A New Data Assimilation System and Upgrading of Physical Processes in JMA's Meso-scale NWP System

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1 Introduction

JMA's meso-scale numerical weather prediction (NWP) system provides information for disaster mitigation based on a Meso-Scale Model (MSM) data assimilation system for forecasting. This report details an upgrade from the previous MSM1702 version (JMA 2019) to the new MSM2003 version and enhancement of related forecasting introduced at 00 UTC on 25 March 2020.

2 Data Assimilation System

Four-dimensional variational (4D-Var) data assimilation is employed to create initial MSM conditions. In the previous MSM1702 version, the forecast model was updated to the new ASUCA specifications (see Section 3.5 in JMA (2019)), while the outer/inner model in the 4D-Var data assimilation system was as per the previous system. In MSM2003, the entire data assimilation system, including the outer/inner model, was updated to allow the operation of a consistent analysis and prediction cycle system. This new ASUCA-based system is known as ASUCA-Var.

2.1 Control variables

The control variables used in ASUCA-Var are the x- and y-components of horizontal wind, underground temperature, skin temperature, surface pressure, potential temperature, soil volumetric water content and pseudo relative humidity. The underground elements here were incorporated as control variables in MSM2003 as necessary to assimilate surface and underground observations, and have significant effects on analysis results.

2.2 Tangent-linear/Adjoint model

All tangent-linear/adjoint (TL/AD) codes were recreated with the update of the dynamical and physical processes of the forecast model. The fully tangent-linearized dynamics process based on non-hydrostatics enables practically sufficient perturbation forecasting, although the TL codes of some physical processes are not implemented due to errors associated with their non-linearity.

2.3 Basic-field update

ASUCA-Var solves linear optimization problems using TL for forward integration in 4D-Var. However, the effect of the non-linear process was insufficiently incorporated in analysis values with linear optimization alone. To address this problem, a basic-field update (Trémolet 2008) was introduced to incorporate non-linear effects into optimization. The basic field is updated twice during optimization.

2.4 Variational Bias Correction

Variational bias correction (VarBC) based on the method of Cameron (2018) was implemented. In the previous assimilation system, satellite brightness temperature was processed with a bias correction coefficient based on the assimilation system used for JMA's global model. However, this method results in insufficient correction, and can even exacerbate the effects of the bias. VarBC solves this problem in MSM2003 and allows assimilation of bias-corrected satellite brightness temperature.

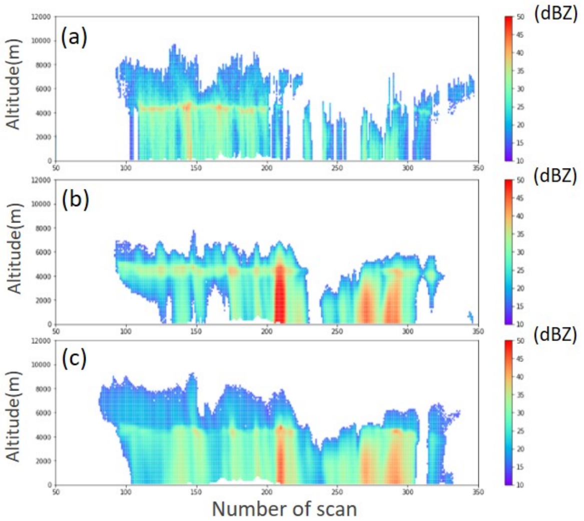

Figure 1. (a) Vertical profiles of reflectivity observed by GPM's KuPR on 7 July 2018. KuPR reflectivity simulation is based on the output of (b) MSM1702 and (c) MSM2003.

3 Forecasting System

Most of the physical processes in MSM2003 were improved, including a revision of scientific assumptions introduced into MSM1702 in addition to physical scheme enhancement. Some physical processes in MSM1702 had been tuned to improve forecast accuracy within an inconsistent system characterized by differences between the outer model and the forecast model, creating issues for performance improvement in the new system with inconsistency elimination. The updating of the physical processes in MSM2003 was designed to address this issue as outlined below.

3.1 Soil moisture

The soil moisture prediction scheme was changed from the Deardorff (1978) method to the Noilhan and Planton (1989) method to prevent significant fluctuations in soil moisture immediately after the start of forecasting and reduce errors in ground surface prediction.

