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

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Doppler Radar vs. Doppler Lidar

Radar observes:

reflectivity and radial winds

inside cumulonimbus

by rain drops

using radio waves.

Lidar observes:

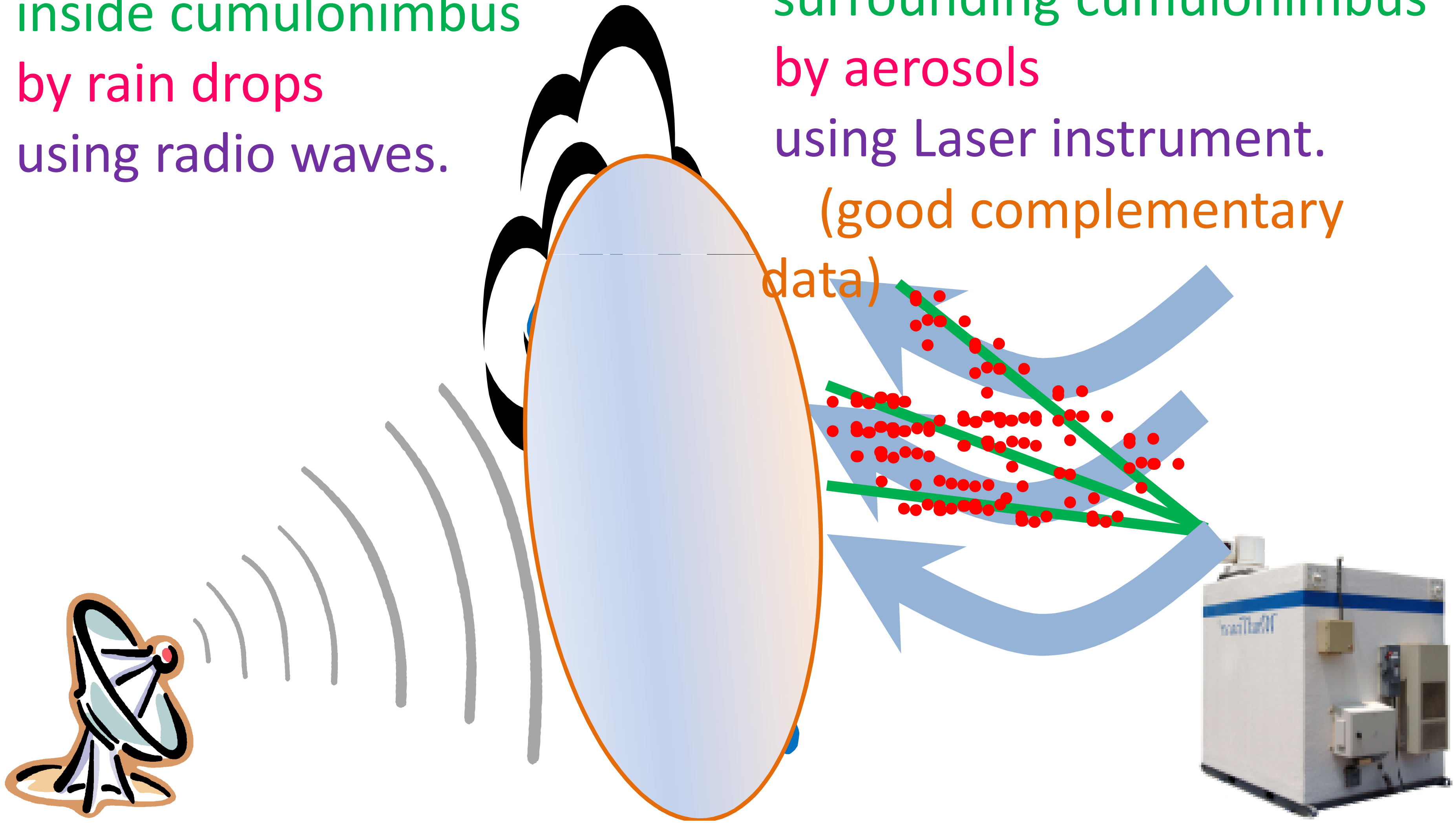
radial winds

surrounding cumulonimbus

by aerosols

using Laser instrument.

(good complementary data)

