A new operational regional model for convection-permitting numerical weather prediction at JMA

Kohei Aranami, Tabito Hara, Yasutaka Ikuta, Kohei Kawano, Kengo Matsubayashi, Hiroshi Kusabiraki, Takahiro Ito, Takumu Egawa, Koji Yamashita, Yukinari Ota, Yoshihiro Ishikawa, Tadashi Fujita, and Jun-ichi Ishida

Numerical Prediction Division, Japan Meteorological Agency
1-3-4, Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan

1 Introduction

In January 2015, a new model developed by the Japan Meteorological Agency (JMA) was put into operation in JMA's convection-permitting regional NWP system LFM (Hara et al. 2013). It replaced the previous system based on the JMA-NHM. Three new components were introduced into LFM – a new dynamical core "ASUCA" (Ishida et al. 2009, 2010), a physical processes package "the Physics Library" (Hara et al. 2012), and a variational data assimilation system "ASUCA-Var" (Fujita et al. 2013). The LFM is a very short-range numerical weather prediction system with a horizontal grid spacing of 2 km. One of its main purposes is to provide quantitative precipitation forecasts (QPFs) for disaster prevention information. It was confirmed that the LFM based on ASUCA (referred to here as the ASUCA-LFM) has a similar level of statistical performance in terms of QPF to the LFM based on the JMA-NHM (referred to here as the NHM-LFM).

This report outlines differences between the ASUCA-LFM and the NHM-LFM, with focus on improvements made to physical processes, data-assimilation system and optimisation, as well as the results of a performance evaluation experiment conducted with the same configuration as the previous operational model.

2 Major updates from the NHM-LFM to the ASUCA-LFM

2.1 Dynamics updates

As described in Ishida et al. (2009, 2010), most of the dynamics were upgraded (e.g., finite volume vs. finite difference, RK3 vs. leap-frog, flux limiter vs. flux correction, time-splitting treatment of precipitable water), which enables the use of a longer time-step interval (16.67 sec vs. 8 sec) without computational instability.

2.2 Physics updates

As described in Hara et al. (2012), physical processes available in the ASUCA-LFM are at least equivalent to those of the NHM-LFM. In fact, numerous improvements are already included in the Physics Library, such as the boundary layer scheme related to the computational stability (Hara 2010), implicit coupling of boundary layer scheme and surface flux scheme, surface flux tiling (i.e., the capacity for consideration of land/sea sub-grid effects in a grid), and the parameterization for convective initiations (Hara 2015). These improvements have been readily incorporated into ASUCA as demonstrated in Hara et al. (2012), resulting in better forecast performance in certain areas as outlined below.

2.3 Optimisation

One of the original motivations in the development of a new dynamical core was the achievement of better computational efficiency on scalar multi-core architecture. Although not described in detail here, the ASUCA-LFM involves a number of computationally expensive factors (e.g., implicit discretization in physics, absence of spatial density reduction in radiation, RK3 instead of the forward-backward for sound wave treatment, and doubling of the I/O size). As a consequence, it was found that the computational expense of the ASUCA-LFM in terms of FLOP is 1.2 times greater than that of the NHM-LFM. However, due to more efficient cache usage, overlapping of communication and computation, and offloading of I/O using io-servers, the ASUCA-LFM completes computation of a nine-hour forecast slightly faster than the NHM-LFM.

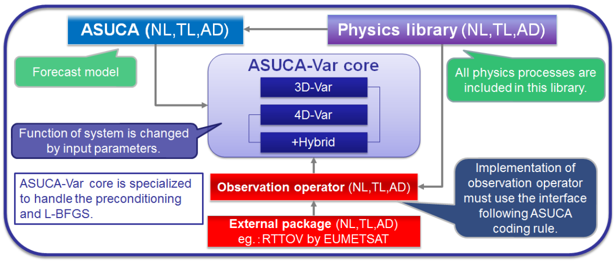

Fig. 1: Schematic diagram of ASUCA, Physics Library, and ASUCA-Var.

2.4 ASUCA-Var

One of the major upgrades to the system is the adoption of ASUCA-Var – a variational data assimilation system based on ASUCA. Fig. 1 shows a schematic diagram of the new framework (ASUCA, Physics Library and ASUCA-Var), in which non-linear (NL), tangent-linear (TL) and adjoint (AD) models are developed in an organised and coordinated way (e.g., TL, NL and AD are included in the same file). This schematic illustrates the ultimate goal of the framework, which is as yet incomplete, and the 3D-Var part of the framework has been incorporated into the ASUCA-LFM. In ASUCA-Var, the forward operators (e.g., observation operator) are TL, whilst JNoVA, which is a 3D-Var system based on the JMA-NHM, employs NL operators. Soil temperature and soil moisture have also been introduced as control variables. Background error was also improved; this was set uniformly in space in JNoVA, but can be set for individual grids in ASUCA-Var. This means, for example, that increment over land can be prevented from spreading over sea areas. Two-dimensional decomposition is also implemented in ASUCA-Var. Atmospheric motion vectors (AMVs) have been additionally incorporated for satellite data.

3 Performance evaluation experiment

An experiment was carried out to evaluate the performance of the ASUCA-LFM as an operational convection-permitting model. The experimental period covered 40 days in each of winter and summer, initialised at three hourly (i.e., 240 initials each). Fig. 2 and Fig. 3 show the equitable threat score (ETS) and the bias score(BS) for the winter and summer periods, respectively. It can be seen that levels of QPF accuracy for the two periods are statistically similar.

