Development of new NHM-4DVAR unified with JNoVA

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1: MRI, 2:JAMSTEC, 3:JMA

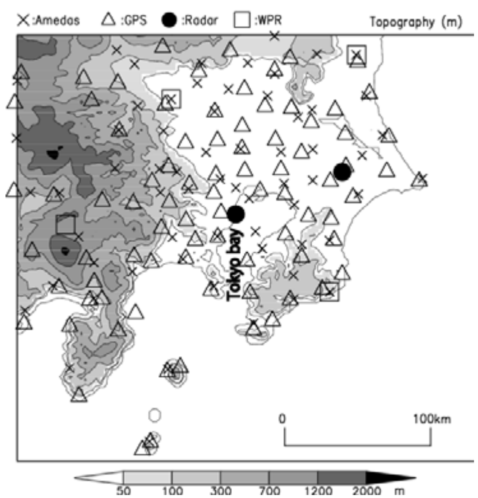
NHM-4DVAR

Model (non incremental)

- Forward : JMANHM (JMA operational mesoscale model)
  (Full model with 3-ice cloud microphysics)
- Adjoint : Dynamical core, Warm rain, Lateral boundary conditions

$$
\begin{aligned}
J(\mathbf{x}_0, \mathbf{x}_{lbc}) \\
&= \frac{1}{2}\left(\mathbf{x}_0{}^b - \mathbf{x}_0\right)^{\mathrm{T}} \mathbf{B}^{-1}\left(\mathbf{x}_0{}^b - \mathbf{x}_0\right) \\
&+ \frac{1}{2}\left(\mathbf{x}_{lbc}{}^b - \mathbf{x}_{lbc}\right)^{\mathrm{T}} \mathbf{B}'^{-1}\left(\mathbf{x}_{lbc}{}^b - \mathbf{x}_{lbc}\right) \\
&+ \frac{1}{2}\left(HM\mathbf{x}_0 - \mathbf{y}^{o}\right)^{\mathrm{T}} \mathbf{R}^{-1}\left(HM\mathbf{x}_0 - \mathbf{y}^{o}\right)
\end{aligned}
$$

Narrow assimilation area



NHM-4DVAR

Observations

- Doppler radial wind and reflectivity by Doppler radar,
  GPS precipitable water vapor, GPS zenith total delay,
  GPS slant total delay,
  Wind profiler, surface wind, surface temperature,
  Virtual temperature profile by RASS,
  Radial wind by Doppler lidar

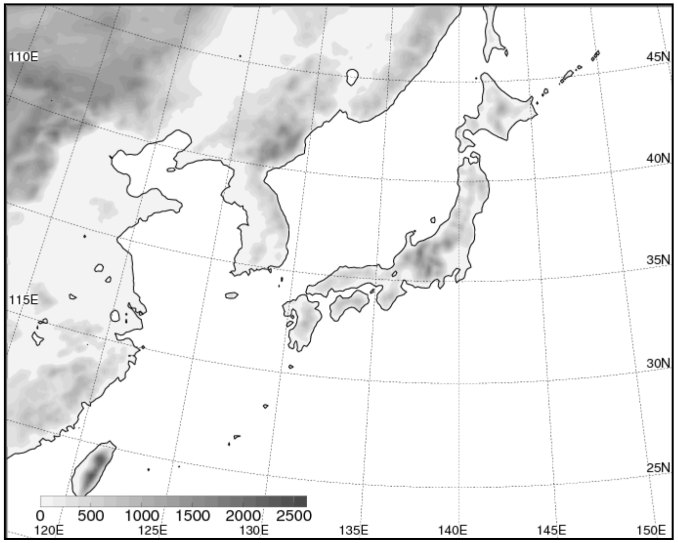
Horizontal resolution

- 2km -> Storm scale

- Kawabata, T., H. Seko, K. Saito, T. Kuroda, K. Tamiya, T. Tsuyuki, Y. Honda and Y. Wakazuki, 2007: An Assimilation Experiment of the Nerima Heavy Rainfall with a Cloud-Resolving Nonhydrostatic 4-Dimensional Variational Data Assimilation System. *J. Meteor. Soc. Japan*, **85**, 255-276.
- Kawabata, T., T. Kuroda, H. Seko, and K. Saito, 2011: A cloud-resolving 4D-Var assimilation experiment for a local heavy rainfall event in the Tokyo metropolitan area, *Mon. Wea. Rev.* **139**, 1911-1931.
- Kawabata, T., H. Seko, K. Saito, T. Kuroda, K. Tamiya, T. Tsuyuki, Y. Honda and Y. Wakazuki, 2013: A Numerical Study on a Mesoscale-Convective System over a Subtropical Island with 4D-Var Assimilation of GPS Slant Total Delays. *J. Meteor. Soc. Japan* (submitted).