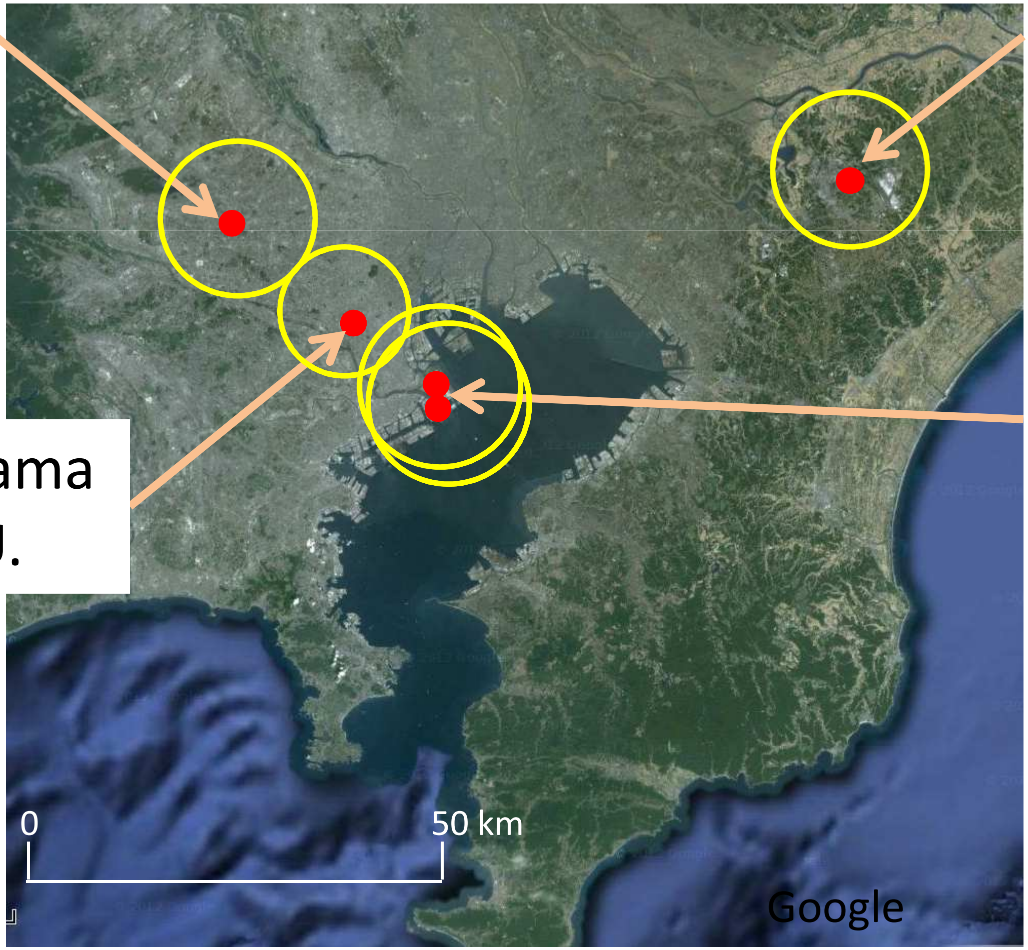


Four Doppler Lidars in west Tokyo

Four of five Doppler Lidars in TOMACS are in west Tokyo

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

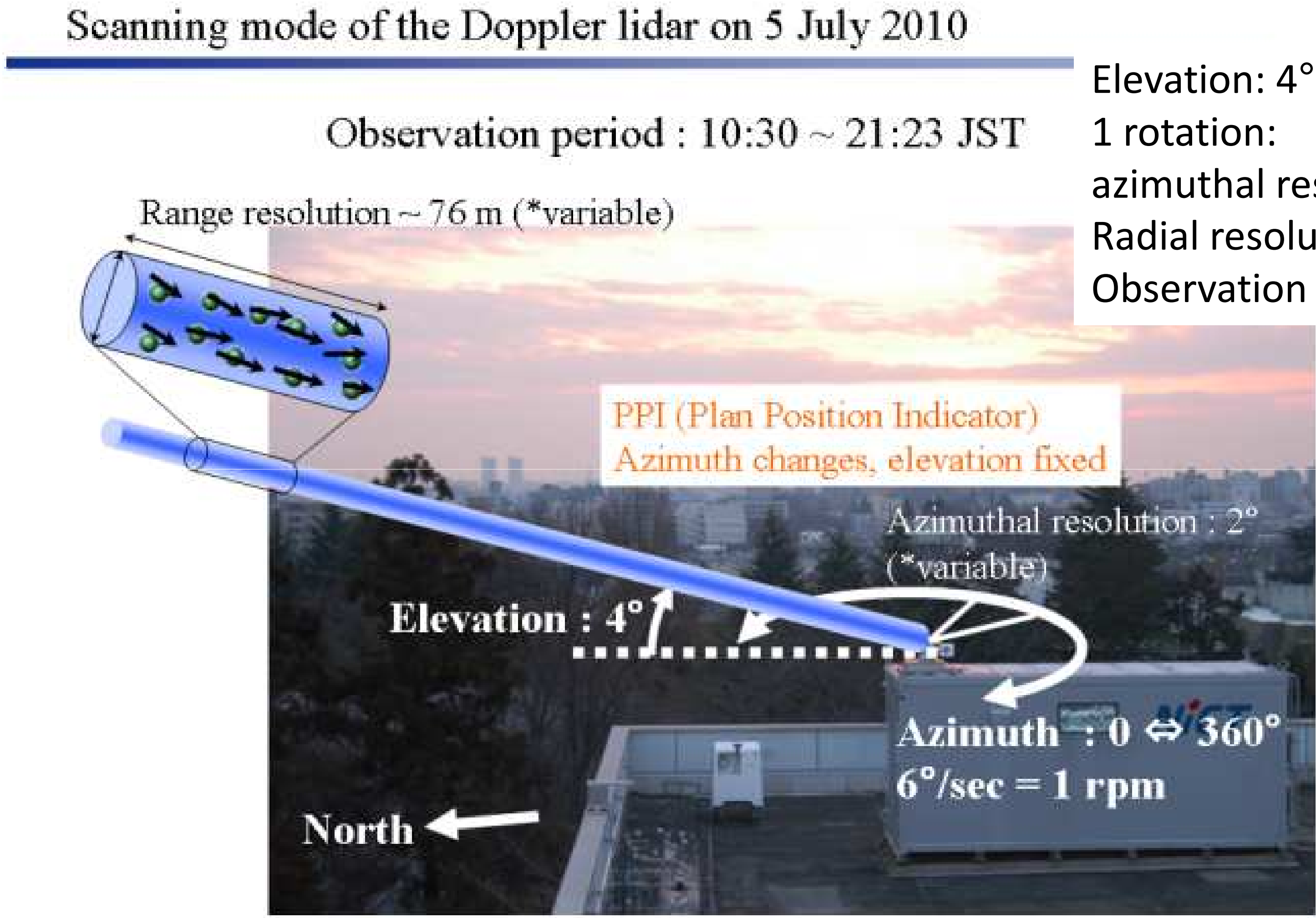
Narita airport as JMA operational instrument.



Two at Haneda airport as JMA operational instruments.

One at Ookayama by Hokkaido U.

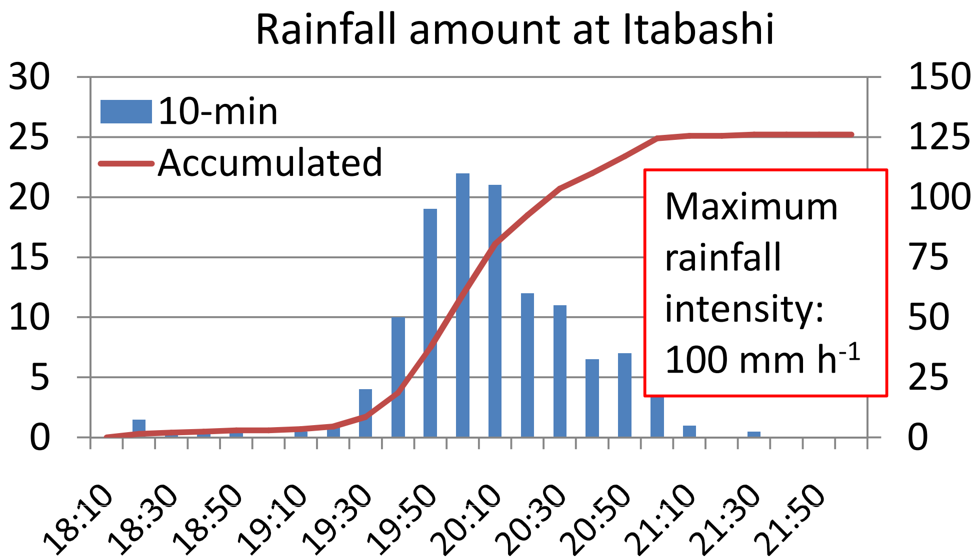
NICT Doppler Lidar at Koganei

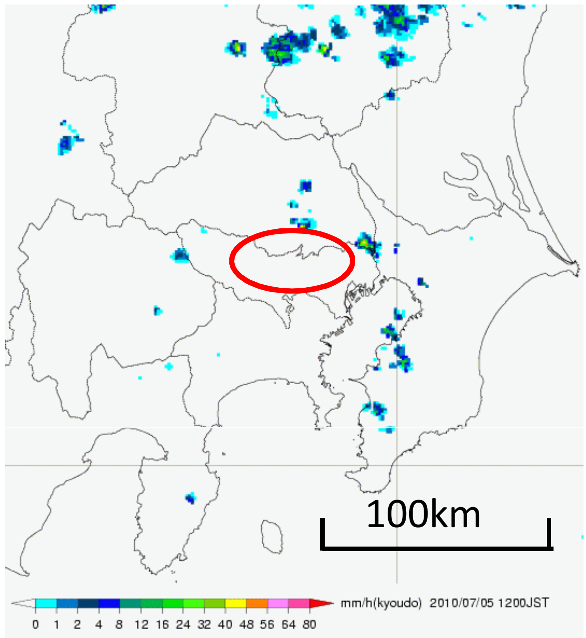


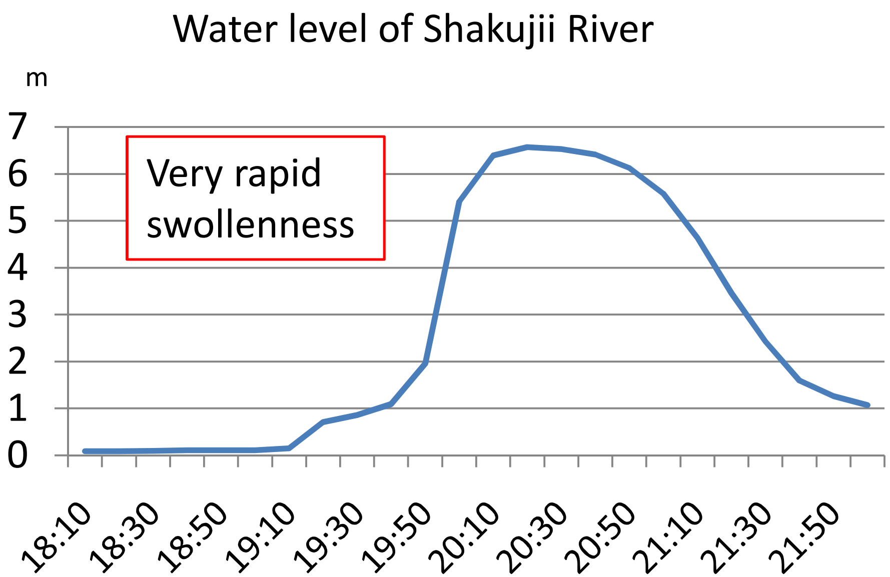
Elevation: 4°
1 rotation: about 1 min
azimuthal resolution: about 2 °
Radial resolution: about 76m
Observation range: 10 – 20 km

