

Development and Results of a Cloud-Resolving Nonhydrostatic 4DVAR Assimilation System (NHM-4DVAR)

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NHM-4DVAR is a cloud-resolving nonhydrostatic 4D-Var data assimilation system based on the JMA Nonhydrostatic Model (NHM), to investigate the mechanism of heavy rainfall events induced by mesoscale convective systems (MCSs). The horizontal resolution of the NHM-4DVAR is set to **2 km** to resolve MCSs.

NHM-4DVAR v1: The forward model is the full nonlinear NHM, while the adjoint model only considers perturbations to the dry dynamics and the advection of water vapor. **Doppler radar's radial wind data (RW), GPS precipitable water vapor data (GPS-PWV) and surface temperature and wind data** are assimilated. The system was applied to a **heavy rainfall event in Tokyo in July 1999, called the Nerima heavy rainfall**. Time sequence of observed rainfall intensity is well reproduced in the assimilation window and the subsequent forecast.

NHM-4DVAR v2: The **warm rain cloud microphysical process** has been implemented to the adjoint model. **New control variables** relevant to the water substances are introduced, and the observation operator of the **radar reflectivity** is developed. This system was applied to a **heavy rain fall event around Tokyo occurred on 4-5 Sep. 2005**. With the assimilation of the radar reflectivity and mesoscale data, location, horizontal size, and rainfall intensity of the observed rain band is well reproduced.

NHM-4DVAR v1 with dry dynamics and water vapor Nerima heavy rainfall event on 21 July 1999

Category	Forward model (nonlinear NHM)	adjoint model
Basic equations	Fully compressible with a map factor	○
Prognostic variables	Momentums, potential temperature, pressure, mixing ratios of water vapor, cloud water, cloud ice, rain, snow and graupel, and kinetic turbulent energy.	Momentums, potential temperature, pressure, mixing ratio of water vapor
Cloud microphysics	3 ice bulk microphysics	Advection of water vapor

$$\pi_B(z) = \pi_{surf} + \int_{surf}^z \frac{dz}{g}$$

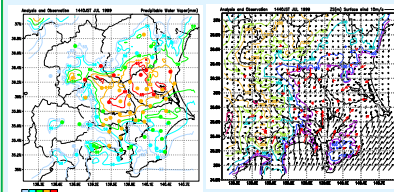
$$\pi = \left(\frac{p}{p_0} \right)^{\frac{1}{\gamma}}$$

Variables	Formula
Wind	u, v, w
Non-Hydrostatic pressure	$\pi_U = \pi - \pi_B$
Potential temperature	θ
Surface pressure	P_s
Pseudo relative humidity	$q_u = qv / q_s^b$

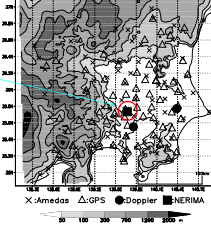
Assimilation result

Left: **PWV**
circles: observations
contour: analysis

Right: **surface wind**
red arrows: observations
black arrows: analysis
color contour: topography

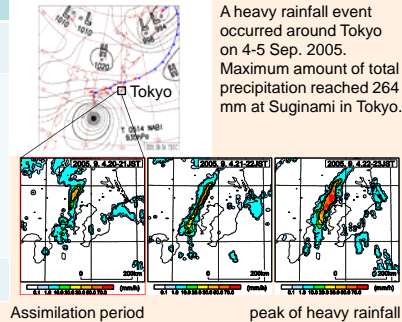


Assimilation area



NHM-4DVAR v2 with warm rain Heavy rainfall event around Tokyo on 4-5 Sep. 2005

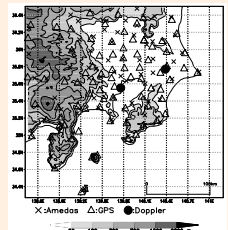
adjoint model
○
Momentums, potential temperature, pressure, mixing ratio of water vapor, cloud water, rain water
Warm rain process



Control variables

Variables	Formula
Wind	u, v, w
Non-Hydrostatic pressure	$\pi_U = \pi - \pi_B$
Potential temperature	θ
Surface pressure	P_s
Total water	$qv + qc$
Rain water	qr / q_s^b
Pseudo relative humidity (for LBCs)	$q_u = qv / q_s^b$

Assimilation area



Observation operator for reflectivity (Z-Qr relation)

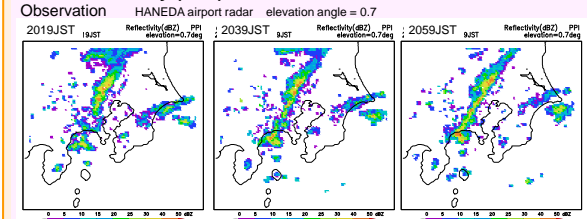
$$Z_{qr} = 10 \times \log_{10} (cqr \times (dns \times qr)^{1.75})$$

cqr : constant, dns : density, qr : mixing ratio of rain water
Assumption: Marshall-Palmer drop size distribution
Observational error: 15dBZ

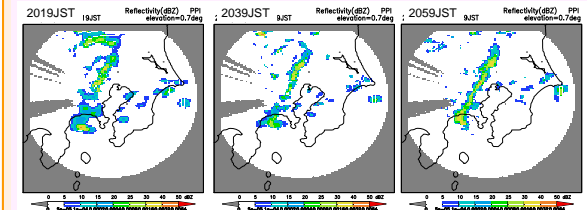
Assimilation results

Analysis reproduces the location, intensity and horizontal size of the main rain band, furthermore, convective cells located on the east of the main rain band.

