Assimilation Experiment on a Local Heavy Rainfall Event Using Doppler Lidar Observations

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Presentation file is HERE!

Assimilation system, Doppler Lidar and Rainfall event

Abstract

A cloud resolving 4D-Var system was applied to a local heavy rainfall event occurred on 5 July 2010 in the west of Tokyo.

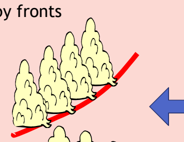
In the control assimilation experiment (CTL), radial wind field by meteorological Doppler Radars and GPS precipitable water vapor data were assimilated, while in the test experiment (LDR), **radial winds by Lidar were assimilated** furthermore.

Comparative experiments show that the LDR forecast reproduces better the observed distribution and intensity of rainfall than the CTL forecast. Difference of zonal wind fields between CTL and LDR suggests that the low level wind modified by the Lidar data assimilation is important to obtain this result.

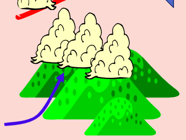
Heavy rainfall scale : < 500km

Localized heavy rainfall scale : < 100km

Large scale convergence by fronts



Updraft by large mountains



Weak forcing on the flat plane

Small horizontal scale

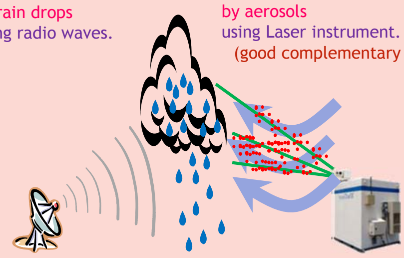
Large fluctuation

Difficulty in forecast!

Doppler Radar vs. Doppler Lidar

Radar observes:
reflectivity and radial winds
inside cumulonimbus
by rain drops
using radio waves.

Lidar observes:
radial winds
surrounding cumulonimbus
by aerosols
using Laser instrument.
(good complementary data)



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).
Kawabata et al. (2007, 2011, 2012)

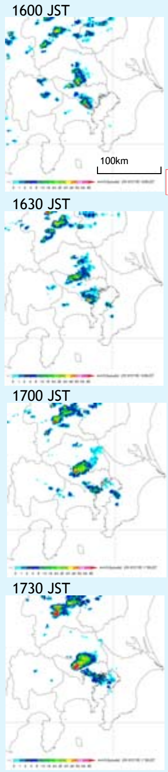
Model
- Forward model : NHM (full nonhydrostatic model)
- Adjoint, tangent linear model :
  - Dynamic frame work
  - Cloud microphysical process (Warm rain)
  - Lateral boundary conditions

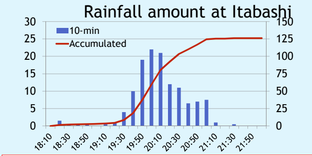
Control variables
Wind (*u*,*v*,*w*), surface pressure, potential temperature, nonhydrostatic pressure, total water, relative rain water,
pseudo relative humidity (for lateral boundary)

Observational data
radial wind, radar reflectivity by Doppler radar,
radial wind by Doppler Lidar,
GPS precipitable water vapor,
GPS zenith total slant delay,
GPS slant total delay,
surface wind, surface temperature

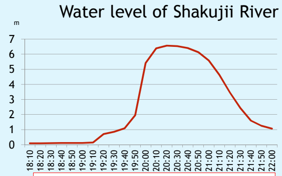
Horizontal resolution : 2 km

Itabashi Heavy Rainfall (05-July-2010)





Maximum rainfall intensity: 100 mm h^{-1}



Rapid increase of water level

- Initiated around 1500 JST in west of Tokyo.
- At 1800 JST, strengthened around NICT observation site.
- At 2000 JST, strengthened again around Itabashi.
- Move to Chiba prefecture around 2100 JST.
- lifetime: 6h, horizontal scale: 30km

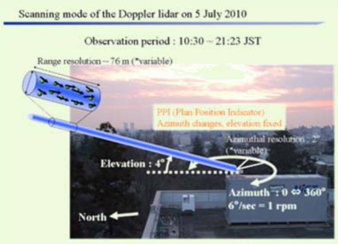
Four Doppler Lidars in west Tokyo

Narita airport as JMA operational instrument.