(Iwai, 2011)

Itabashi Heavy Rainfall (05-July-2010)

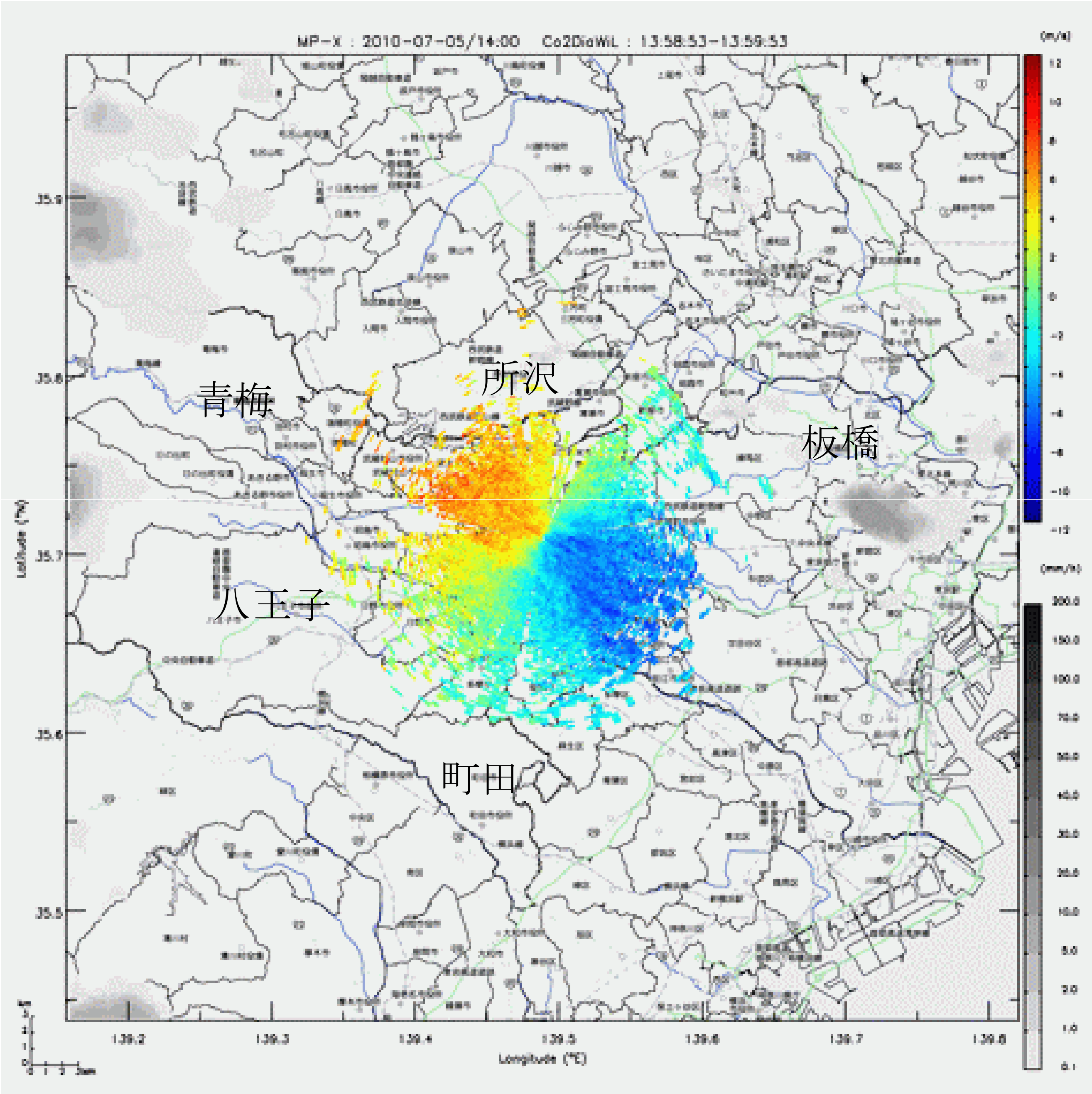






* Initiated around 1500 JST in west of Tokyo.
* At 1800 JST, strengthened around NICT observation site.
* At 2000 JST, strengthened again around Itabashi.
* Move to Chiba prefecture around 2100 JST.
*lifetime: 6h, horizontal scale: 30km

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

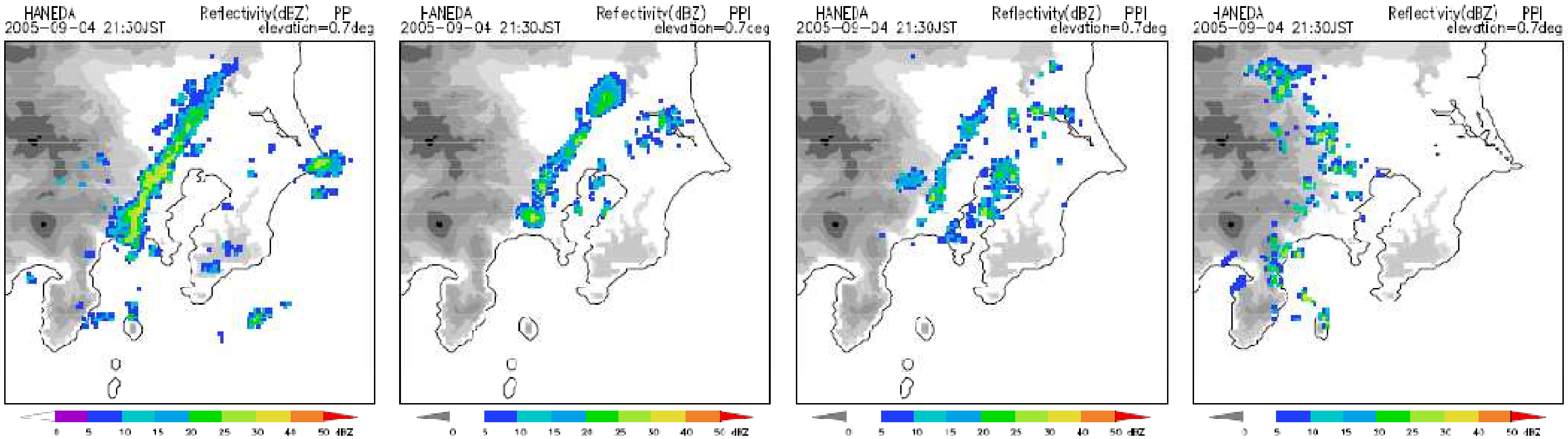
- Doppler radial wind and reflectivity by Doppler Radar,
  GPS precipitable water vapor, GPS zenith total delay,
  GPS slant total delay,
  Wind profiler, surface wind, surface temperature,
  Virtual temperature profile by RASS,

Horizontal resolution

- 2km

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.