JNoVA

- JMA operational nonhydrostatic assimilation system
- Incremental method: nonlinear simplified JMANHM and its adjoint model.
- Inner loop model: 15 km, outer loop model: 5 km
- Large scale condensation scheme
- Diagnostic eddy diffusion scheme, mixing layer scheme, land-surface scheme, and ground temperature prediction
- Excluding radiation, and convective parameterization.
- Assimilation window: 3 hours



JNoVA

Control variables: u, v, potential temperature, surface pressure, and pseudo relative humidity.
Penalty term: digital filter
Observations: Surface pressure, upper soundings, airplane observations, wind profiler, Doppler radar radial wind, accumulated rainfall amount, precipitable water vapor, retrieved temperature profile by satellites…

$$J(\mathbf{x}_0) = \frac{1}{2}\left(\mathbf{x}_0{}^{b} - \mathbf{x}_0\right)^{\mathrm{T}}\mathbf{B}^{-1}\left(\mathbf{x}_0{}^{b} - \mathbf{x}_0\right) + \frac{1}{2}(HM\mathbf{x}_0 - \mathbf{y}^{\boldsymbol{o}})^{\mathrm{T}}\mathbf{R}^{-1}(HM\mathbf{x}_0 - \mathbf{y}^{\boldsymbol{o}}) + \boldsymbol{J_p}$$

Brief history of NHM-4DVAR and JNoVA

First stage

- The 2nd laboratory of the Forecast Research Department of MRI and the Numerical Prediction Division of JMA began to develop a mesoscale nonhydrostatic 4D-Var assimilation system in 2002.
- The tangent linear and adjoint models of the system were based on the JMA nonhydrostatic model (JMANHM ver. 2002).
- A dry version of the assimilation system was made in 2003.

Second stage

- MRI developed a moist version of the system using JMANHM ver. 2002 in order to be adopted to storm-scale.
  -> NHM-4DVAR ver. 1 (Kawabata et al. 2007)
- NPD adopted the newer version of JMANHM to develop a newer assimilation system with several physical processes as a successor operational assimilation system.
  -> JNoVA (“JMA Nonhydrostatic model” –based Variational Data Assimilation)

Third stage

- NHM-4DVAR was advanced with warm rain process (ver. 2: Kawabata et al. 2011).
- JNoVA has been operated at JMA since 2009.

Motivation

- Kei computer

  MRI attends to Strategic Programs for Innovative Research (SPIRE) funded by the Ministry of Education, Culture, Sports, Science & Technology.

