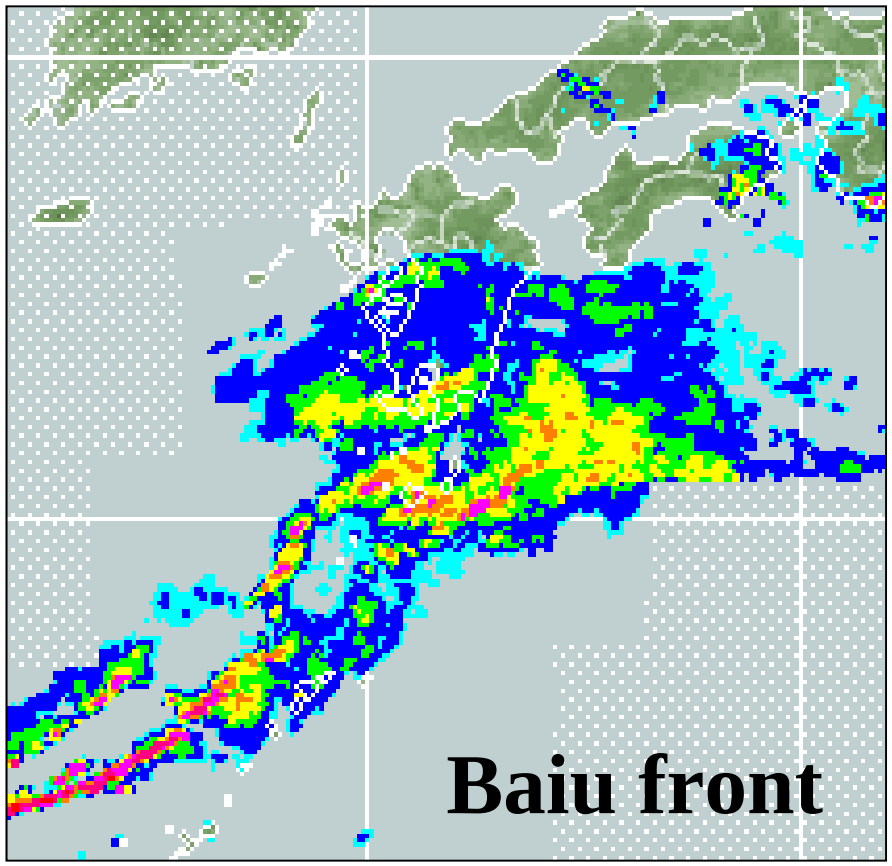
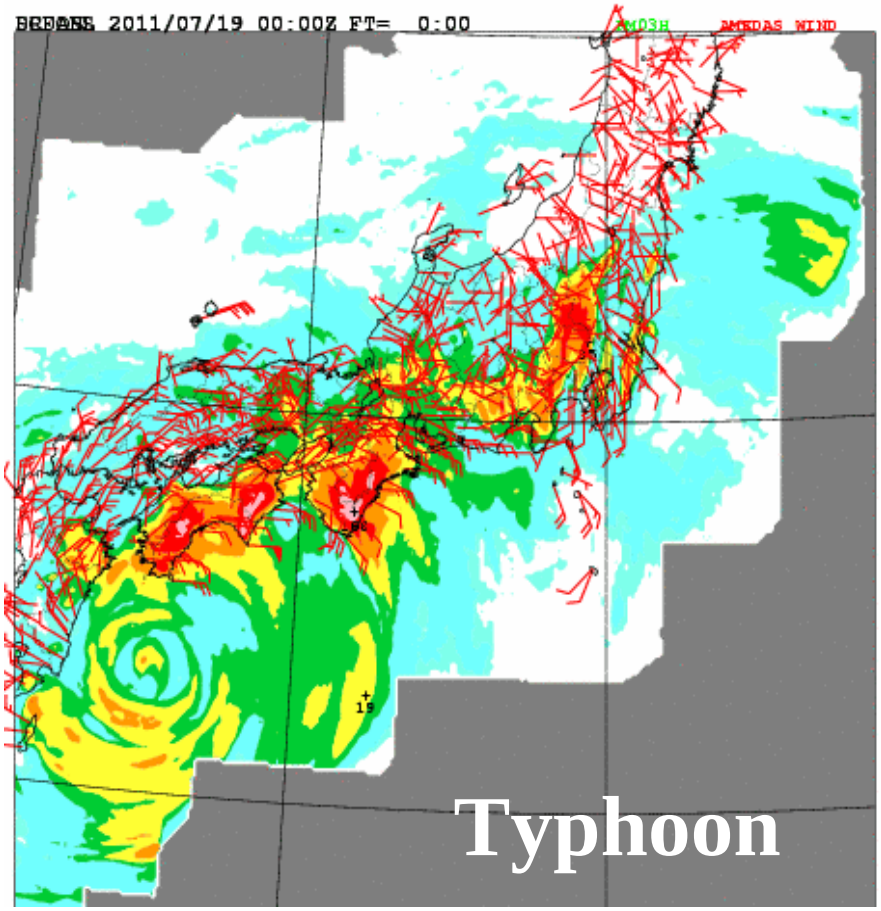
Development of a Two-way Nested LETKF System for Cloud Resolving Model

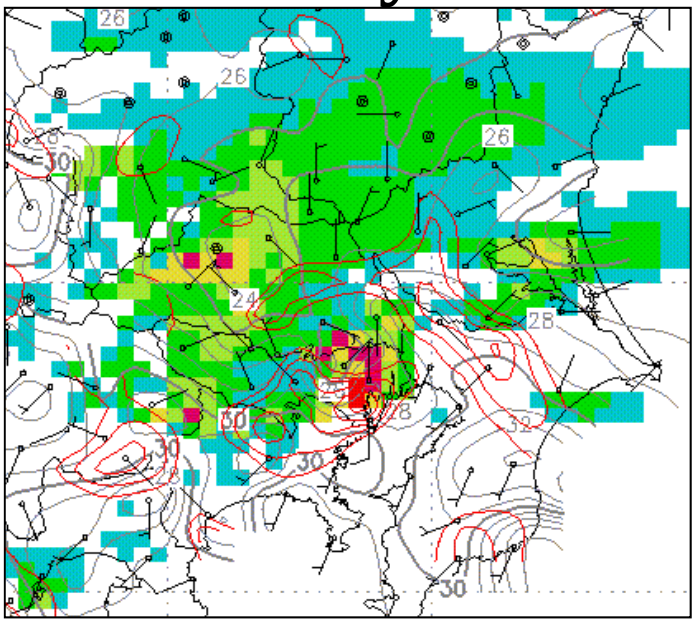
H. Seko, T. Tsuyuki, K. Saito, M. Kunii (JMA/MRI), and T. Miyoshi（RIKEN)