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



2130 JST
Obs

4DVAR with
assimilation of
radar reflectivity

4DVAR without
radar reflectivity

1st guess

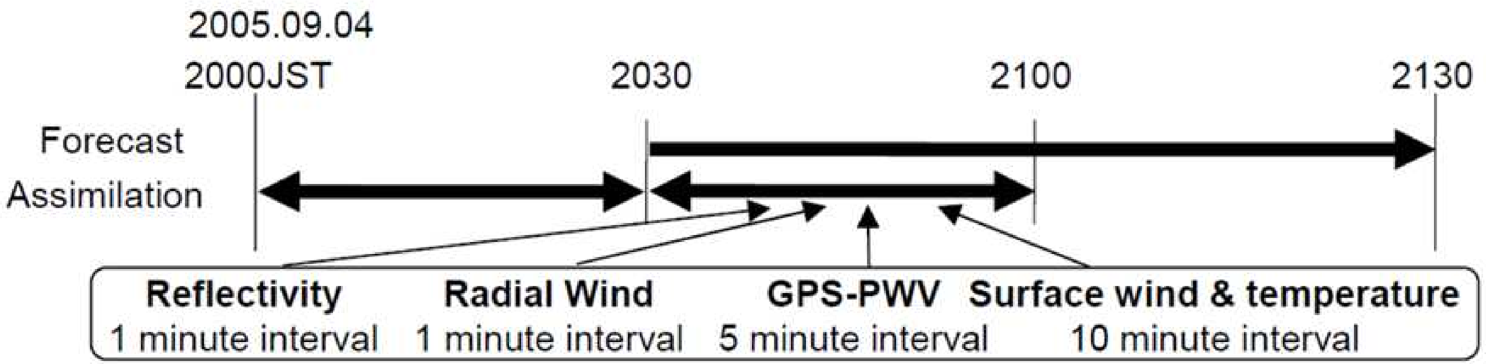
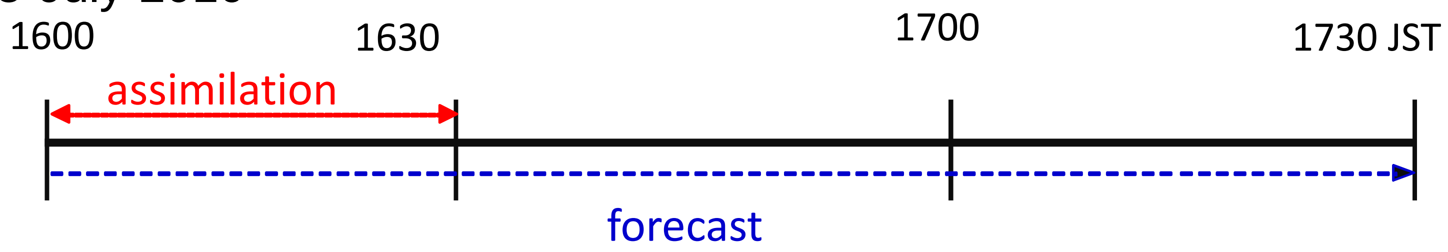


FIG. 9. Schematic diagram of assimilation experiment.

Kawabata, et. al., 2011: *Mon. Wea. Rev*.

4D-Var Experiment for Lidar data

05-July-2010



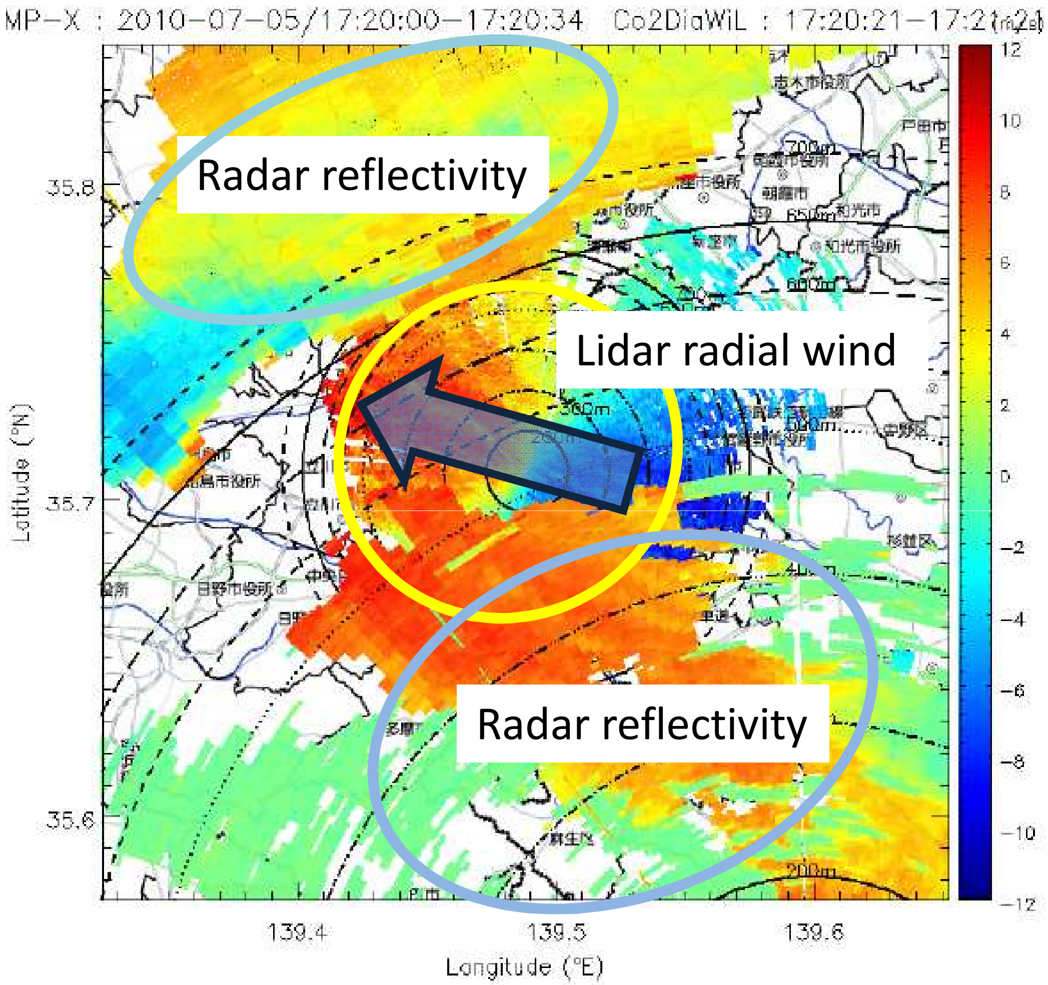
Observation

- **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**

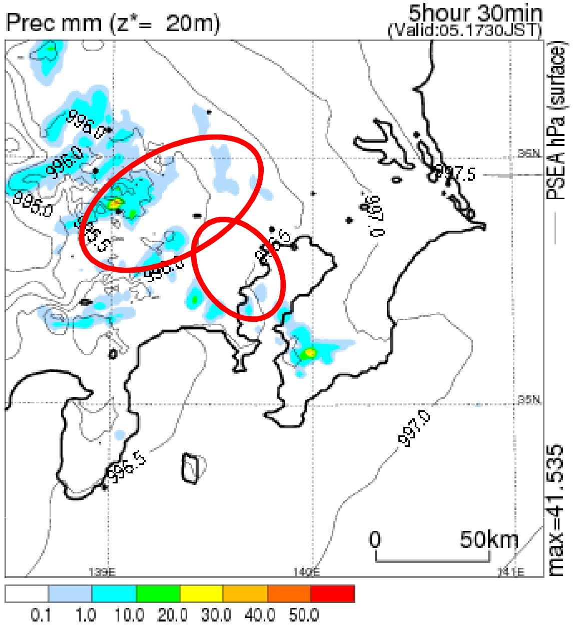
Radar and Lidar Observations



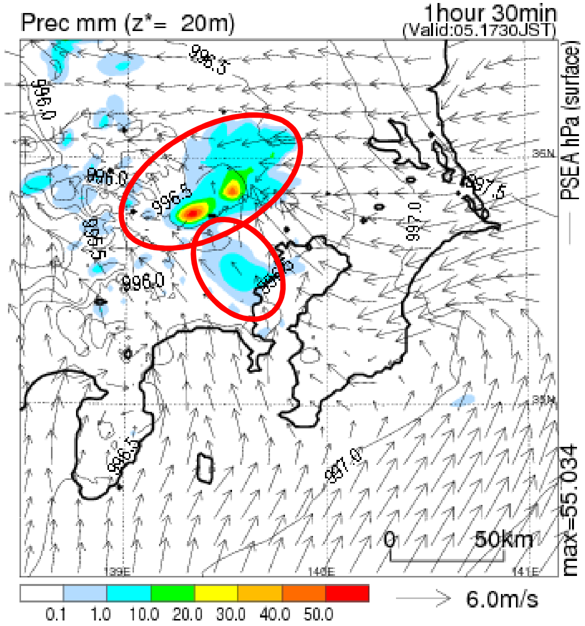
Airport meteorological radars at Haneda and Narita observe radial winds and reflectivity inside the cumulonimbus.

NICT Doppler Lidar observes the surrounding wind field in south-east of the cumulonimbus.

