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Development of Limited-Area NWP Systems at JMA

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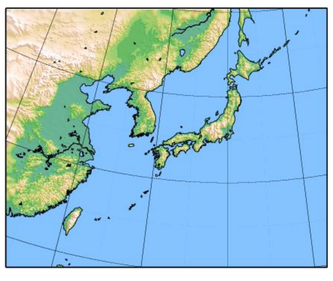
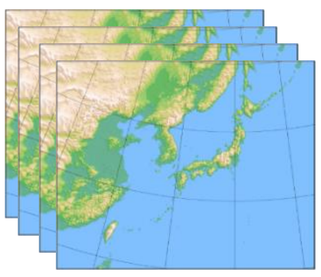
1. Regional operational NWP systems at JMA

Meso-Scale Model (MSM):
Horizontal resolution: 5km
Vertical levels / top: 96 / 37.5km
Forecast hours (initial times):
78 hours (00, 12 UTC)
39 hours (03, 06, 09, 15, 18, 21 UTC)
Initial conditions: Meso-scale analysis (MA) (4D-Var)



Local Forecast Model (LFM):
Horizontal resolution: 2km
Vertical levels / top: 76 / 21.8km
Forecast hours (initial times):
10 hours (00–23 UTC hourly)
Initial conditions: Local analysis (LA) (hybrid 3D-Var)

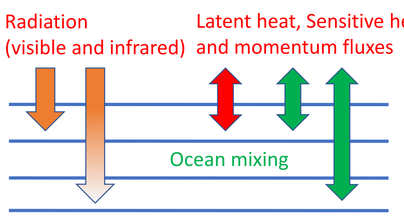
Meso-Scale Ensemble Prediction System (MEPS):
Horizontal resolution: 5km
Vertical levels / top: 96 / 37.5km
Forecast hours (initial times):
39 hours (00, 06, 12, 18 UTC)
Initial conditions: Meso-scale analysis with ensemble perturbations (SV)
Ensemble members: 21 (Control = MSM**)**



2. Update of Meso-Scale Model (MSM2203)

Highlights:
- Increasing vertical layers from 76 to 96 (the model top is enhanced from 21.8 to 37.5 km)
- The forecast range is extended from 51 to 78 hours at 00 and 12 UTC
- Introducing a one-dimensional ocean mixed layer model (OML)

- The previous MSM (MSM2003) often predicts excessively intensified typhoons.
  - A fixed SST is one of the reasons for over-intensification.
- An ocean mixed layer model is introduced to represent SST cooling induced by typhoons in the update (MSM2203).
- The Price-Weller-Pinkel model (PWP model; Price et al., 1986) is employed.
  - The ocean interacts with the atmosphere by the heat flux and wind stress on the sea surface.
  - Vertical mixing in the ocean is induced by static instability and/or shear instability.



1D Equations in the ocean

$$\frac{\partial T}{\partial t} = \frac{-1}{\rho_0 C}\frac{\partial F}{\partial z}$$
$$\frac{\partial S}{\partial t} = -\frac{\partial E}{\partial z}$$
$$\frac{\partial V}{\partial t} = -f \times V - \frac{1}{\rho_0}\frac{\partial G}{\partial z}$$

Boundary conditions on the sea surface:
$F(0) = Q$ heat flux
$E(0) = S(E-P)$ water budget
$G(0) = \tau$ wind stress

Fig. 1 Schematic illustration of the PWP model

- Over-intensification bias in the central pressure is alleviated in MSM2203.
- Mean error of the central position is not improved.