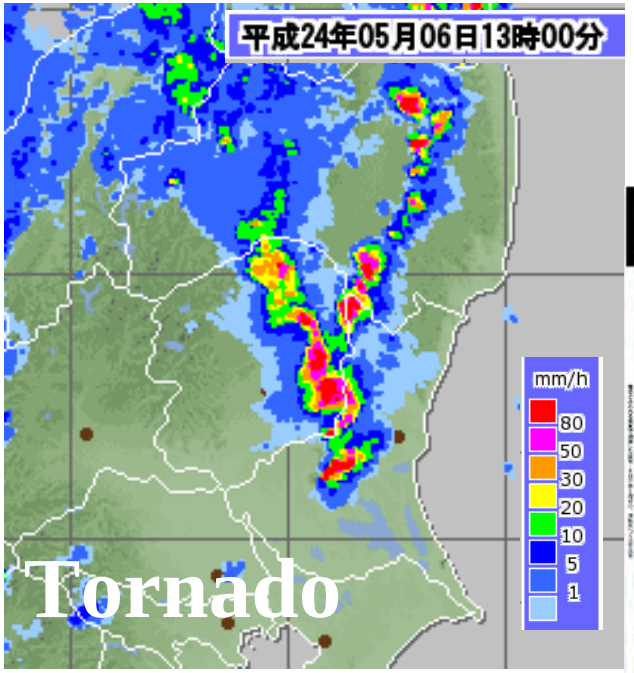




- **Almost every years, heavy rainfalls of Baiu fronts and typhoons cause floods and landslides in Japan.**
- **Predictions of these phenomena are relatively easier because these rainfalls are caused by large scale convergence or topography.**

Local heavy rainfall



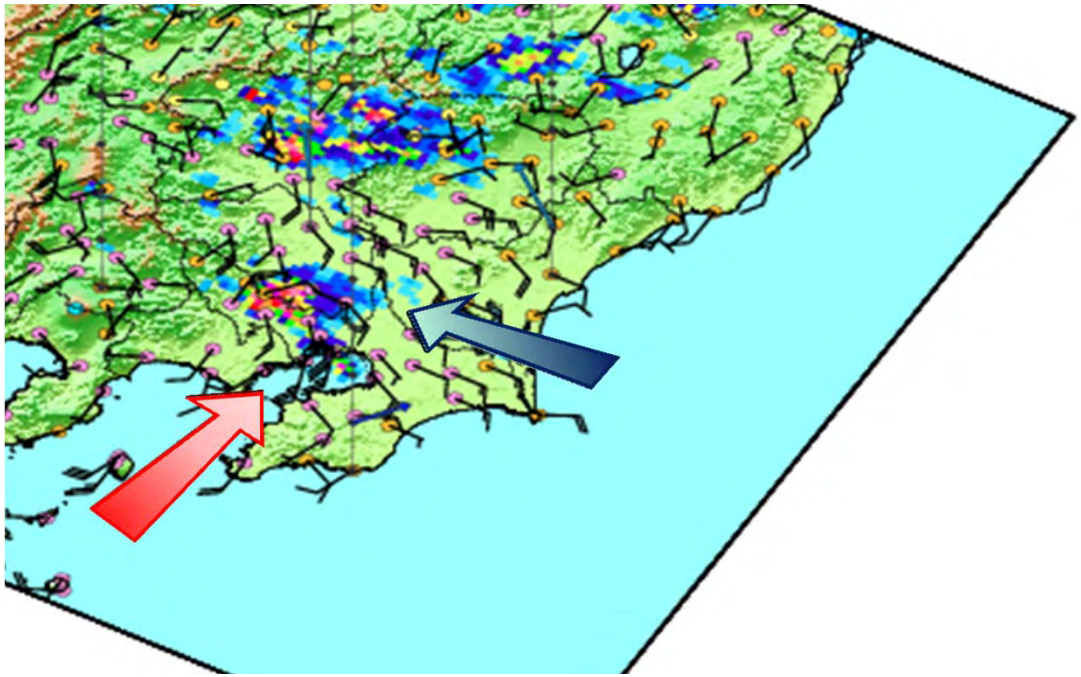


- **Besides Baiu fronts and typhoons, local heavy rainfall and tornados cause disasters.**
- **Predictions of these phenomena are difficult because they are generated in weak convergence. Accuracy of their forecasts should be improved (Data assimilation. Probabilistic forecast)**

→ **Cloud resolving two way nested LETKF system.**

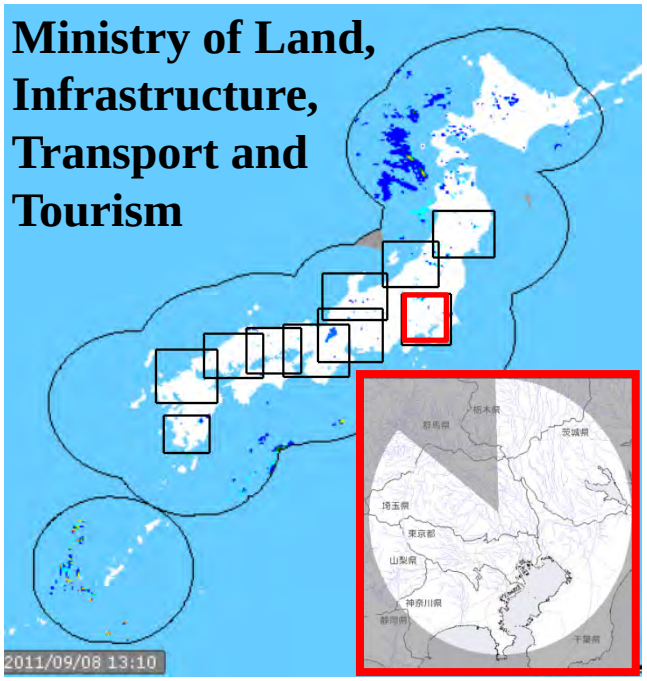
Necessity of a nested assimilation system

- **Local heavy rainfalls cause urban flash floods.**
- **To reproduce local heavy rainfalls, mesoscale environment and convection cells should be reproduced simultaneously by the numerical models with large and small grid intervals.**