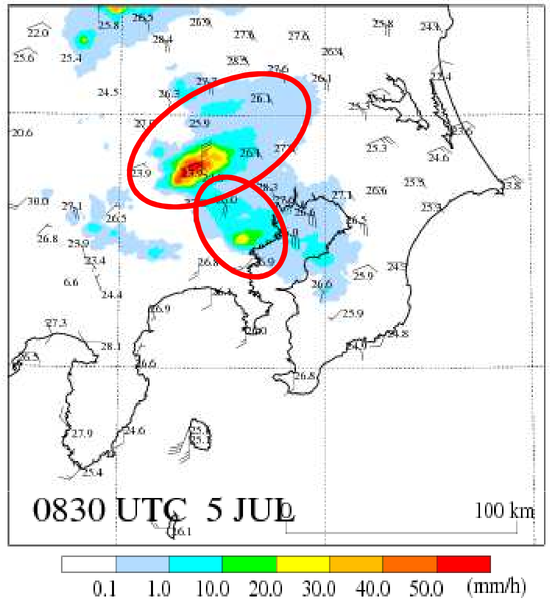
Forecast result (1h accumulated rainfall)



Background



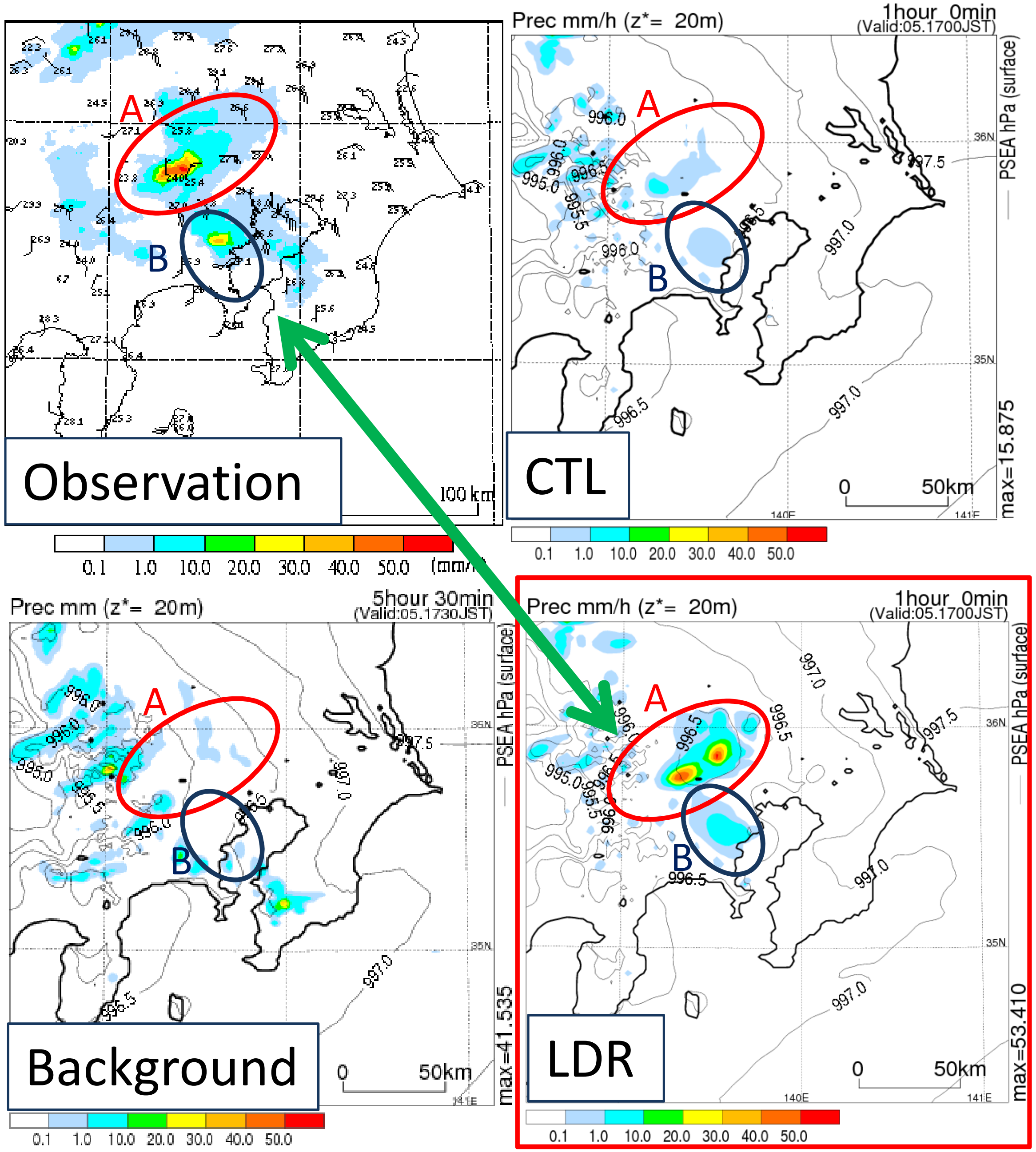
Forecast (FT=1.5h)



Observation

- 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.

1h accumulated rainfall amount at FT=1h

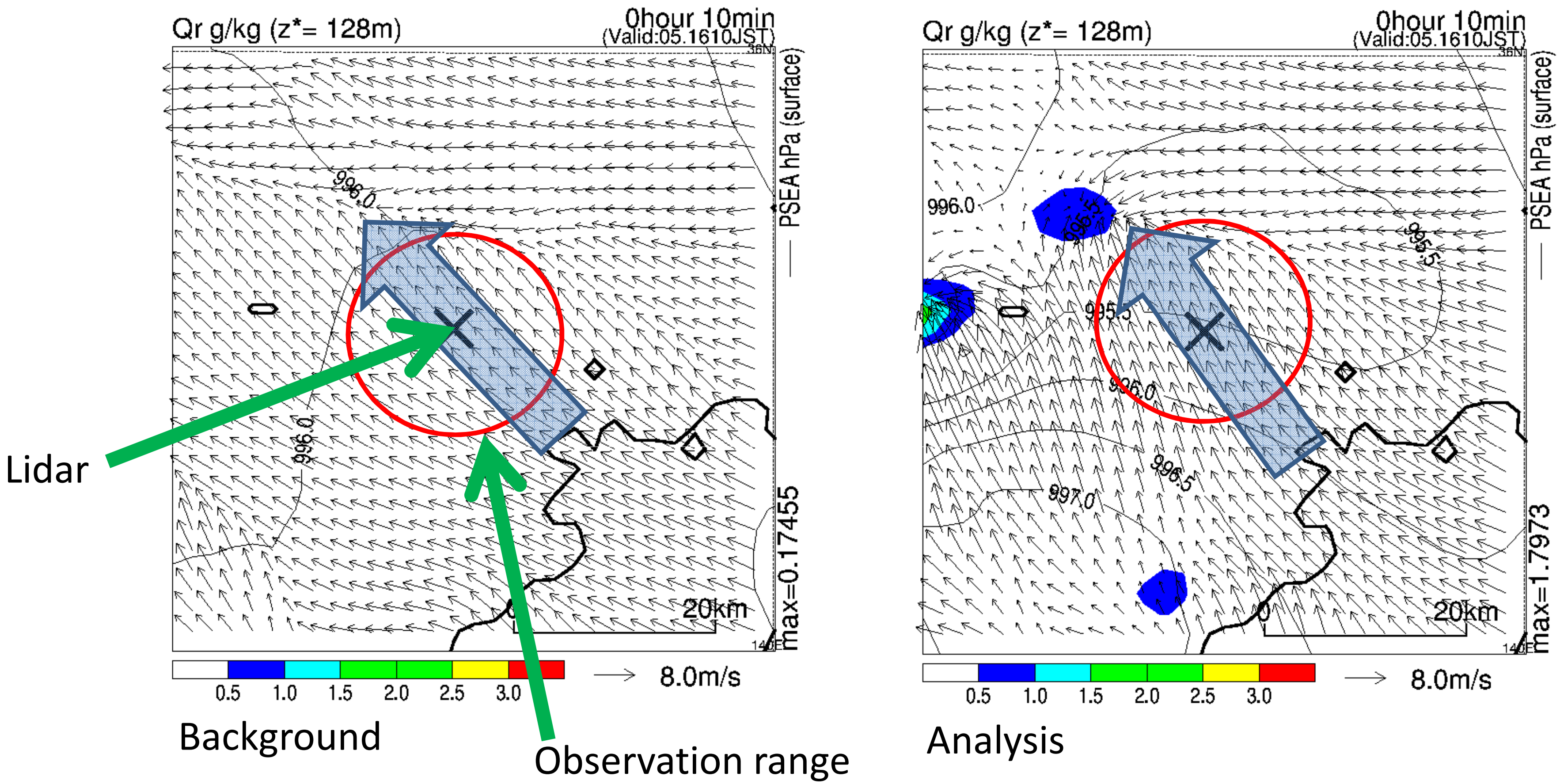


In Background, no strong convective areas.