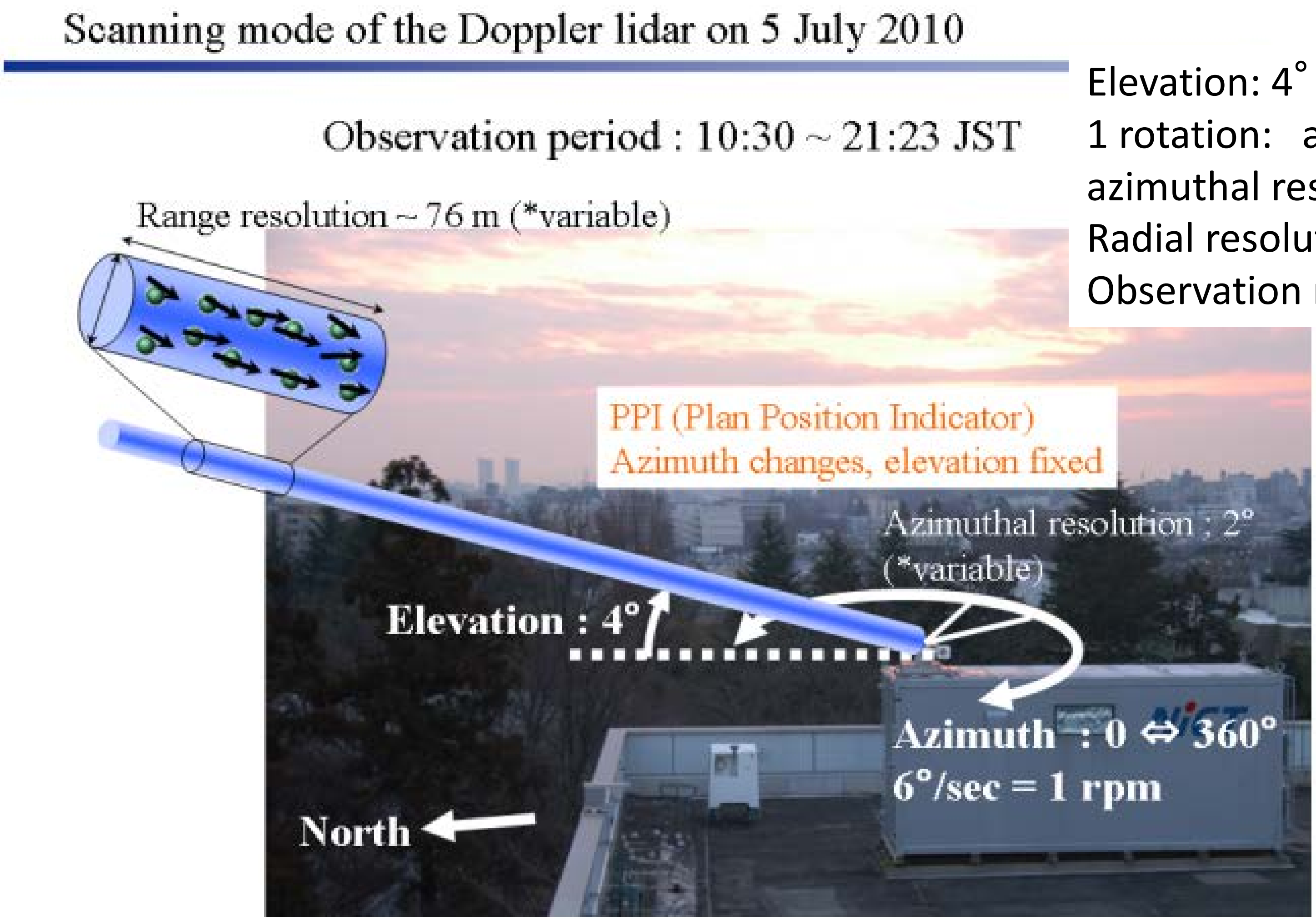
  We conduct the science plan of “Development of cloud resolving 4 dimensional data assimilation system” on whole of Japan area.

  NHM-4DVAR is storm-scale assimilation system, but it has been conducted only in narrow areas. While JNoVA is operationally run all over Japan, but its resolution is not so high.

  A new system, NHM-4DVAR + JNoVA, is the best solution.

- Physical processes and the penalty term in JNoVA are useful to NHM-4DVAR.
- Developments at NPD become available to new NHM-4DVAR, i.e., direct assimilation of radiation brightness temperature given by satellites.