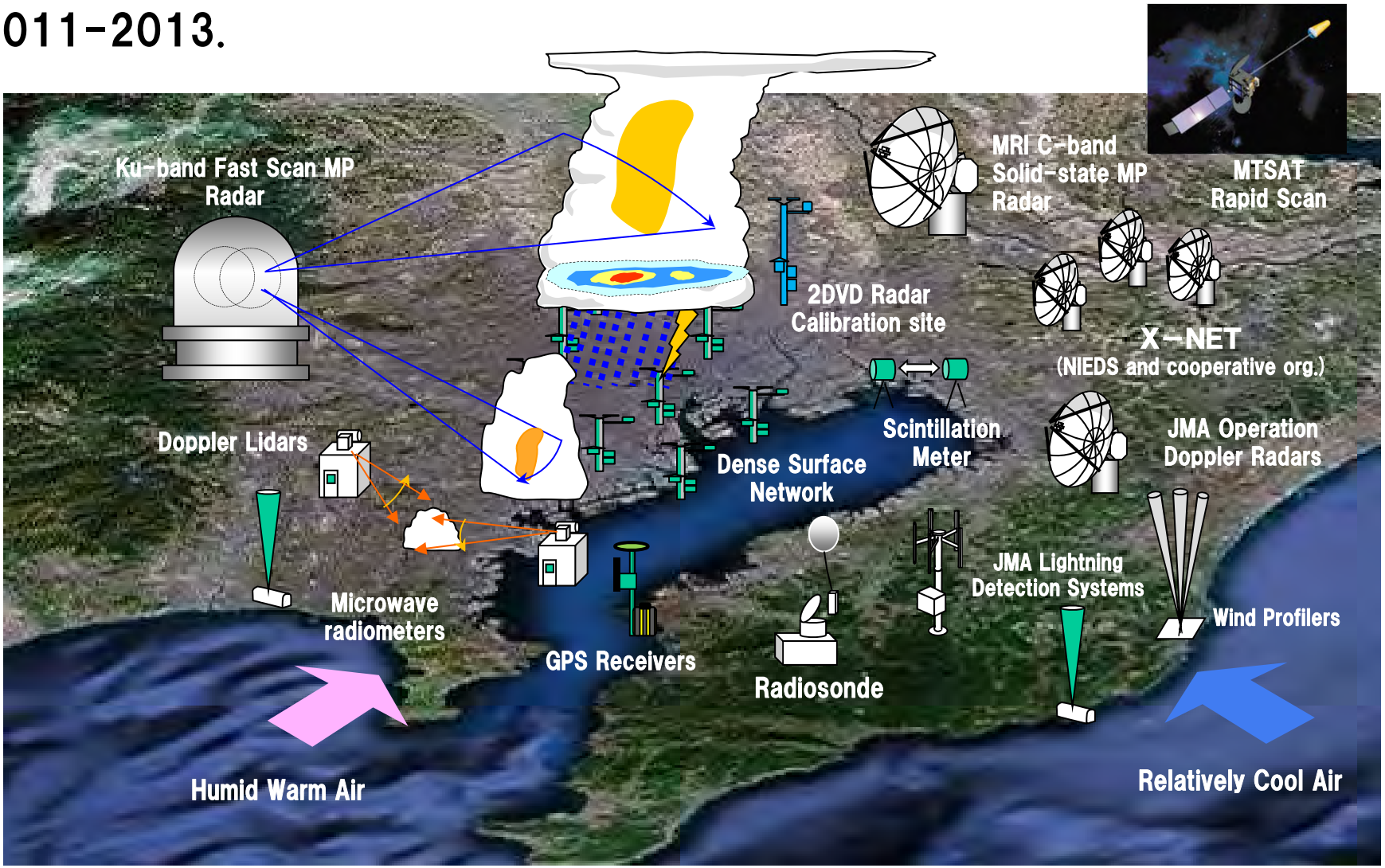
Necessity of a nested assimilation system

- Local heavy rainfalls cause urban flash floods.
- To reproduce local heavy rainfalls, mesoscale environment and convection cells should be reproduced simultaneously by the numerical models with large and small grid intervals**.**
- **An X-band radar network and a GPS network have been established in Japan. This high resolution data can be used as assimilation data to improve the intensity and positions of convection cells.**



Field Experiments (TOMACS)

A field campaign in the Tokyo metropolitan area with a dense observation network is being performed by MRI and thirteen groups in the summers of 2011-2013.

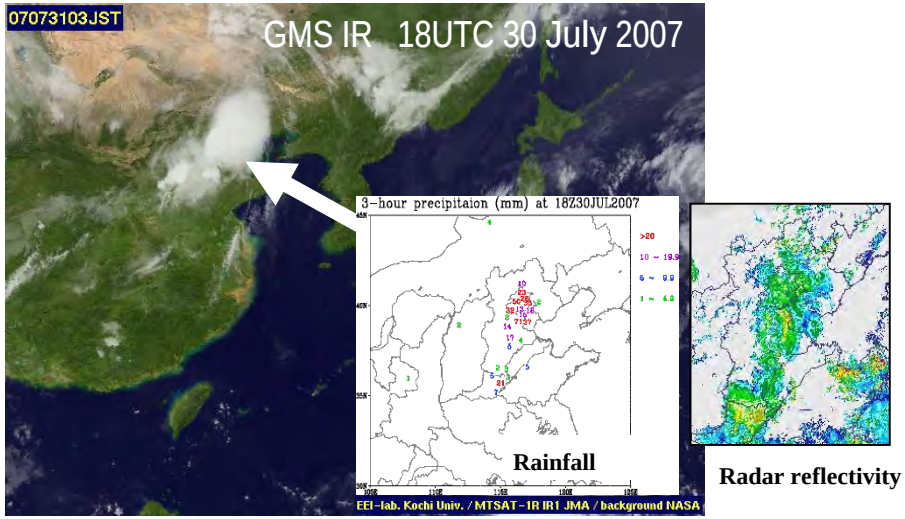


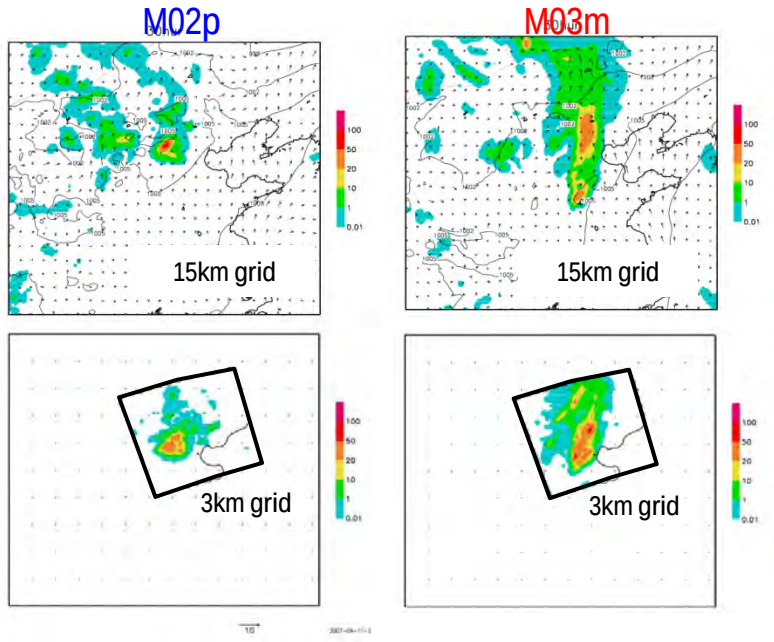
Necessity of a nested assimilation system

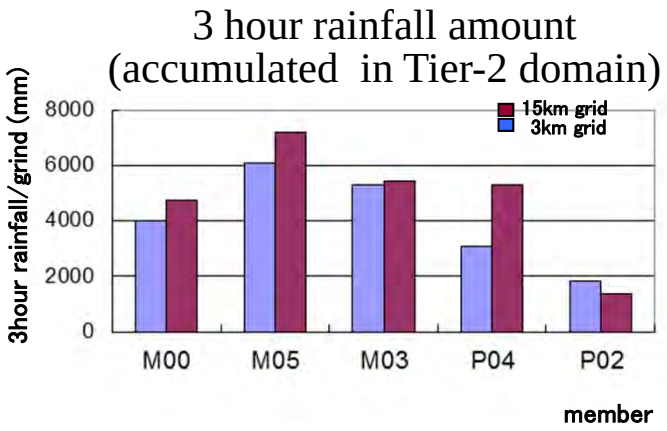
- Local heavy rainfalls cause urban flash floods.
- To reproduce local heavy rainfalls, mesoscale environment and convection cells should be reproduced simultaneously by the numerical models with large and small grid intervals.
- An X-band radar network and a GPS network have been established in Japan. This high resolution data can be used as assimilation data to improve the intensity and positions of convection cells.
- **LETKF (Local Ensemble Transform Kalman Filter; Miyoshi and Aranami, 2006) was used in this study. To reflect the results of the inner LETKF in the outer model, a two-way nested system has been developed.**