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

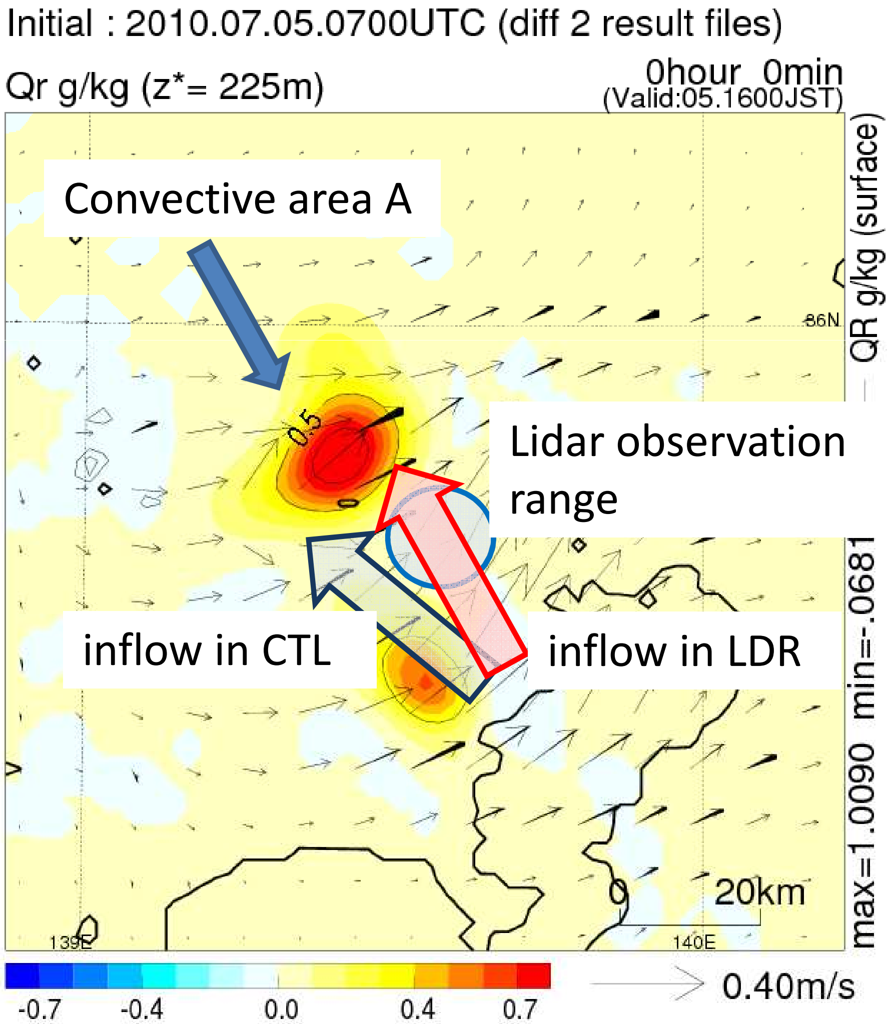


Wind speed becomes slightly faster and wind direction slightly changes to south.
--> Inflow wind to the cumulous and the convergence around the rainfall region are intensified.

Difference of wind vector (LDR – CTL)

z=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 Lidar observation range and on its surrounding area.

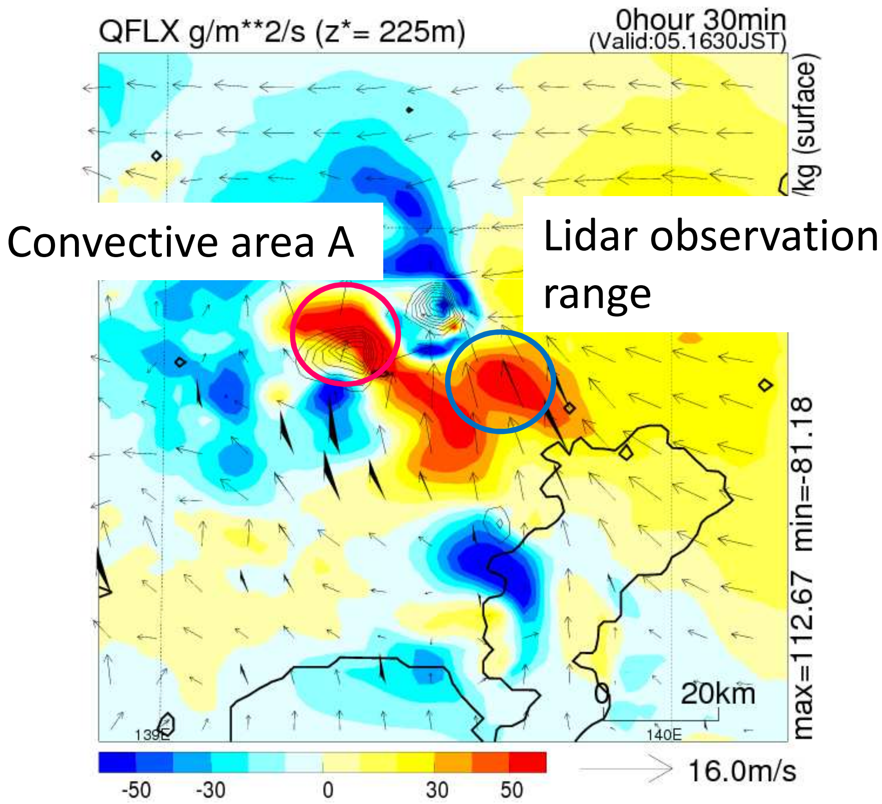
The wind direction of the inflow to the cumulonimbus is changed southerly after the assimilation of Doppler Lidar observations.

→ Effective water vapor transportation

Difference of water vapor flux (LDR - CTL)

z = 225 m, FT=30min

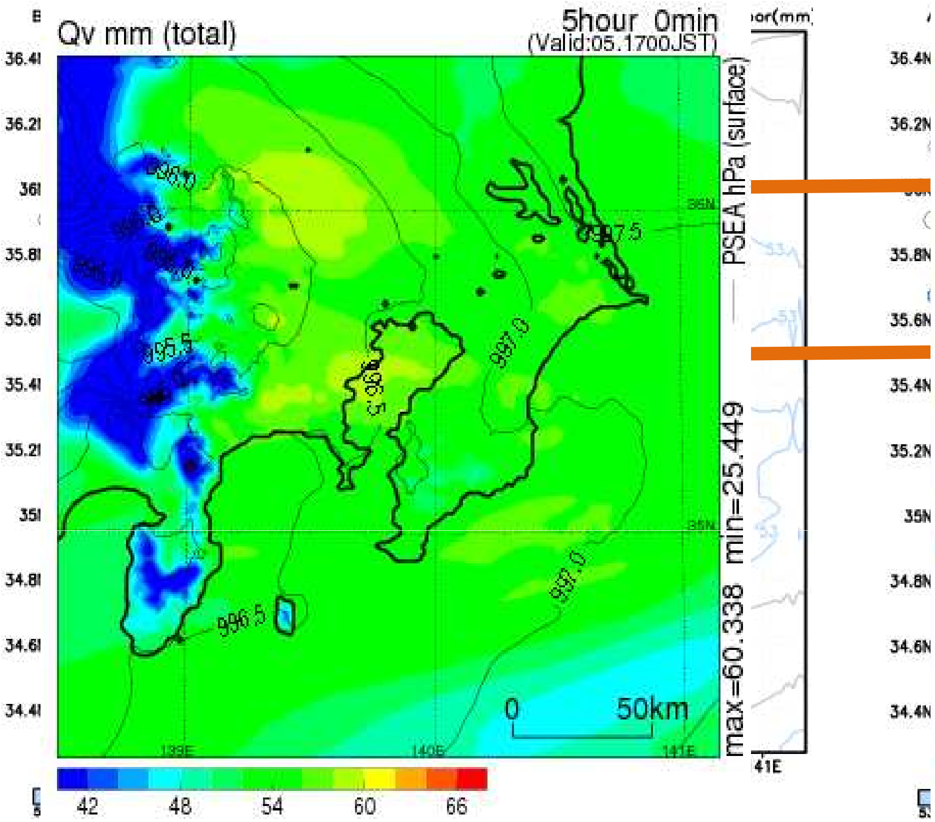
Vectors: Horizontal wind vectors at 225 m height in LDR.
Colored shades: Difference of water vapor flux between LDR and CTL.