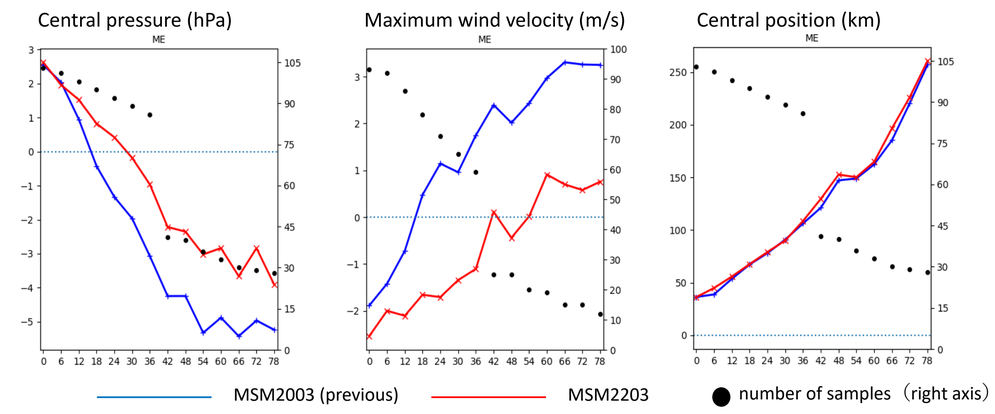


Fig.2 Mean errors of central pressure (left), maximum wind velocity (center) and central position (right) for typhoon forecasts (1 July to 15 September, 2020). The horizontal axis is the forecast range (hour).

- MSM2203 can represent SST cooling observed in the east side of the typhoon. It contributes to reducing error of the central pressure.
- SST given in MSM2003 does not change from the initial value.

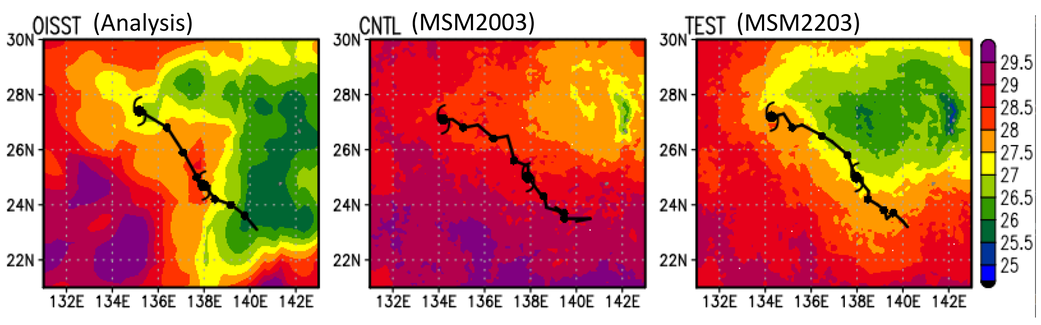


Fig.3 Center position (black line) and SST (color shade) for Typhoon Krosa (2019) at 00 UTC on 13 August (FT=48).

3. Update of Local Analysis (LA2203)

Highlight:
- Introducing hybrid 3D-Var using the ensemble perturbations of MEPS

The cost function J(x):

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}[\mathbf{H}(\mathbf{x}-\mathbf{x}^b)-\mathbf{d}]^T \mathbf{R}^{-1}[\mathbf{H}(\mathbf{x}-\mathbf{x}^b)-\mathbf{d}]$$

- The background error covariance B is calculated as the average of the climatological Bc and the ensemble based Be.
- Bc is horizontally homogeneous and isotropic.
- Be is created from the ensemble perturbations of MEPS.
  - 100 members (20 ensemble members x 5 lagged forecasts of MEPS) are used.
  - Introducing Be enables to represent the flow-dependent and anisotropic background error covariance B.

- The analysis increment in the hybrid 3D-Var reflects the ensemble spread predicted by MEPS.
- The prediction using hybrid 3D-Var captures the area in which heavy precipitation occurs better than that using 3D-Var.

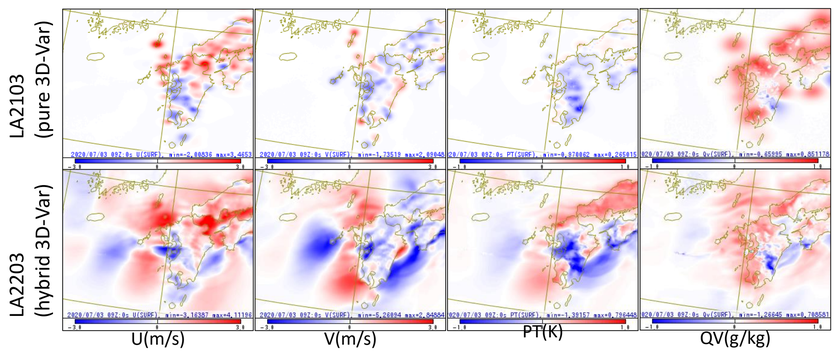


Fig. 4 Analysis increment at the surface with pure 3D-Var (upper panels) and hybrid 3D-Var (lower panels)