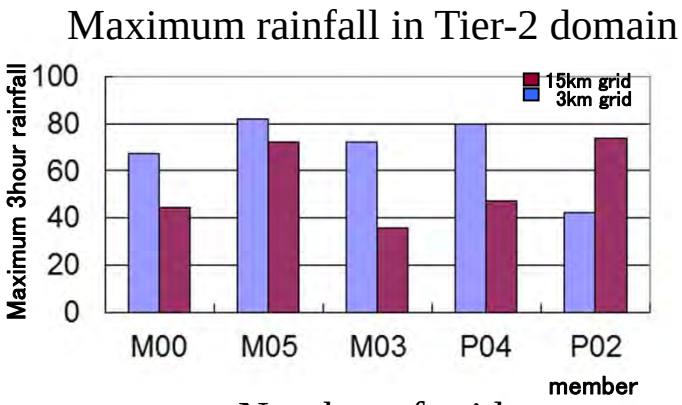
Necessity of a nested assimilation system

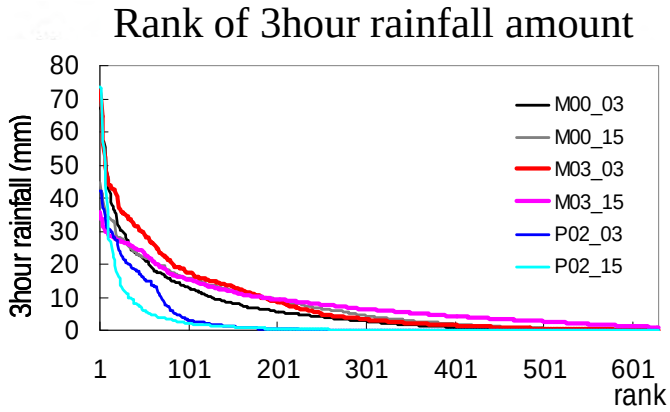
- Thunderstorm occurred on 31st July 2007, which was one of targets of B08RDP Tier2 experiments was reproduced by NHM.
- Rainfall system extending north-south direction passed Beijing City and 3-hour rainfall of 70 mm was observed there.
- Rainfall intensity and rainfall amount were reproduced by the NHM with grid interval of 2km (Tier2). Initial and boundary conditions of Tier-2 were produced from the output of the NHM with grid interval of 15km (Tier-1).
- Rainfall intensity and rainfall amount with the grid interval of 15km were produced from outputs of 2km, and compared with the results of Tier1.