Radar reflectivity (dBZ)



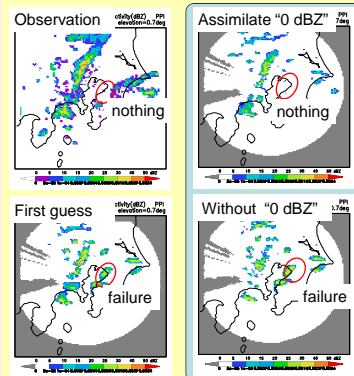
Analysis



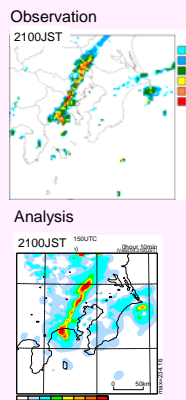
Assimilation of "0 dBZ" observation

If reflectivity is
✓ over 10 dBZ in the first guess field and
✓ under 10 dBZ in the observations,
the grid is regarded as the false precipitation to be eliminated, and "0 dBZ" information is used.

Observational error:
✓ normal error x 4
"0 dBZ" observations are NOT real observations.



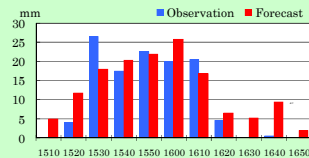
Rainfall intensity (mm/h)



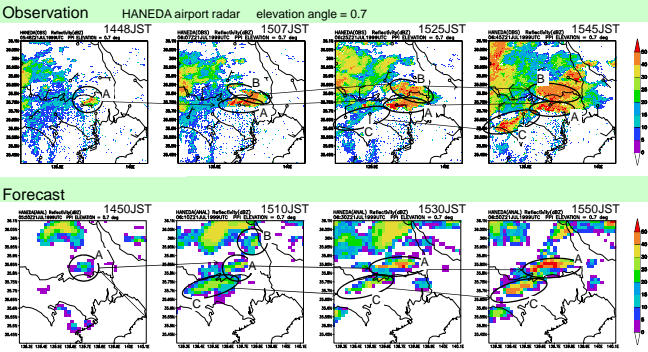
Forecast results

- Formation and development of the convective cells, which caused the Nerima heavy rainfall, are well reproduced.
- 10-minute rainfall amount of the forecast are quantitatively in good agreement with the observation.

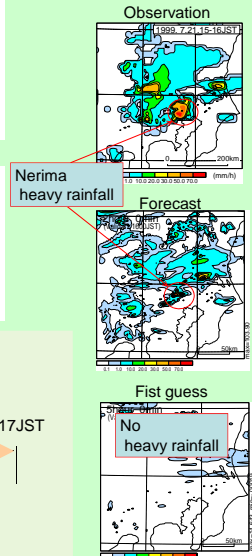
10-minute rainfall amount at Nerima



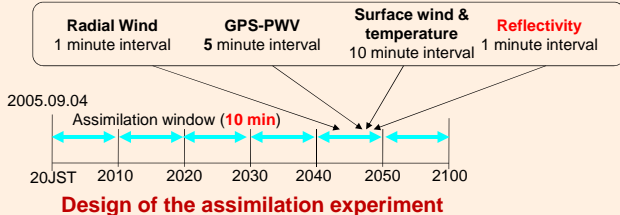
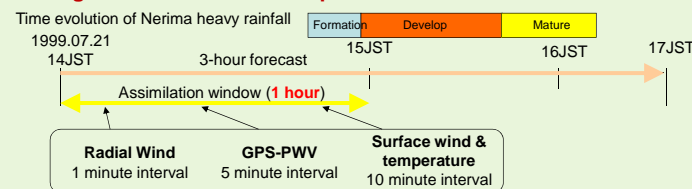
Radar reflectivity (dBZ)



Hourly accumulated rainfall amount



Design of the assimilation experiment



Acknowledgment

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Reference

Kawabata et al., 2007: An Assimilation and Forecasting Experiment of the Nerima Heavy Rainfall with a Cloud-Resolving Nonhydrostatic 4-Dimensional Variational Data Assimilation System, *Journal of the Meteorological Society of Japan*, Vol. 85, No. 3, 255-276