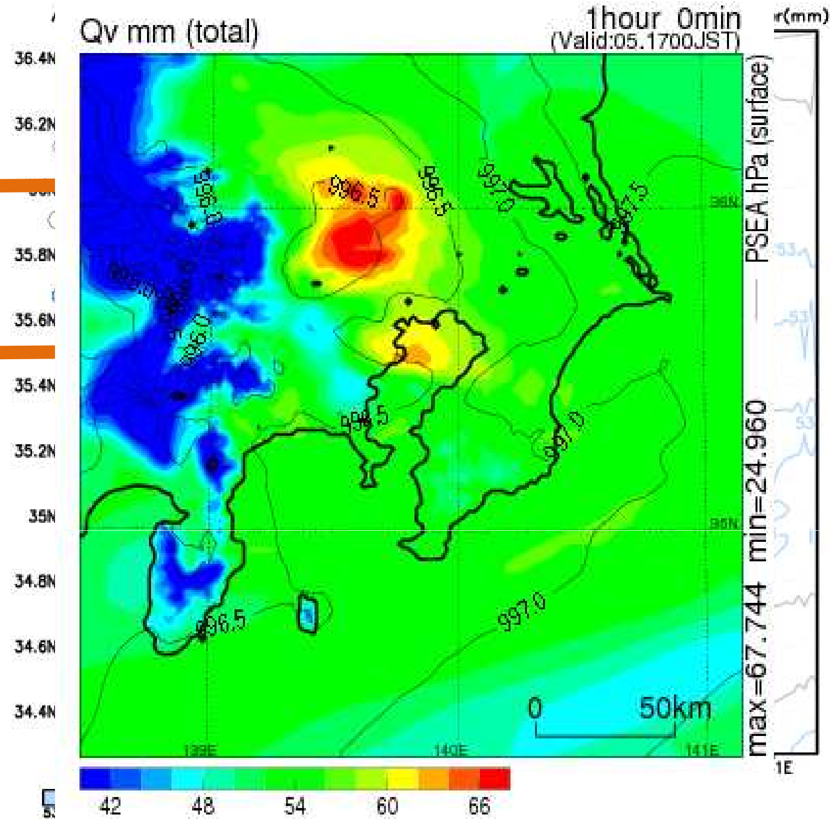
The difference of wind direction provides the difference of water vapor flux.

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



1^{st} guess



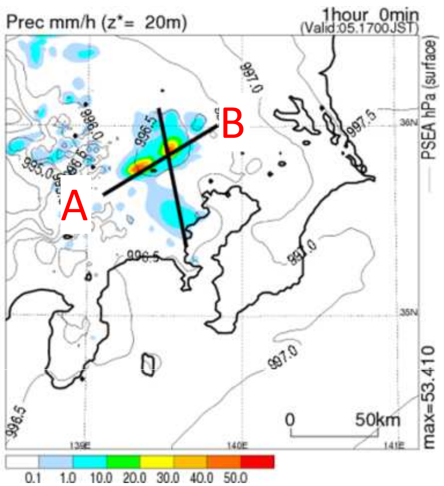
4DVAR analysis

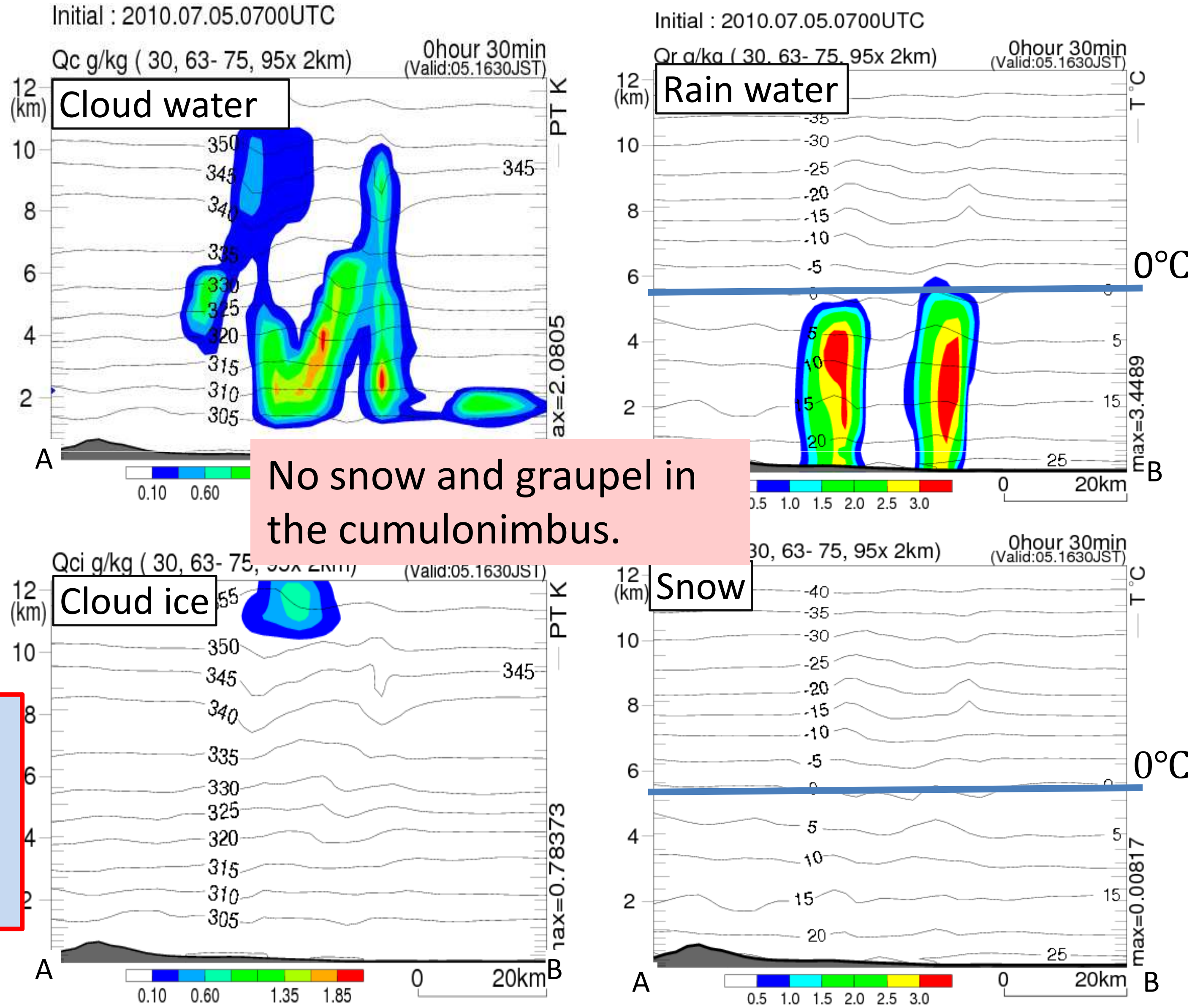
Less humidity distribution is modified. Difference seems small, but one in forecast becomes larger.

Kawabata. (2012)

Analysis of the cumulonimbus in LDR

Vertical cross-section of water substances (FT=30min)





No snow and graupel in the cumulonimbus.