Two at Haneda airport as JMA operational instruments.

One at Ookayama by Hokkaido U.

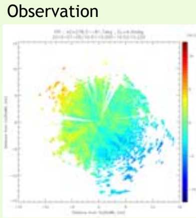
NICT Doppler Lidar (used in this study)



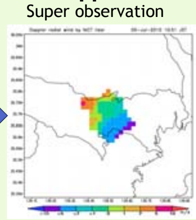
Elevation: 4°
1 rotation: about 1 min
azimuthal resolution: about 2°
Radial resolution: about 76m
Observation range: 10 – 20 km
(Iwai, 2011)

Assimilation method for Doppler Lidar

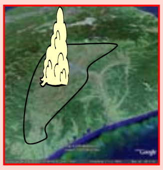
Observation



Super observation



Super Obs: high-dense observations are interpolated into model grids.



Radar and surface data are provided by Japan Meteorological Agency, GPS data by the Geospatial Information Authority of Japan.

References

- Kawabata, T., H. Seko, K. Saito, T. Kuroda, K. Tamiya, T. Tsuyuki, Y. Honda, and Y. Wakazuki, 2007: An assimilation and forecasting experiment of the Nerima heavy rainfa11 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., Y. Shoji, H. Seko, K. Saito, 2012: 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)

Assimilation and forecast experiment (data denial impact test)

Summary

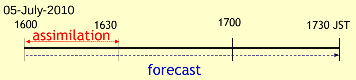
Data assimilation experiment was conducted on the Itabashi heavy rainfall event using NHM-4DVAR.

Assimilated observations are radial wind by Doppler Lidar, radial wind by Doppler Radar, radar reflectivity, and GPS precipitable water vapor.

By assimilating Doppler Lidar data, the intense rainfall region was forecasted similar to the observation.

The reproduced cumulonimbus consists of warm rain cloud, and this characteristic feature is consistent with the radar observational analysis by Yamada (2012).

4D-Var Experimental design



Observation

- **GPS Precipitable water vapor** every 10min
- **Radar reflectivity** every 1min
- **Radial winds by Doppler Radars** every 1min
- **Radial winds by Doppler Lidar** every 1min
  ← On (LDR) / Off (CTL)

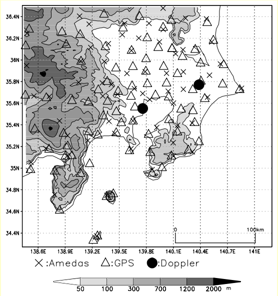
First guess

- **Downscaling from JMA NHM initiated with JMA meso analysis**

Horizontal resolution

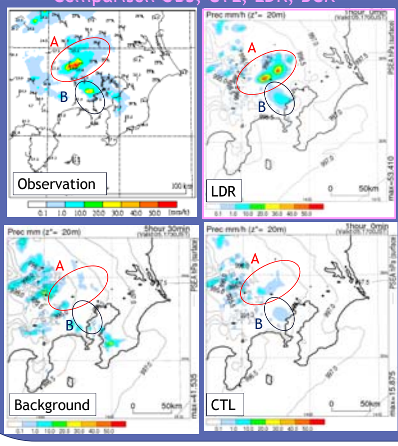
- **Assimilation and forecast: 2 km**

Observation sites
Assimilation area



Impact test

Comparison OBS, CTL, LDR, BCK

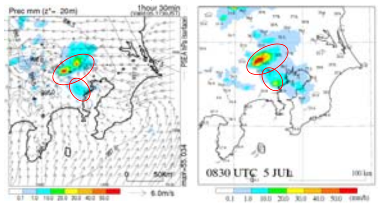


In Background, no strong convective areas.

In CTL, 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}.

Forecast result (1h accumulated rainfall)

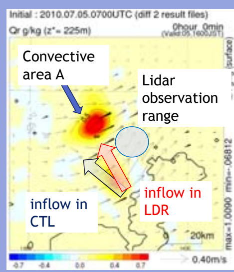


Forecast (FT=1.5h) Observation

- This forecast is free from observation assimilation (1630 – 1730 JST).
- Intensity, location and horizontal size of the north convection are comparable to those observation.