3.2 Surface flux

The surface flux scheme in MSM1702 involved the use of gridded values in the middle of the layer. As the spatial discretization scheme in the MSM was applied using

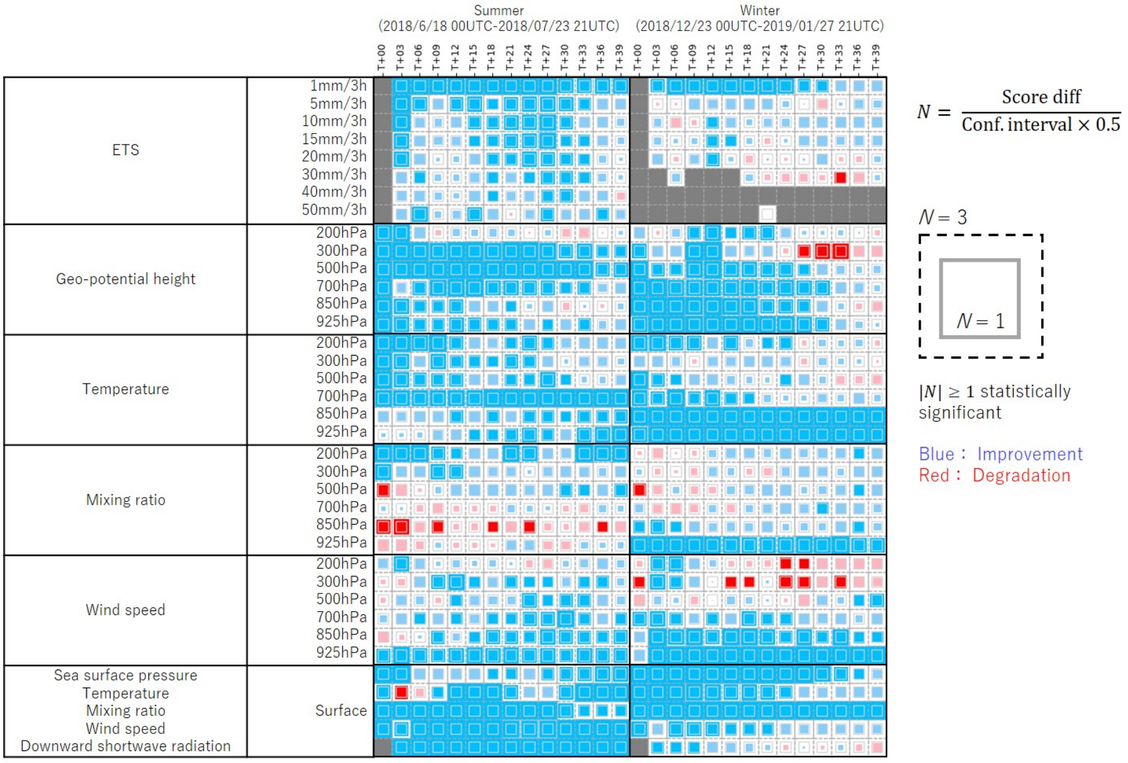

Figure 2. Observation score difference between MSM2003 and MSM1702. Columns show the score of the summer cycle from 00 UTC on 18 June 2018 to 21 UTC on 23 July 2018 and the winter cycle from 00 UTC 23 December 2018 to 21 UTC 27 January 2019, with 288 forecasts verified in each period. Square sizes indicate difference magnitude, $N > 1$ represents statistical significance, and blue/red indicate improvement and degradation, respectively.

the finite volume method, the use of gridded values as volume-averaged data should be strictly consistent. Accordingly, a new surface flux scheme based on volume averaging (Nishizawa and Kitamura 2018) was implemented in MSM2003.

3.3 Cloud

The cloud microphysics scheme was improved by revising the definition of hydrometeors and certain processes. The cloud process issues observed in MSM1702 were identified by comparing the hydrometeors of the forecast model with those from GPM satellite observation. Figure 1 shows the impact of the cloud microphysics scheme update, including improved rain profile data for the lower troposphere. Hydrometeor bias in the atmosphere was eliminated and forecast accuracy was improved.

3.4 Radiation

Upper-cloud diagnosis in the radiation scheme of MSM1702 exhibited overestimation as compared to satellite observation. The improved cloud coverage diagnosis in MSM2003 reduced errors in short-wave radiation on the ground and surface temperature.

3.5 Planetary boundary layer

Implicit treatment was adopted in the prognostic equation for mean variables based on evaluation of counter-gradient turbulent transport terms with later time-step values of turbulent variances, thereby eliminating numerical oscillation errors.

4 Impact of the upgrade

Figure 2 shows differences between MSM2003 and MSM1702 for equitable threat score (ETS) against radar/raingauge-analyzed precipitation and root mean square error against radiosonde values over the whole domain and for surface observations in Japan. Forecast accuracy for precipitation, temperature, water vapor, geopotential height, wind speed and surface elements is significantly improved for all categories except water vapor for the lower atmosphere in summer. A slight degradation in water vapor accuracy results from a reduction of compensating errors due to excessive evaporation in the cloud microphysics scheme.

5 Summary

In this work, the new ASUCA-Var data assimilation system was introduced into operational meso-scale NWP, and the physical processes of the forecasting system were enhanced. This upgrade produced the highest improvement of forecasting quality observed in the last decade and optimized accuracy in deterministic meso-scale NWP prediction.

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