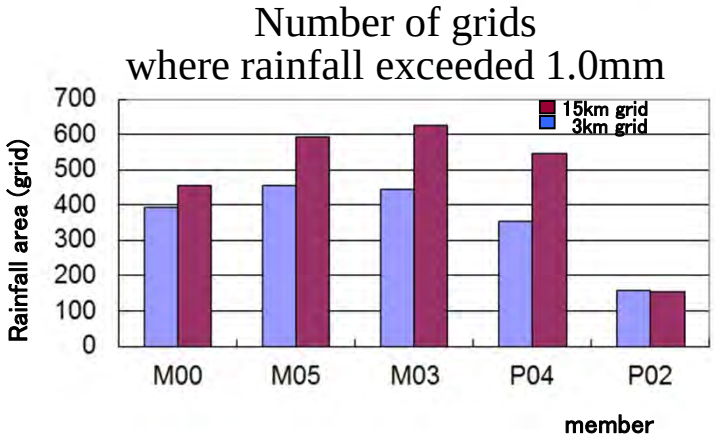






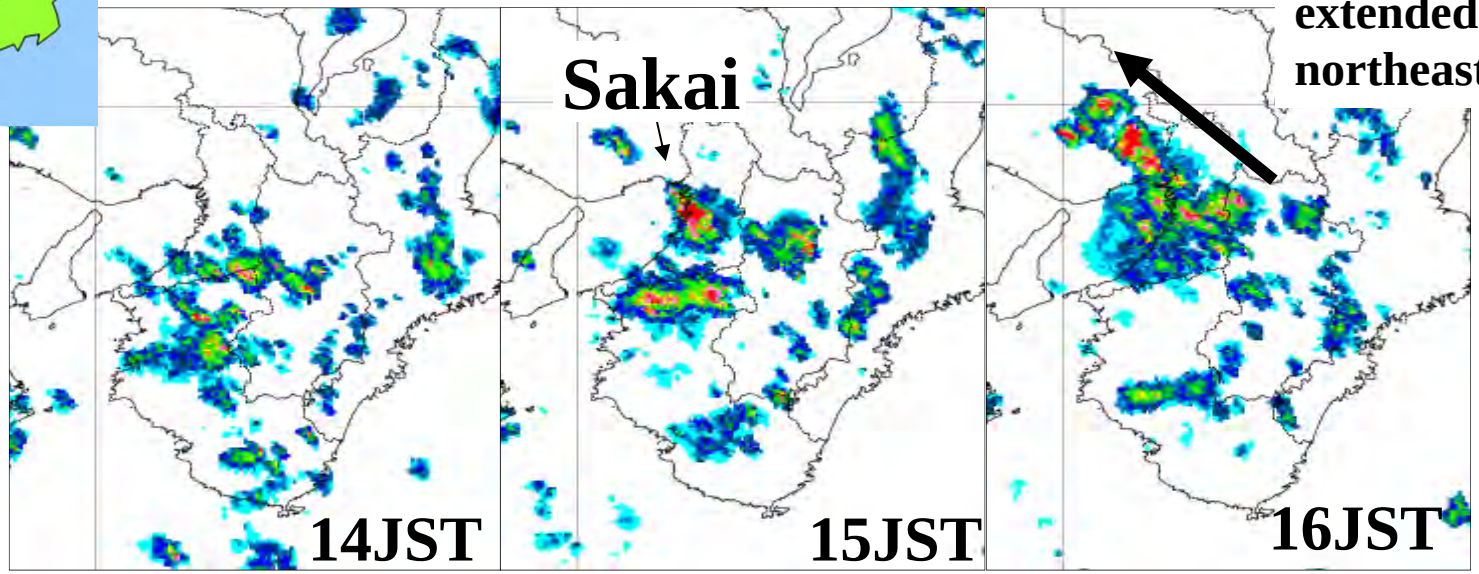






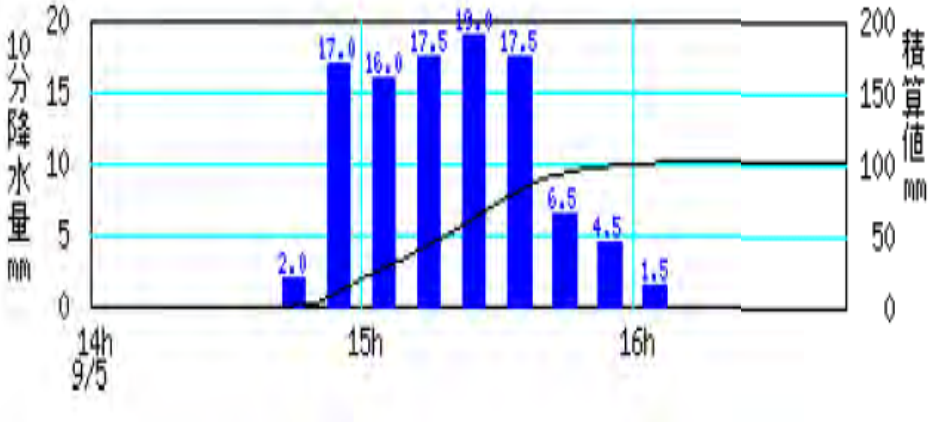
- Except P02, rainfall amounts of Tier-1（15km） were larger than those of Tier-2（km）.
- Maximum of rainfalls of Tier-2（2km） was larger than those of Tier-1（15km）.
- Grid numbers where rainfall exceeds1.0mm of Tier-1（15km）were wider those of Tier-2（2km）.
- Histogram indicates that rainfall was more concentrated in Tier-2（2km）.
- Rainfall amounts and intensities of Tier-2 (2km) can not be simply estimated from those of Tier-1（15km）.

Sakai-city intense rainfall event on 5th Sep. 2008

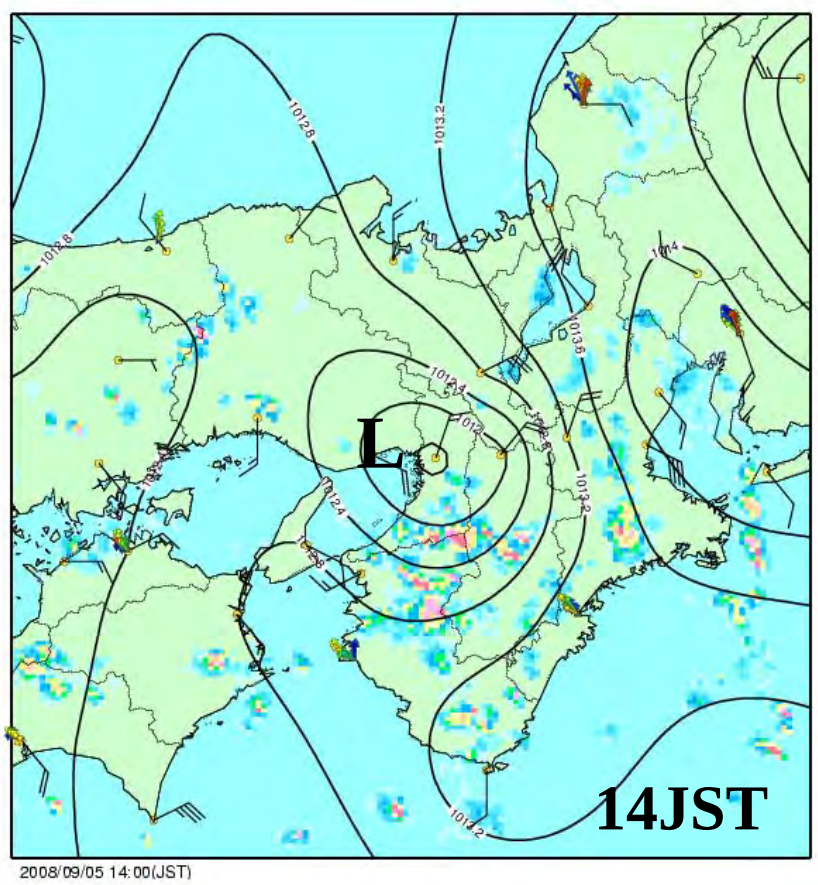


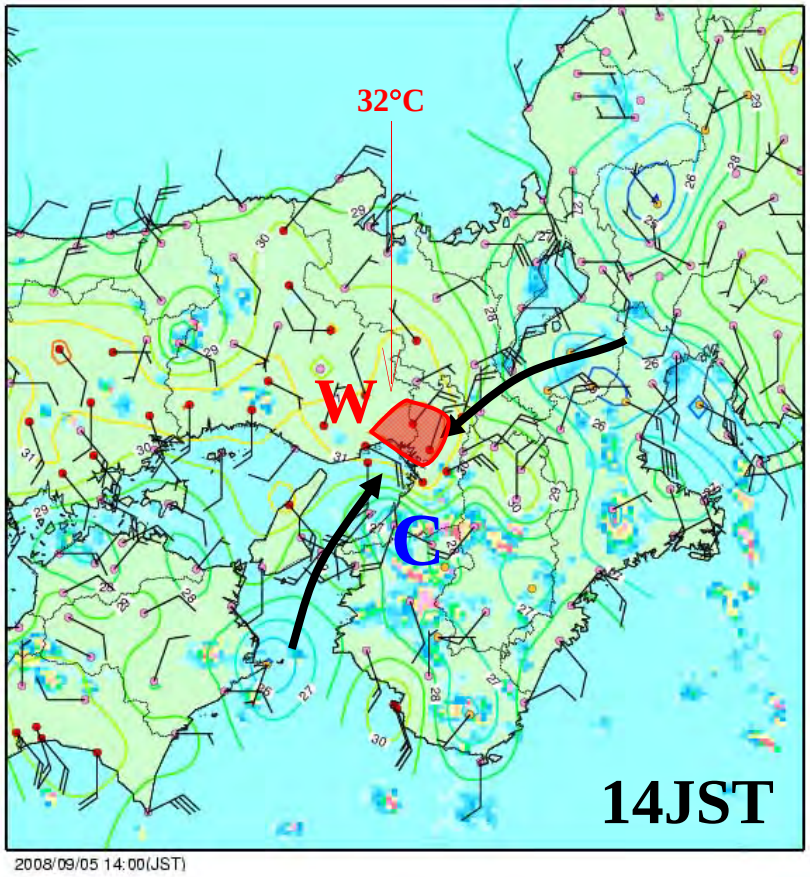
Rainfall region extended northeastward

Echo distribution observed by convectional radars (5th Sep. 2008)



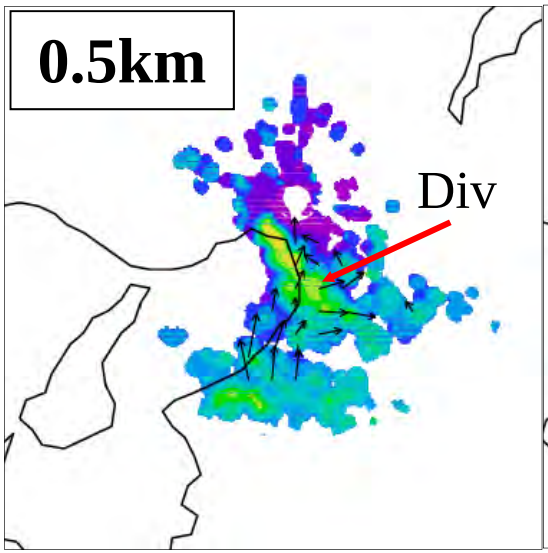
Ten minutes rainfall amounts from 14 JST to 17 JST at Sakai-city.