Difference of wind vector and rain water (LDR – CTL)

z=225m FT=0

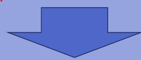


Vectors: difference of horizontal wind vectors between LDR and CTL
Colored shades: mixing ratio of rain water

Mixing ratio of rain water in the convective area A increases in LDR.

Differences of wind vectors are distributed on the Lidar observation range and its surrounding area.

The wind direction of the inflow to the cumulonimbus is changed southerly by the assimilation of Doppler Lidar observations.
→ Effective water vapor transportation

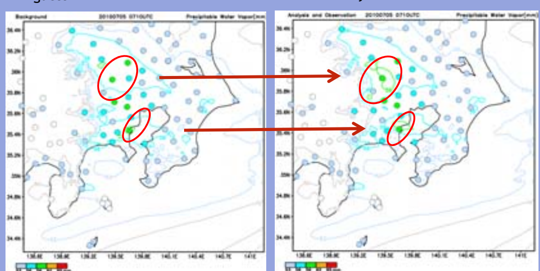


What are keys for the successful result?

The successful result is given by improvements of "water vapor field" by GPS assimilation and "advection of water vapor" by Lidar assimilation.

Precipitable Water Vapor

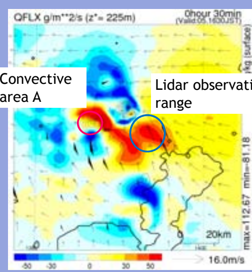
1st guess 4DVAR analysis



Less humidity distribution is modified. Difference seems small, but one in forecast becomes larger.

Difference of water vapor flux (LDR - CTL)

z = 225 m, FT=30min



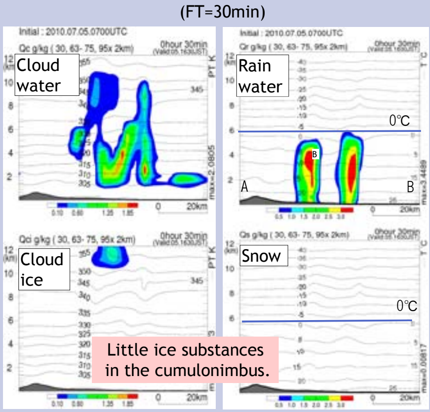
Vectors: Horizontal wind vectors at 225 m height in LDR.
Colored shades: Difference of water vapor flux between LDR and CTL.

The difference of wind direction provides the difference of water vapor flux.

Water vapor inflows to the cumulonimbus more in LDR than in CTL. This difference intensified rainfall A in LDR.

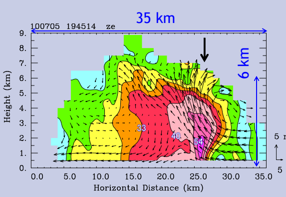
The heavy rainfall was produced without ice phase (warm rain).

Analysis of the cumulonimbus in LDR
Vertical cross-section of water substances
(FT=30min)

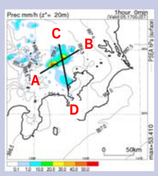


evidence

Analysis by actual radar observation

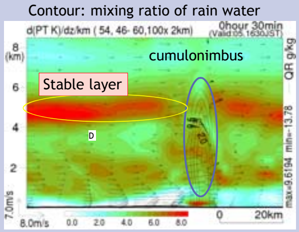


Courtesy of Dr. Yamada (MRI)

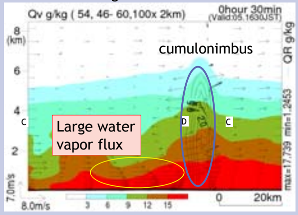


Analysis of the cumulonimbus in LDR
Vertical cross-section of water vapor and stable layer
(FT = 30 min)

Color shade: dθdz
Contour: mixing ratio of rain water



Color shade: water vapor
Contour: mixing ratio of rain water



Q. Why warm rain?
A. Stable layer.
Since there existed a stable layer at 5-km height, the cumulonimbus hardly developed over the freezing level.

Q. Why such intense rainfall?
A. Large flux of water vapor.
Very humid air over 15 g kg^{-1} inflowed to the cumulonimbus with strong sea breeze over 10 m s^{-1}.