Study on fine-resolution numerical weather prediction model in local-scale forecast

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1 Introduction

A numerical weather prediction (NWP) model called the Non-Hydrostatic Model (NHM), originally developed by the Japan Meteorological Agency (JMA) (Saito et al. 2007), is currently operated in the Hong Kong Observatory (HKO) to support very short term weather forecast. The current version of NHM is operated with horizontal resolution at 5 km and it is planned to increase the resolution to 2 km with a view to better resolve mesoscale or storm-scale features in convective systems. However, it is found that precipitation forecasted by current 5 km NHM is often overestimated for convective storms and the forecast rainfall distribution is sometimes unrealistic. The problems are probably due to difference in the nature or properties of convective storms and precipitation processes occurred in southern China compared to Japan or mid-latitude regions. The project is thus aimed at studying the impact of various parameters in the cloud microphysics and convective parametrization processes in NHM, and determine a set of optimal parameters to reduce the problem of over-forecast of precipitation.

2 Methods

Some of the parameters defined in the cloud microphysical process and convective parameterization scheme are universal (e.g. the density of water) while some others are dependent on the geographical location (e.g. tropical or mid-latitude) or they are defined based on previous field experiments. Besides, there are parameters assigned with respect to the numerical scheme which simplify the representation of internal circulation of storm (e.g updraft) or to maintain the numerical stability. The following subsection will discuss the parameters investigated in this study. As there are a number of tuning parameters, the numerical experiments were first performed by varying one of the parameters within a guess range until a best forecast rainfall pattern is obtained. Then with this parameter held fixed, experiments were continued by varying the next parameter to find its optimal value.

2.1 Convective parameterization process

(a) Thresholds for triggering targeted moisture diffusion (TMD)

TMD is implemented in order to control grid point storm and the associated intense grid scale precipitation. A default of 2.0 ms$^{-1}$ is set in the model which states that TMD will be
applied when the vertical velocity at a certain grid-point exceeds this value. To further reduce the likelihood of development of grid-point storms, the threshold is lowered from 2.0 ms\(^{-1}\) to 1.0 ms\(^{-1}\) so that the TMD is triggered earlier when convective cells initiate.

(b) Reduction rate of CAPE

The reduction rate of CAPE (Convective Available Potential Energy) controls the amount of energy remained to trigger the storm development in subsequent time steps of model integration. A larger value means a greater reduction and hence a more stable environment will be resulted. It is reported in the literature of JMA-NHM that the reduction rate of CAPE has been reduced from 90% to 85% to minimize undesired excessive stabilization of the model atmosphere. Given that the aim of this study is to reduce excessive precipitation, we will investigate the effect on precipitation forecast with a larger value of reduction rate.

2.2 Cloud microphysical processes

The cloud microphysical processes in cloud-resolving model like NHM are very complex and there are a lot of physical processes which have mutual interaction with each other. Among a number of parameters defined in the cloud microphysical processes, the following quantities are studied in this project.

(a) The intercept parameter of raindrop (\(N_0\))

It is a parameter controlling the size distribution of raindrop. The default value was approximated by Marshall-Palmer relationship which was derived at mid-latitude region. It should be related to the geographical difference and changes should be considered in a convective environment. In particular, Waldvogel (1974), Tokay and Short (1994) discuss about the changes of the intercept parameter with respect to different convective precipitation cases. According to Pattnaik and Krishnamurti (2007), the \(N_0\) value can be as to \(1 \times 10^9\) m\(^{-4}\) for convection occurred in tropical areas in Australia.

(b) The intercept parameter of graupel (\(N_{0g}\))

According to Gilmore et al (2004), the value of \(N_{0g}\) depends on the size of graupel and is about \(10^6\) - \(10^8\) m\(^{-4}\) when the graupel’s diameter is smaller than 1mm; the larger the graupel, the smaller the \(N_{0g}\). If we assume a smaller graupel given a warmer topical climate than mid-latitude, \(N_{0g}\) shall be increased.
(c) Fall speed parameters and range of size of graupel

There are four parameters corresponding to the fall speed of these precipitations. Two are related to graupels’ masses while another two are variables \((a\) and \(b\)) in the expression: \(V = a D^b\) where \(D\) is the diameter, \(V\) is the fall speed. Based on Kajikawa’s measurement and parameterization of graupel’s fall speed, parameter settings for lump graupel and conical graupel are tested.

(d) Fall speed parameters and range of size of snow

From Kajikawa’s measurement, different types of crystals such as hexagonal plate, hexagonal plate with sector-like branches, hexagonal plate with broad branches, stellar and dendrite, were selected for simulations.

(e) Change on the evaporation rate of raindrop/ graupel/ snow

It was a simple guess that if more evaporation is allowed, less precipitation would reach the ground as rain.

3. Case study and discussion of results

A total of 4 model runs (00 and 06 UTC 6 June; 00 UTC 7 June and 00 UTC 24 June) including 2 rainstorm and 1 tropical cyclone (TC) cases were investigated with new parameter values. A brief summary of results and impact in the forecasts are given in the Table 1. In particulars, comparison of the model forecast rainfall using a set of optimal new parameters with that from the operational setting will be discussed in the following context. Furthermore, the model forecast fields are further processed to derive plots of equivalent radar reflectivity and Doppler velocity which are used to compare side-by-side with radar imagery.