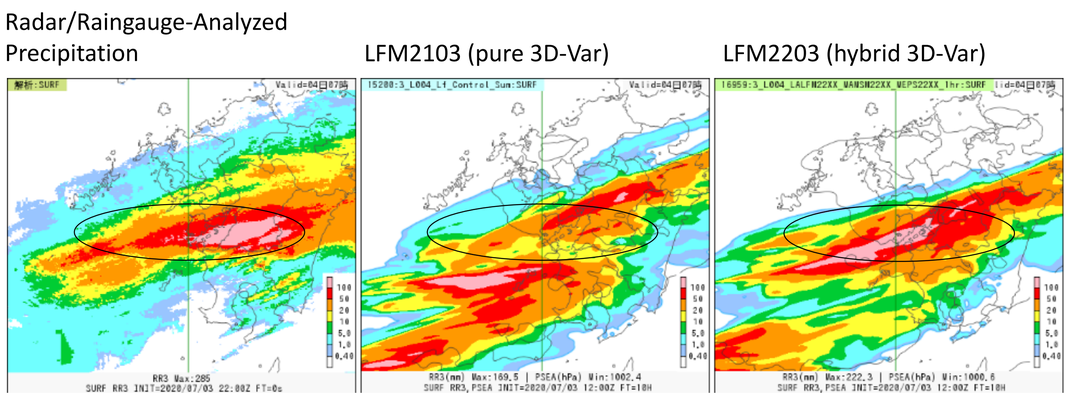


Fig.5 3-hour accumulated precipitation for 19-22 UTC on 3 July 2020 (FT=10). The analysis increment shown in Fig. 4 are used in the initial values of these forecasts.

4. Feasibility study: GPU porting of the forecast model ASUCA

- GPU based systems are growing in the current HPC world.
  - Desirable code design for GPUs is different from that for CPUs.
- GPU porting for the regional model ASUCA is ongoing.
  - The OpenACC directives are used to minimize development cost.
- Several time-consuming processes have been ported for GPUs.
  - It may be required that all the processes are calculated on GPUs (because data transfer between CPU and GPU is too slow).

Time-consuming processes:
- short time step to solve sound waves (HE-VI)
- advection
- sedimentation of water substance
- physical processes

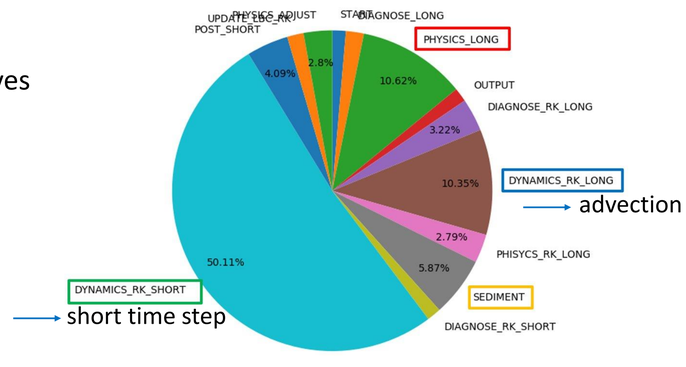


Fig. 6 Proportion of elapsed time (incl. MPI communication) in LFM (2km)

Acceleration ratio against 2 CPUs (calculation with 150x150x76 grids)
CPU: Intel Xeon Gold 6226 (12 cores/CPU), GPU: NVIDIA Tesla V100
Dynamical processes (advection and HE-VI) are well accelerated with GPU.
Optimizing the physical processes is not so easy.
Most of the innermost loops (vertical direction) in physical processes cannot be vectorized.

Dynamics			Physics			
advection	short time step (HE-VI)	sedimentation	microphysics	convection (deep)	PBL	radiation
x7.17	x2.57	x1.23	x1.1	x1.8	x1.2	x1.7

References:

- Ishida et al., ASUCA: the JMA operational non-hydrostatic model, J. Meteor. Soc. Japan, 100 (2022), in press, doi:10.2151/jmsj.2022-043
- Price et al, Diurnal cycling: Observations and models of the upper ocean response to diurnal heating, cooling, and wind mixing, J. Geophys. Res., 91 (1986), 8411–8427.
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