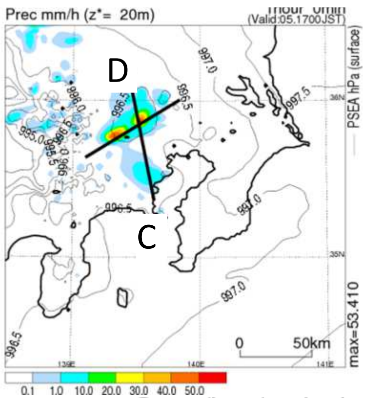
The heavy rainfall was produced without ice phase (warm rain).

Contours : potential

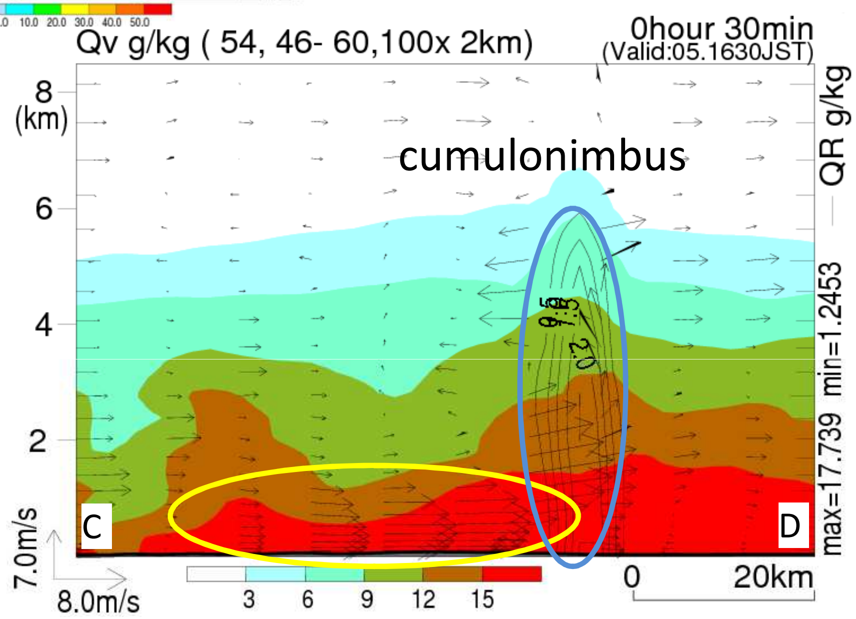
Contours : temperature

Analysis of the cumulonimbus in LDR

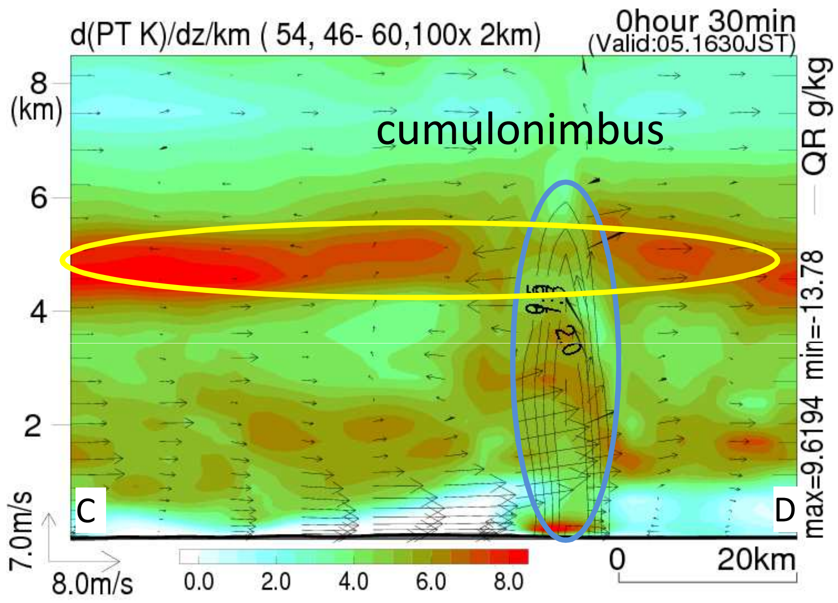
Vertical cross-section of water vapor and stable layer (FT = 30 min)



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



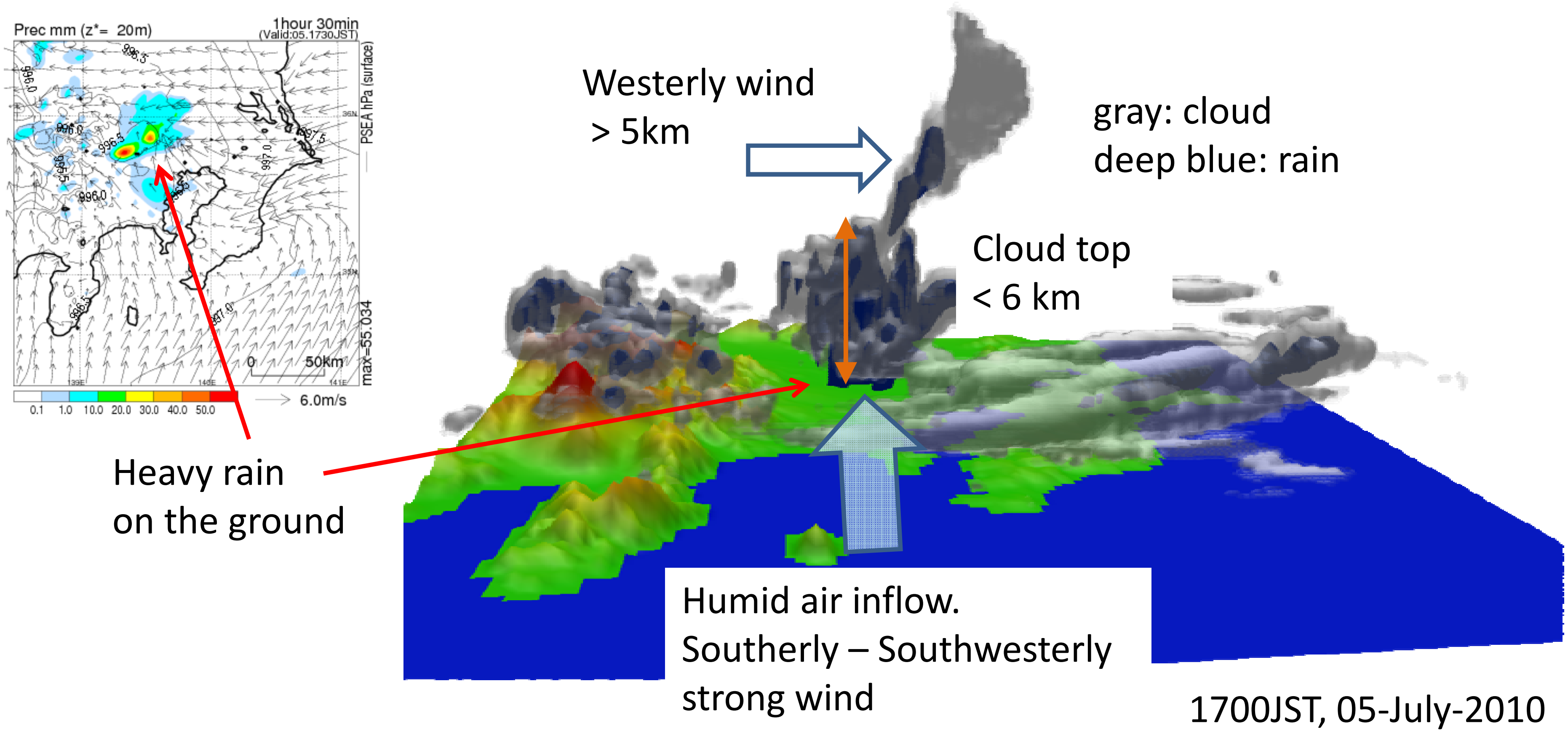
Color shade: dtdz
Contour: mixing ratio of rain water



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



1700JST, 05-July-2010

- 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).