3.1 Comparing the rainfall forecast

The forecast hourly rainfall (T+6 hr at 06 UTC 6 June 2008) using the best setting of parameters (Fig. 1a) was less than the operational forecast (Fig. 1b) and more close to the actual rainfall amount (SWIRLS rainfall analysis in Fig. 1c).

3.2 Comparing the simulated reflectivity and the actual reflectivity echo in radar

The equivalent reflectivity at about 3km level was calculated in the above forecast, the corresponding estimated rain rate (using \(Z=200R^{1.6}\) relation) was plotted and compared with the actual radar imagery (Fig. 2). The results show the intensity of reflectivity was weaker
in the forecast using the best modified setting as compared to the operational NHM which is in consistent with the above rainfall forecast.

3.3 **Comparing the simulated radial velocity and the actual Doppler velocity**

It can be observed that (Fig. 3) the forecast radial velocity using the best setting has similar pattern as that from the operational NHM. Moreover, the location of zero-isodope is better simulated using the new settings when comparing with the actual Doppler velocity image.

3.4 **Compare TC case with non-TC case**

After using the best parameter setting, the changes in forecast rainfall and radial speed in TC case are similar to those in non-TC case. But one should notice that (Fig. 4) when the restriction of evaporation was reduced to 0% (all evaporation events are allowed), the rainfall near the TC center at and after the T+10 hour was reduced significantly. The effect of this parameter to the simulated structures of rain bands near TC center will be explored in future study.

5 Conclusions and Future Work

From the experiments, the intercept parameter of raindrop has the most significant effect on the forecast rainfall amount.

Furthermore, several settings in fall speed parameters of graupels also showed influence on the forecasted rainfall. Further study on the graupel type for storms occurring in the vicinity of Hong Kong and southern China is expected to provide clues to select the most realistic setting.

Last but not least, the restriction on the evaporation had fluctuated effect on rainstorm case, an increasing value of intercept parameter of graupels resulted in more localized and intense storms; while the fall speed parameters of snow showed negligible effect. These parameters may not need changes.
Acknowledgement

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Reference


Table 1. Summary of results

<table>
<thead>
<tr>
<th>Physical Process</th>
<th>Parameter</th>
<th>Default value</th>
<th>Range of modification</th>
<th>Resulted changes in the forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convective parameterization</td>
<td>Updraft threshold in TMD</td>
<td>2.0 ms⁻¹</td>
<td>1.0 ms⁻¹</td>
<td>After reducing its value, rainrate falls significantly at later forecast hour</td>
</tr>
<tr>
<td></td>
<td>Reduction of CAPE</td>
<td>90%</td>
<td>85%~90%</td>
<td></td>
</tr>
<tr>
<td>Cloud microphysics</td>
<td>The intercept parameter of raindrop (N₀)</td>
<td>8x10⁶ m⁻⁴</td>
<td>8x10⁶ ~ 1x10⁹ m⁻⁴</td>
<td>Rainfall reduced significantly when N₀ increased</td>
</tr>
<tr>
<td></td>
<td>The intercept parameter of graupel (N₀g)</td>
<td>4x10⁶ m⁻⁴</td>
<td>1.1x10⁶ ~ 4x10⁸ m⁻⁴</td>
<td>Rainfall reduced significantly when N₀g increased, but the major storm became intense and localized</td>
</tr>
<tr>
<td>Fall speed parameters and range of size of graupel</td>
<td>Settings for lump and conical graupels</td>
<td></td>
<td></td>
<td>Several settings reduced rainfall in a reasonable manner</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A few settings are appropriate:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V (cm s⁻¹) = 420 D⁰.⁶⁴ or</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>733 D⁰.⁸⁹ (lump) or</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>590 D⁰.⁷⁶ (conical)</td>
</tr>
<tr>
<td>Fall speed parameters and range of size of snow</td>
<td>Settings for different types of crystals</td>
<td></td>
<td></td>
<td>Some settings gave negligible effect; some reduced rainfall significantly but also reduced desired light rain region</td>
</tr>
<tr>
<td>Evaporation rate of raindrop/ graupel/ snow</td>
<td>50%~70%</td>
<td></td>
<td>0%~50%</td>
<td>Fluctuated effecting rainstorm cases; reduced rainfall near TC center in the TC case (after the 10th forecast hour)</td>
</tr>
</tbody>
</table>
Appendix

(a) current NHM

(b) best modified settings applied

(c) Actual hourly rainfall analysis from SWIRLS

Fig. 1 T+6 hr forecast hourly rainfall based on NHM run at 00 UTC 6 June 2008
Fig. 2 T+6 hr forecast rainfall rate (in mm/hr) derived from simulated equivalent reflectivity based on NHM run at 00 UTC 6 June 2008
Fig. 3 T+6 hr forecast Doppler velocity (in m/s) based on NHM run at 00 UTC 6 June 2008
Fig. 4 T+10 hr forecast hourly accumulated rainfall based on NHM run at 00 UTC 24 June 2008