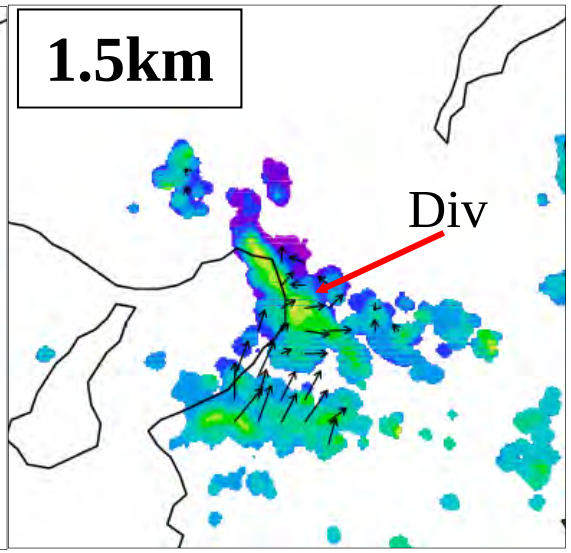


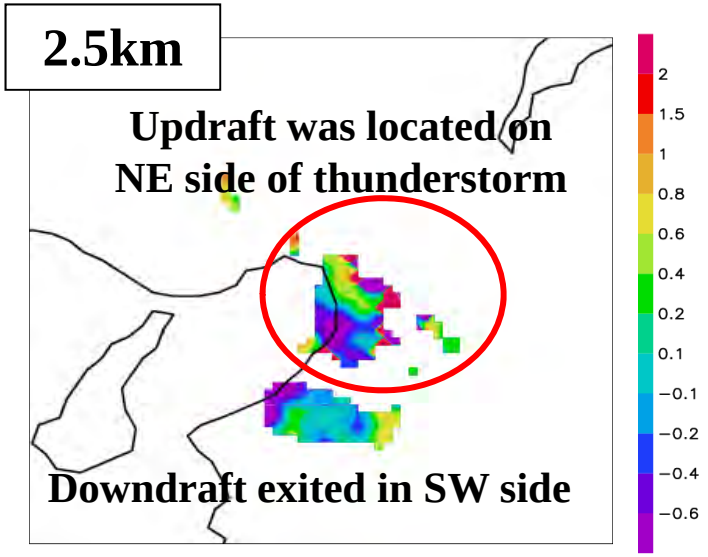


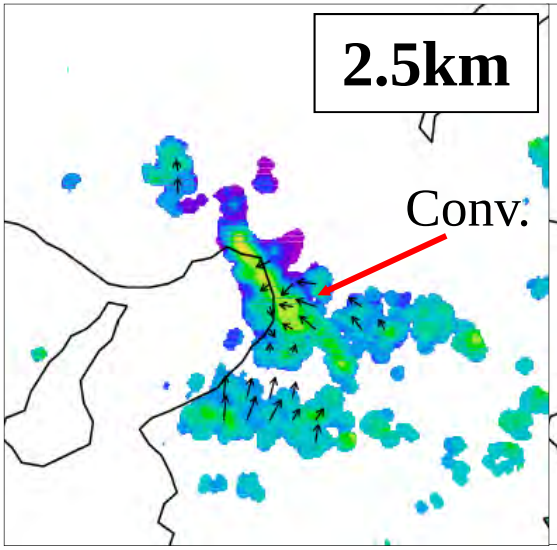
- There was a high temperature area at Osaka and a thermodynamic low system was generated here.
- A northeasterly flow and a southerly flow were converged at Osaka Plain.