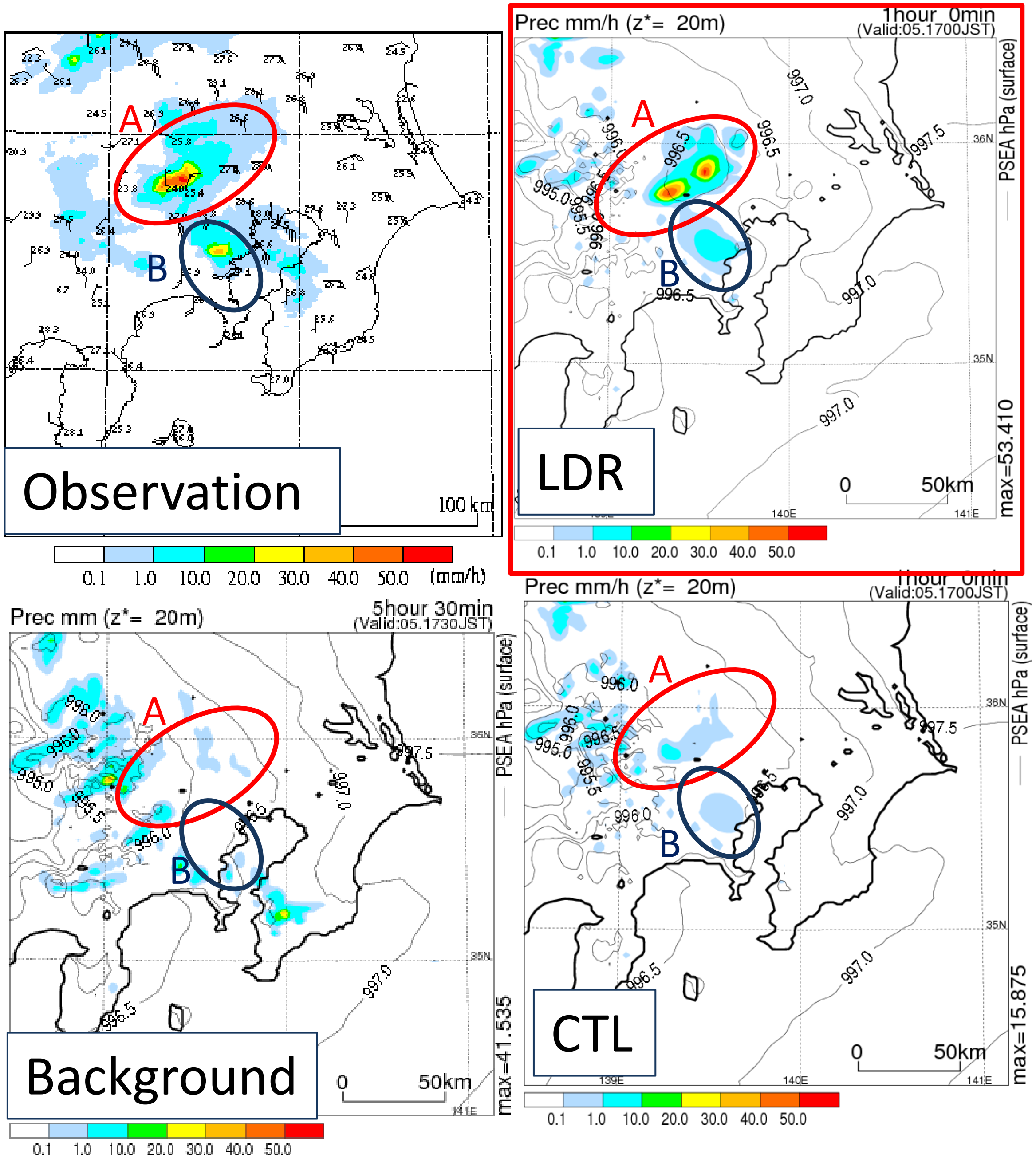
Recent result by NHM-4DVAR



Elevation: 4°
1 rotation: about 1 min
azimuthal resolution: about 2 °
Radial resolution: about 76m
Observation range: 10 – 20 km

NICT Doppler Lidar at Koganei (Iwai, 2011)

Comparison OBS, CTL, LDR, BCK



In Background, no strong convective areas.

In CTL, similar rainfall regions (A, B) appear but their intensity is weak (< 10 mm h^{-1}) compared with Observation.

In LDR, both convective areas of A and B are reproduced well with the maximum rainfall intensity of 53 mm h^{-1}.

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Horizontal resolution

- 2km

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Specifications of the new system

	Nonlinear model of the new system	JNoVA	NHM-4DVAR	New NHM-4DVAR
Resolution	2 km	15 km	2 km	2 km
Incremental method	--------	Yes	No	Yes
Moisture process	3-ice bulk	Large scale condensation	Warm rain	Warm rain
Turbulence	Diagnostic eddy diffusion	Diagnostic eddy diffusion	No	Diagnostic eddy diffusion
Land-air process	(Sea)Kondo (Land)Louis	(Sea)Kondo (Land)Louis	No	(Sea)Kondo (Land)Louis
soil temperature	heat diffusion (4 layers)	heat diffusion (4 layers)	No	heat diffusion (4 layers)
Radiation	Sugi and Tada	No	No	No

Current status on the development

- Coding has been already finished.

- Tangent linear check

α	Linear model	Nonlinear model	Residual	Ratio
0.100E-07	0.57748516E-02	0.57268568E-02	0.83806579E-02	0.10083807E+01
0.100E-06	0.57748514E-01	0.57268568E-01	0.83806269E-02	0.10083806E+01
0.100E-05	0.57748709E+00	0.57268568E+00	0.83840217E-02	0.10083840E+01
0.100E-04	0.57746499E+01	0.57268568E+01	0.83454402E-02	0.10083454E+01
0.100E-03	0.57804628E+02	0.57268568E+02	0.93604602E-02	0.10093605E+01
0.100E-02	0.57866296E+03	0.57268568E+03	0.10437287E-01	0.10104373E+01
0.100E-01	0.57789938E+04	0.57268568E+04	0.91039576E-02	0.10091040E+01
0.100E+00	0.57396881E+05	0.57268568E+05	0.22405618E-02	0.10022406E+01
0.100E+01	0.54421498E+06	0.57268566E+06	-0.49714330E-01	0.95028567E+00

- Adjoint check

  LEFT TERM = 0.2963489651449746E+20
  RIGHT TERM = 0.2963489651449752E+20
  DIFFERENCE = 0.6144000000000000E+05

- Bug fix!

Future plan

- Actual observation assimilation experiment
- Hybrid system
- Parameter estimation?