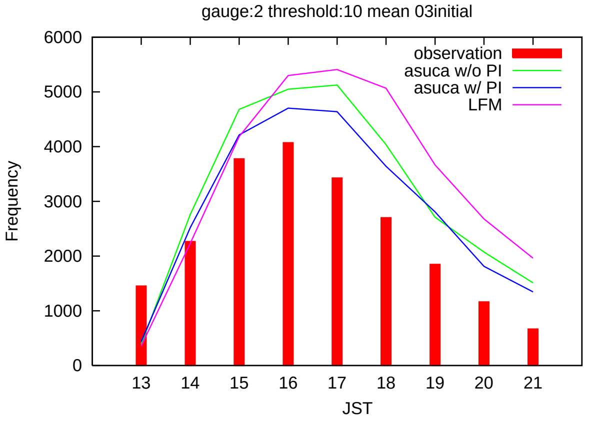

Fig. 2: As per Figure 1, but for precipitation exceeding 10mm/h

(ϕ_{initial} and ϕ_{final}, respectively) :

$$\frac{\partial \phi}{\partial t} = \frac{\phi_{\text{final}} - \phi_{\text{initial}}}{\tau}. \tag{2}$$

In the modified scheme to parameterize convective initiation, a longer value of τ is adopted (meaning weaker convective activity and smaller tendencies from convection) aiming at representing weaker vertical transport and release of latent heat in the initial stage of convection. In addition, the convection scheme is modified so that final states and tendencies are diagnosed at every timestep, as opposed to the fixed-interval evaluation of the original KF scheme (e.g. five minutes). Updating of tendencies at every timestep makes the modified scheme more sensitive to developing convection produced by dynamical processes in models.

If dynamical processes in models do not produce updraft due to convection even with the realization of an unstably stratified layer, the parameterization is activated and modifies layer stratification by weakly transporting heat and moisture vertically and releasing latent heat through the phase transition of water, resulting in the production of a local low pressure area. Once such a local low pressure area is generated, dynamical processes in models calculate convergence into the low pressure area and promotes development of convection. As it acts very weakly, the parameterization just helps dynamical processes to foster the convective system.

The blue lines in Figures 1 and 2 indicate forecast frequency from ASUCA with the parameterization to help initiation. For levels of precipitation exceeding 1 mm/h (Figure 1), the forecast frequency at 13 JST (usually the initial stage of convection) is much closer to the observation frequency (but still smaller than the actual observation). The overall temporal evolution of precipitation frequency is also significantly improved for precipitation exceeding both 1 mm/h and 10 mm/h (Figure 2). The new parameterization is proven to be quite effective in easing convective initiation delay.

6 Discussion

Development of the proposed parameterization for convective initiation was motivated by recognition that various scales related to convective phenomena are mixed. While the parameterization currently targets convective initiation which cannot necessarily be resolved even in cloud-permitting models with horizontal grid spacing of a few kilometers, there are other phenomena that cannot be resolved even if vertical transport by convection is represented. By way of example, entrainment plays an important role because it controls convective activity by diluting cumuli. However, its scale may be too small to resolve in cloud-permitting models. This may be one reason why overly strong vertical velocity is sometimes predicted in high resolution models when no convective schemes are adopted. To represent the effect of entrainment-related weakening of convective activity (and secure computational stability) in ASUCA, vertical velocity is suppressed by adding an extra term to its tendency. However, evaluation of this extra term has no robust physical basis because it depends only on the CFL conditions and involves no consideration for the physical processes of entrainment. More physical methods of estimating effects of entrainment are necessary for further model improvement.

The proposed parameterization for convective initiation is just one example, and it is challenging to treat resolved and unresolved phenomena at the same time. It is exactly related to “Grey Zone” problem.

References

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