D-VAR Assimilation Experiment of a Local Heavy Rainfall Event Using Doppler Lidar Observations

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Contents

- Doppler Lidar
- NHM-4DVAR
- Itabashi Heavy Rainfall Event
- Assimilation & Forecast Result
- Summary
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)
Four Doppler Lidars in west Tokyo

Four of five Doppler Lidars in TOMACS are in west Tokyo

One at Koganei by NICT (used in this study).

One at Ookayama by Hokkaido U.

Narita airport as JMA operational instrument.

Two at Haneda airport as JMA operational instruments.
NICT Doppler Lidar at Koganei

Scanning mode of the Doppler lidar on 5 July 2010

Observation period: 10:30 ~ 21:23 JST

Range resolution ~ 76 m (*variable)

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

(Iwai, 2011)
Itabashi Heavy Rainfall (05-July-2010)

Rainfall amount at Itabashi

Water level of Shakujii River

* 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

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

Very rapid swollenness

* 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
Precipitation and observed radial winds; 2010 July 5 14:00 – 21:25 JST

Color: NICT Doppler Lidar radial velocity
Shade: MLIT MP radar composited precipitation

Iwai et al. (2011)
Cloud Resolving Nonhydrostatic 4D-Var Assimilation System （NHM-4DVAR）

Model (not incremental)
- Forward: JMANHM (JMA operational mesoscale model) (Full model with 3-ice cloud microphysics)
- Adjoint: Dynamical core, Warm rain, Lateral boundary conditions

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,

Horizontal resolution
- 2km

4D-VAR experiment for MCS in west Tokyo on 4 September 2005

Fig. 9. Schematic diagram of assimilation experiment.

4D-Var Experiment for Lidar data

05-July-2010
1600 1630 1700 1730 JST

assimilation

forecast

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
Radar and Lidar Observations

Airport meteorological radars at Haneda and Narita observe radial winds and reflectivity inside the cumulonimbus.

NICT Doppler Lidar observes the surrounding wind field in south-east of the cumulonimbus.
Forecast result (1h accumulated rainfall)

- This forecast is free from observation assimilation (1630 – 1730 JST).
- Two convective areas are seen in both the forecast and observation.
- Intensity, location and horizontal size of the north convection is similar to one of the observation.
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\(^{-1}\).
Assimilation of Lidar data

Wind speed becomes slightly faster and wind direction slightly changes to south.
--> Inflow wind to the cumulous and the convergence around the rainfall region are intensified.
Difference of wind vector (LDR – CTL)  
\[ z=225\text{m } FT=0 \]

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

Initial: 2010.07.05.0700UTC (diff 2 result files)  
\[ Q_r\text{ g/kg (z}^\text{*}= 225\text{m)} \]

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

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

The wind direction of the inflow to the cumulonimbus is changed southerly after the assimilation of Doppler Lidar observations.

→ Effective water vapor transportation
Difference of water vapor flux (LDR - CTL) 
\[ z = 225 \text{ m}, \text{ FT}=30\text{min} \]

**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.

Left figure shows that water vapor inflows to the cumulonimbus more in LDR than in CTL. This difference intensified rainfall A in LDR.
Precipitable Water Vapor

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

Kawabata. (2012)
Analysis of the cumulonimbus in LDR
Vertical cross-section of water substances (FT=30min)

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

No snow and graupel in the cumulonimbus.
Analysis of the cumulonimbus in LDR
Vertical cross-section of water vapor and stable layer
(FT = 30 min)

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

Q. Why warm rain?
A. Stable layer.
Since there existed a stable layer at 5-km height, the cumulonimbus did not develop over the freezing level.
3D structure of the Cumulonimbus

• Vertical scale of the convective core is below 6 km height.
• The cumulonimbus is warm rain cloud.
• Southerly wind over 10 m s\(^{-1}\) flow in 0-2km layer with humid air over 10 g kg\(^{-1}\) mixing ratio of water vapor.
• Westerly wind flow in middle and upper level of atmosphere.
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).