Enhancement of Computational Stability in the Mesoscale Model of the Japan Meteorological Agency

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1 Introduction

The Japan Meteorological Agency (JMA) has operated a mesoscale numerical weather prediction system (MSM) for disaster prevention and aviation forecasting since March 2001. A non-hydrostatic model (JMA-NHM; Saito et al., 2006) was introduced in September 2004, and has been in operational use since then. The horizontal resolution was enhanced from 10 km to 5 km in March 2006, and the forecast time was extended from 15 to 33 hours in May 2007.

During the summer of 2007, the MSM terminated abnormally up three times due to computational instability caused by small-scale storms associated with tropical depressions.

2 Characteristics of the abnormally terminated cases

Figure 1 shows the case initialized at 09 UTC on 7th August 2007. Very intense precipitation (over 170 mm/hour, not shown) was calculated around Typhoon Pubuk (T0706), which was approaching the island of Taiwan in this case. Figure 1 (b) shows a cross section of the rain. An abnormally jagged rain distribution with a strong vertical wind speed was calculated. The common characteristics of the abnormally terminated cases were as follows: (i) instability occurred around a tropical depression; (ii) abnormally jagged distributions of rain (and graupel) were seen around the regions of instability; (iii) topography was not necessarily a factor, as instability occurred around 24 °N 137 °E over the sea.

3 Modifications against computational instability

Figure 2 shows a cross section of the mixing ratio of rain for another abnormally terminated case. Jagged distribution was also seen here. This abnormal pattern was considered to be the result of an issue in dealing with the vertical advection and sedimentation of rain and graupel. Figure 3 shows the same data as Figure 2 but for an experiment in which sedimentation flux time integration was made in the adjustment process, instead of the tendency included in cloud microphysics. This approach appears to be effective in removing the jagged distribution, but the precipitation histogram changes and the vertical wind speed remains strong. Another approach should therefore be considered.

To prevent serious deterioration of forecasting by the model, the modifications outlined below were implemented, and were mainly applied for columns with strong vertical wind speed. (1) Modification of the Target Moisture Diffusion (TMD; Saito and Ishida, 2004): TMD was changed to apply it to all grid points in vertical columns, while the original scheme was designed to apply it to grid points. The threshold value of TMD was also changed from the vertical speed of the z* coordinate to that of hybrid coordinates. TMD was changed so that it is also activated for columns adjacent to those where it is triggered in order to improve water vapor conservation. (2) Modification of the Box-Lagrangian scheme

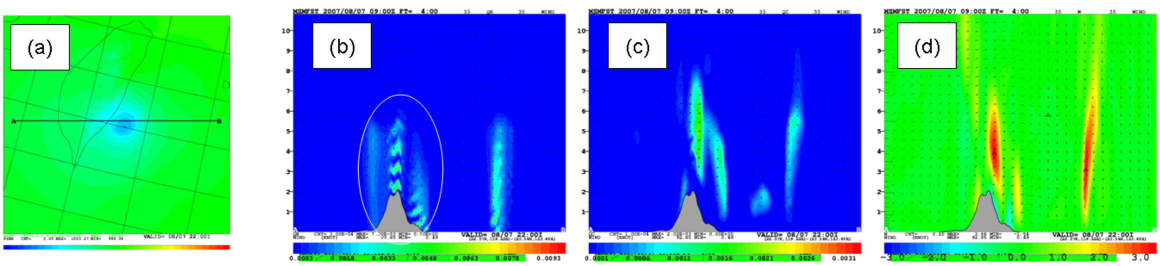

Figure 1: (a) Horizontal distribution of sea level pressure around Taiwan island at the forecast time of 4 hour for the case of 7th August 2007. (b) Cross section of mixing ratio of rain along with line AB. (c) Cross section of mixing ratio of cloud water. (d) Cross section of the vertical wind speed.

(BL; Kato, 1998): The correction method for the tendencies of the BL scheme was designed to avoid negative values of water substances after each cycle of time integration in consideration of the original value (value at $t - \Delta t$), the tendency from cloud microphysics and the BL scheme. The BL scheme was changed to consider the tendency from advection and diffusion in addition to the above tendencies. (3) Change in the vertical advection scheme for rain and graupel: To avoid jagged distribution, a first-order upwind advection scheme was applied for rain and graupel with columns where the maximum vertical wind speed exceeds 6 m/s. (4) Modification of the Kain-Fritsch scheme (K-F, Kain and Fritsch, 1990): The following three changes were introduced for columns where the maximum vertical wind speed exceeds 3 m/s: (i) The removal ratio of CAPE (Convective Available Potential Energy) under the K-F scheme was changed from 85% to 100%. (ii) Limitation of the lifetime of deep convection was abolished. (iii) The tendencies already applied were reset and recalculated. (5) Increase of nonlinear damping strength (Nakamura, 1978): The time constant of nonlinear damping for all prognostic variables was changed from 1,200 seconds to 600 seconds for effective reduction of the vertical wind speed.

By applying (1) - (5), the jagged distribution shown in Figure 2(b) was alleviated significantly. The result was intermediate between Figure 2(b) and Figure 3(b).

4 Results of a longer period experiment and Conclusion

It was confirmed that all the abnormally terminated cases in 2007 were integrated stably when the modifications described in this article were applied. The statistical verifications for a 2-week period in summer and a 1-week period in winter confirm that the model performance is neutral before and after the modifications. These modifications were implemented to the operational model in September 2008.

Thus various kinds of modifications to avoid the computational instability have been implemented to the MSM at JMA, without deteriorating the model accuracy. Yet the treatments implemented this time are tentative. To solve the computational instability problem at bottom, we need to scrutinize the fundamental part of model, which may be the interaction of dynamical and physical processes.

References

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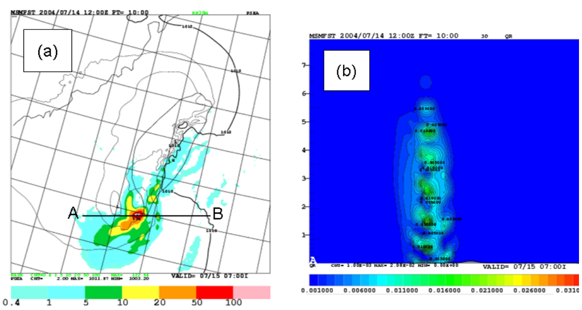

Figure 2: (a) 1 hour accumulated precipitation and sea level pressure at forecast time of 10 hours of the case of 12UTC 14 July 2004 initial. (b) Vertical cross-section of rain along the line AB in the left panel.

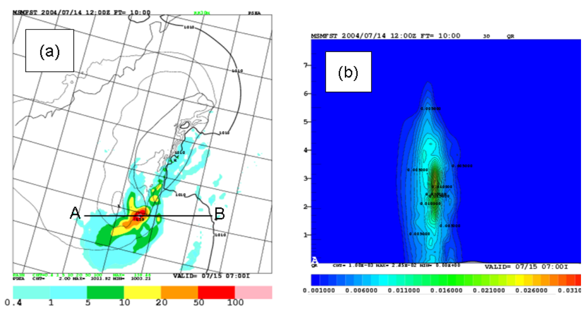

Figure 3: Same as Figure 2 but for the experiment with adjustment time integration of sedimentation flux.