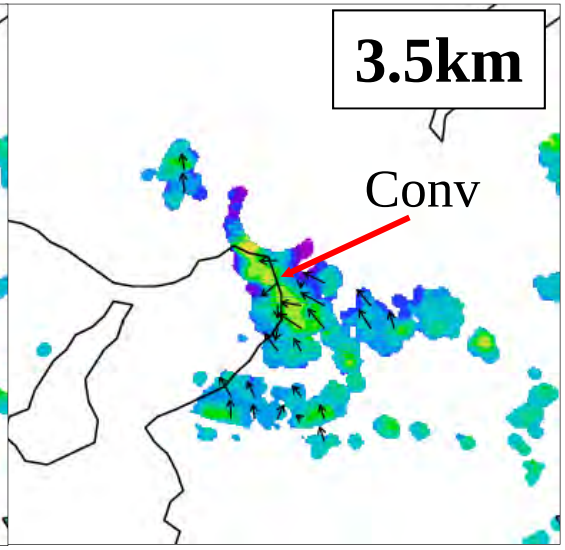
Airflow Structure of heavy rainfall

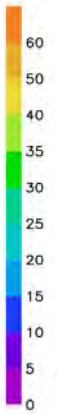


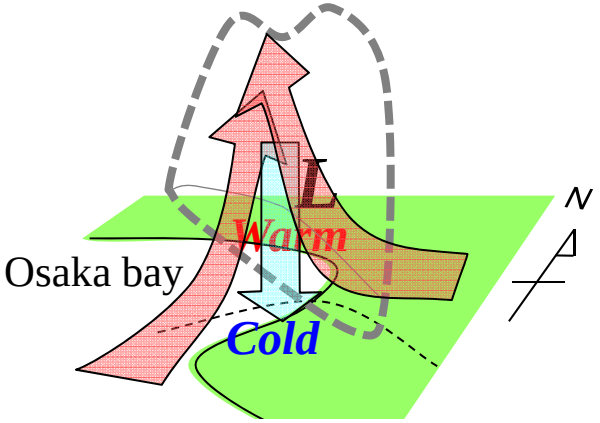








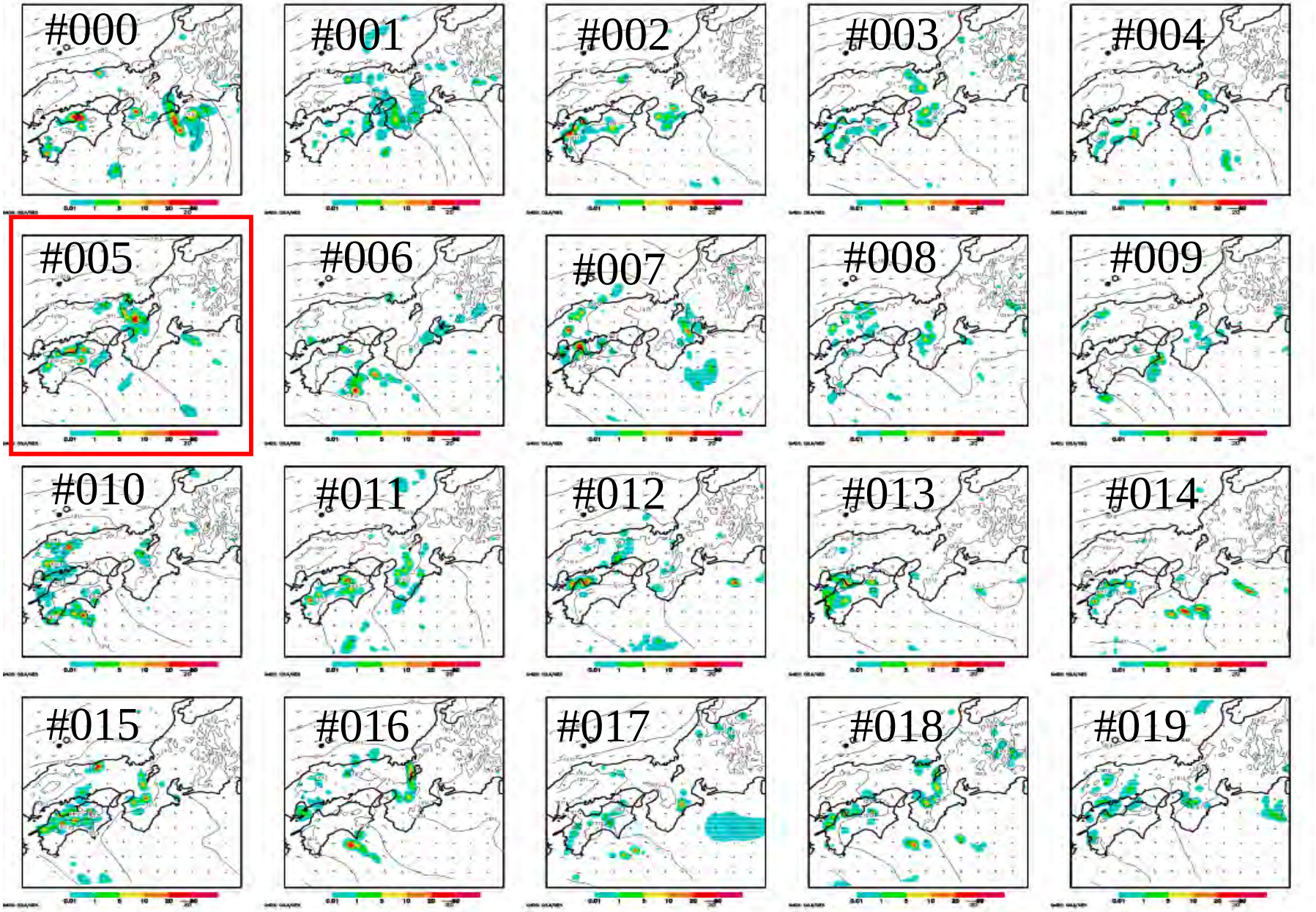




Schematic illustration of airflow structure

(Left) Horizontal wind at 1520JST obtained by Dual analysis from Osaka and Kanku radar data. (Right) Vertical wind distribution at 1520JST.

Results of Single LETKF (5km-NHM)



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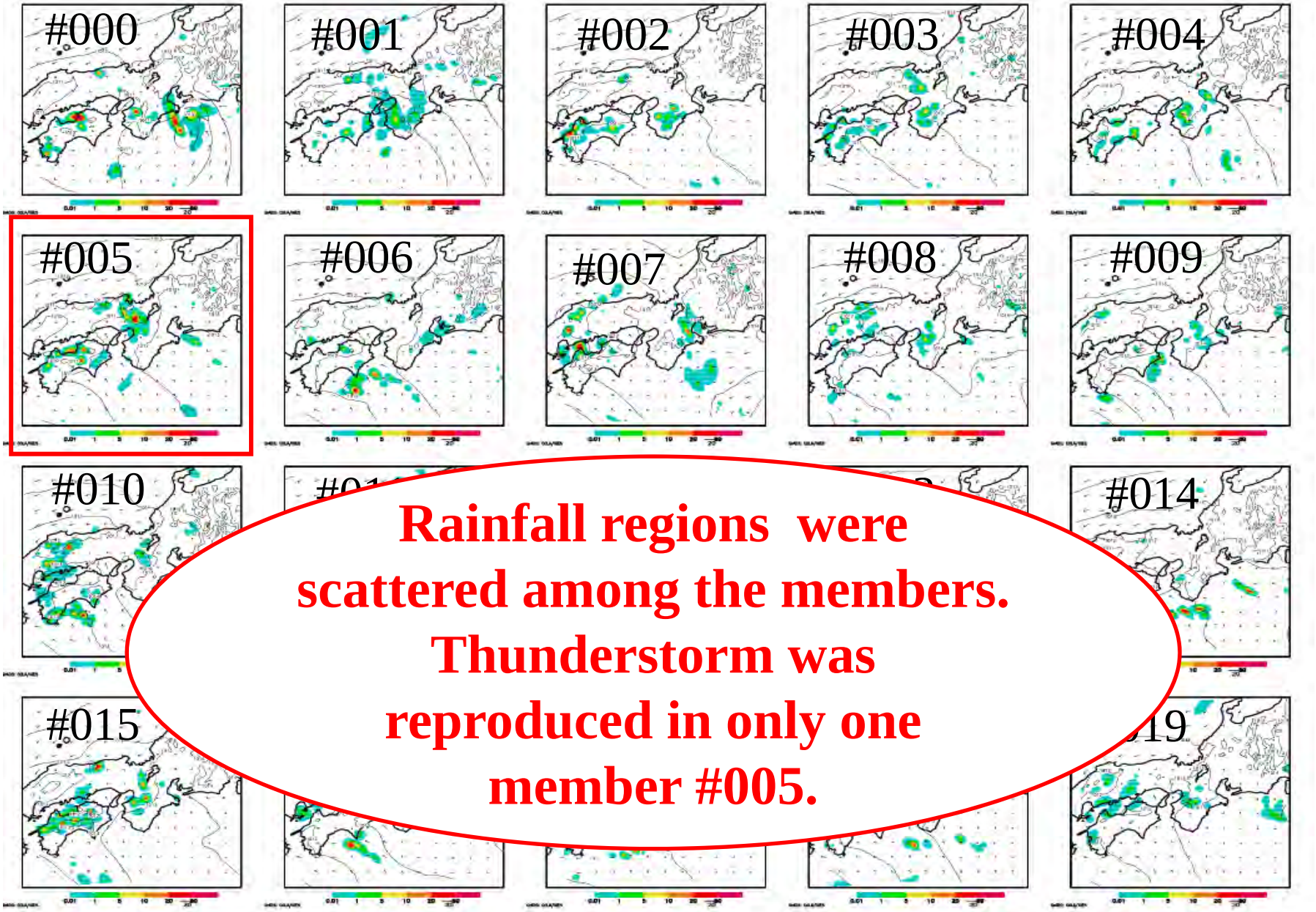
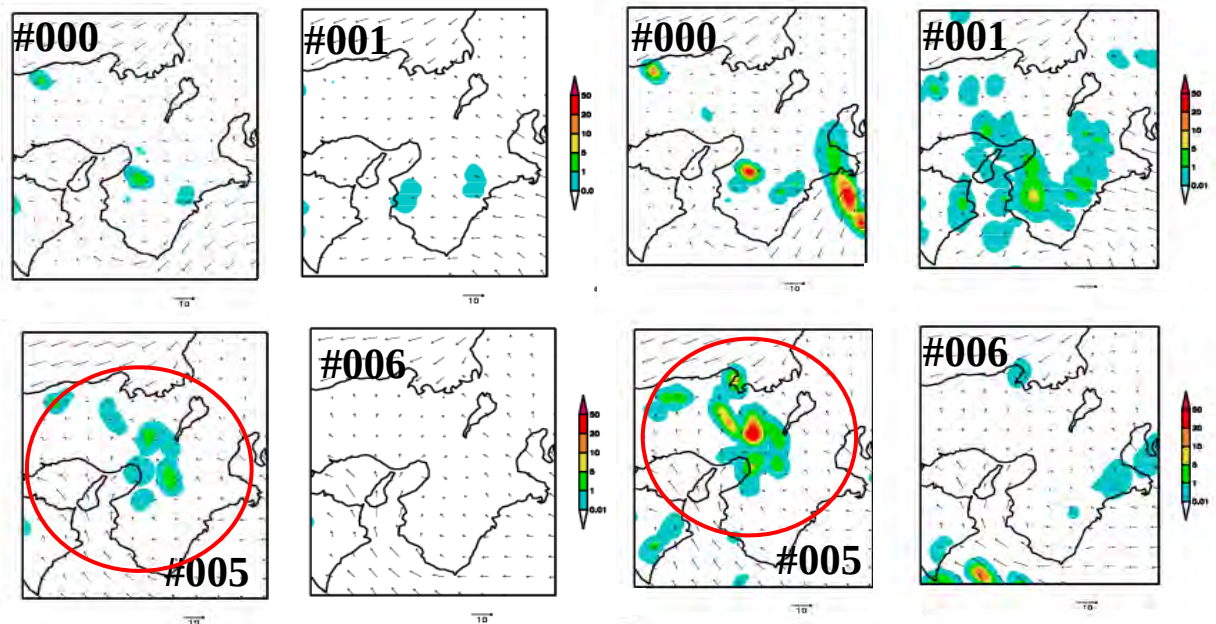