*E-mail: aranami@met.kishou.go.jp

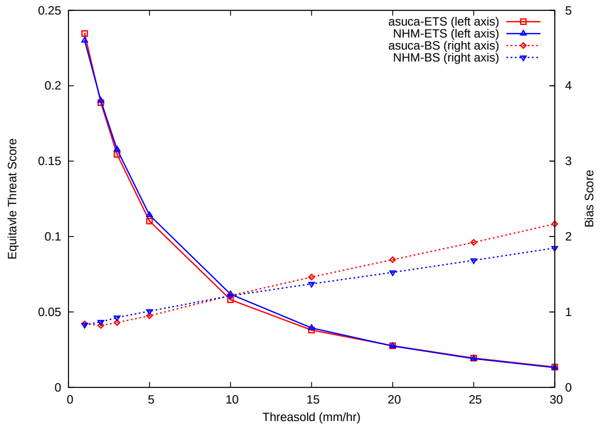

Fig. 2: Equitable threat score (solid lines, left axis) and bias score (dashed lines, right axes) for the summer experiment. Red lines indicate the scores of ASUCA-LFM, and the blue lines indicate the score of NHM-LFM. x-axis indicates threshold in mm/hr.

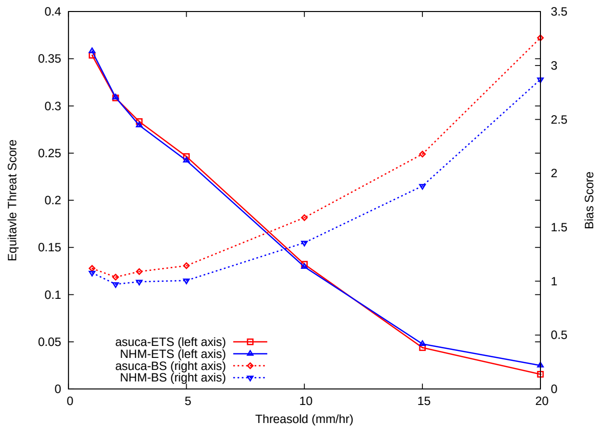

Fig. 3: Same as Fig. 2 but for the winter experiment.

Although the precipitation forecasts have similar overall accuracy, some aspects are better with the ASUCA-LFM. One such improvement is the enhanced representation of the diurnal cycle of rainfall consisting of showers associated with unstably stratified layers. The introduction of the parameterization for convective initiation (Hara 2015) is a primary factor behind this improvement.

It was also confirmed that forecast performance for near-surface variables (including 10-m wind, screen level temperature and humidity) is statistically similar or better. One exception is surface pressure, where forecasting was less accurate due to the exact mass conservation of the ASUCA-LFM. That is, the ASUCA-LFM represents the total mass change of the coarser model (which provides the lateral boundary conditions for LFM) better than the NHM-LFM.

Fig. 4 shows observed and simulated infrared images of a cold-air outbreak case in the winter experiment. It can be seen that ASUCA-LFM produces more realistic (low-level) cloud associated with this cold air than the NHM-LFM. It was also found that these differences can be generally seen for instances of cold air outbreak, mainly due to the improvement of the boundary layers scheme.

4 Conclusions

The new operational-limited area model based on ASUCA, the Physics Library, and ASUCA-Var was successfully launched in January 2015. This represents only the start of development based on these components rather than being a goal in itself. In future work, ASUCA will be introduced for another coarser regional model (known as the Meso-Scale Model) at JMA with a horizontal grid spacing of 5 km and a longer forecast period. As indicated by Hara et al. (2012), the Physics Library provides a basis of the “seamless” developments, which is highly important for further progress in the field.

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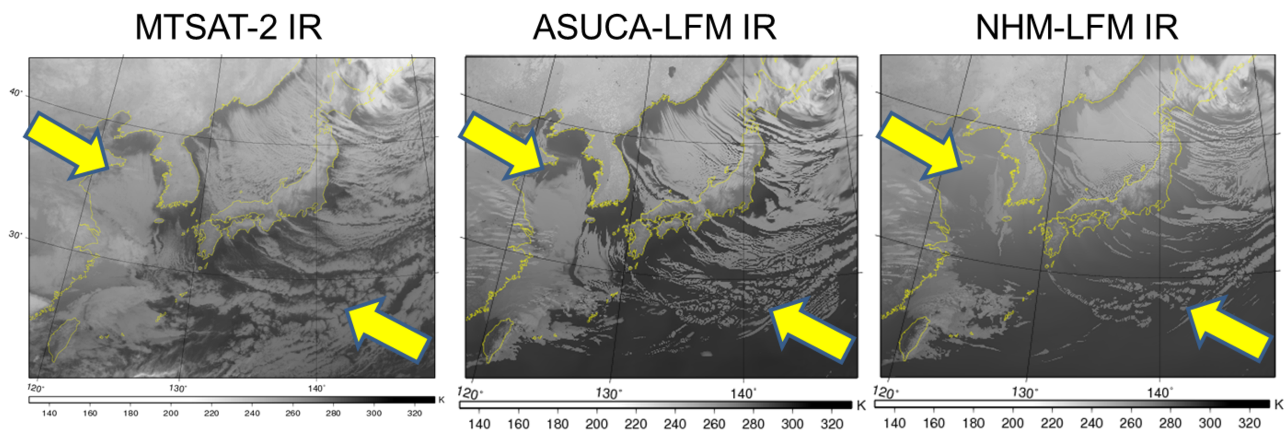

Fig. 4: Observed infra-red satellite image (left), simulated image using ASUCA-LFM (centre) and NHM-LFM (right) for a case of cold air outbreak.