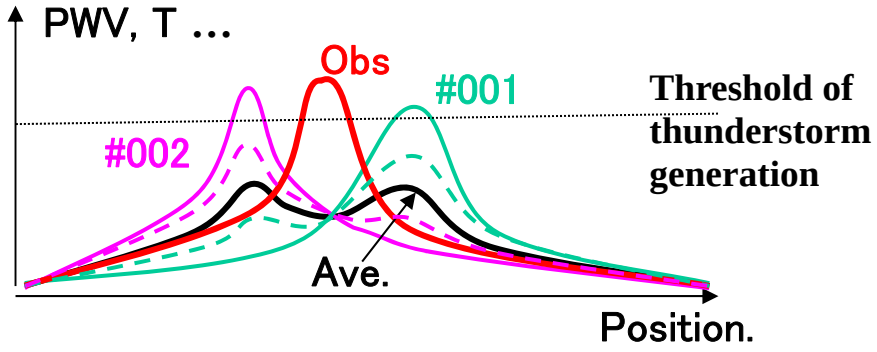
Experiments with changing amplitudes of deviations



$RMS_{max\_}T_{surf}$=7.4K→5K

$RMS_{max\_}T_{surf}$=7.4K→7.4K

Reason why thunderstorm was not reproduced



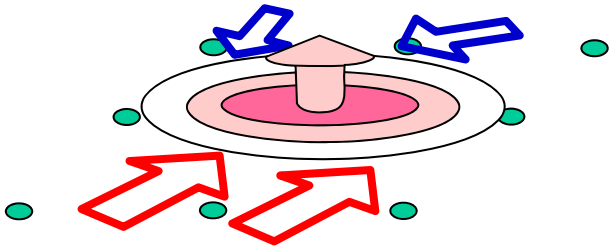
Position of thunderstorm was not reproduced by changing deviation amplitude.

More assimilation data is needed

NHM-3DVar（JNoVA0）

(Miyoshi ,2003,Seko 2008)

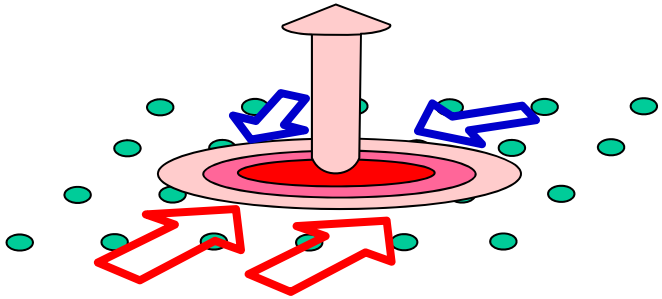
Assimilation of Radial wind data



LETKF

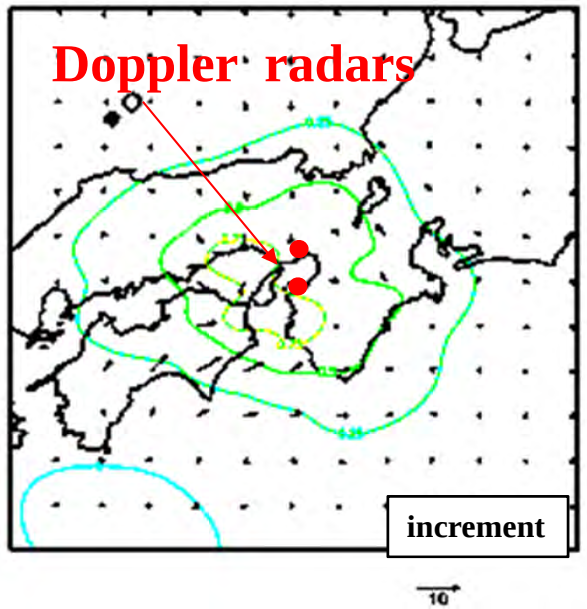
Grid interval is too coarse

⇒updraft is weak



NHM-3DVar

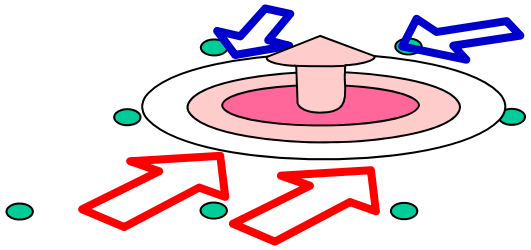
Updraft is modified by assimilation of Doppler radar data



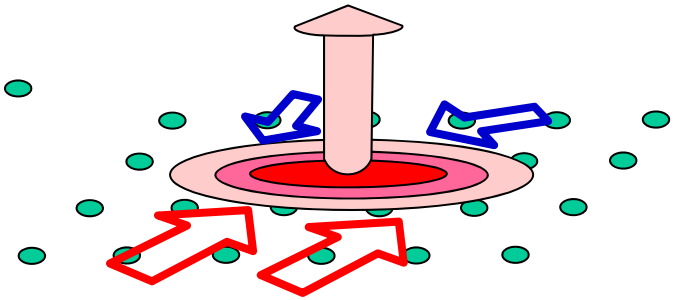
Increment of surface temperature and horizontal wind

When Doppler radar data was assimilated, initial convergence was intensified.

Assimilation of Radial wind data

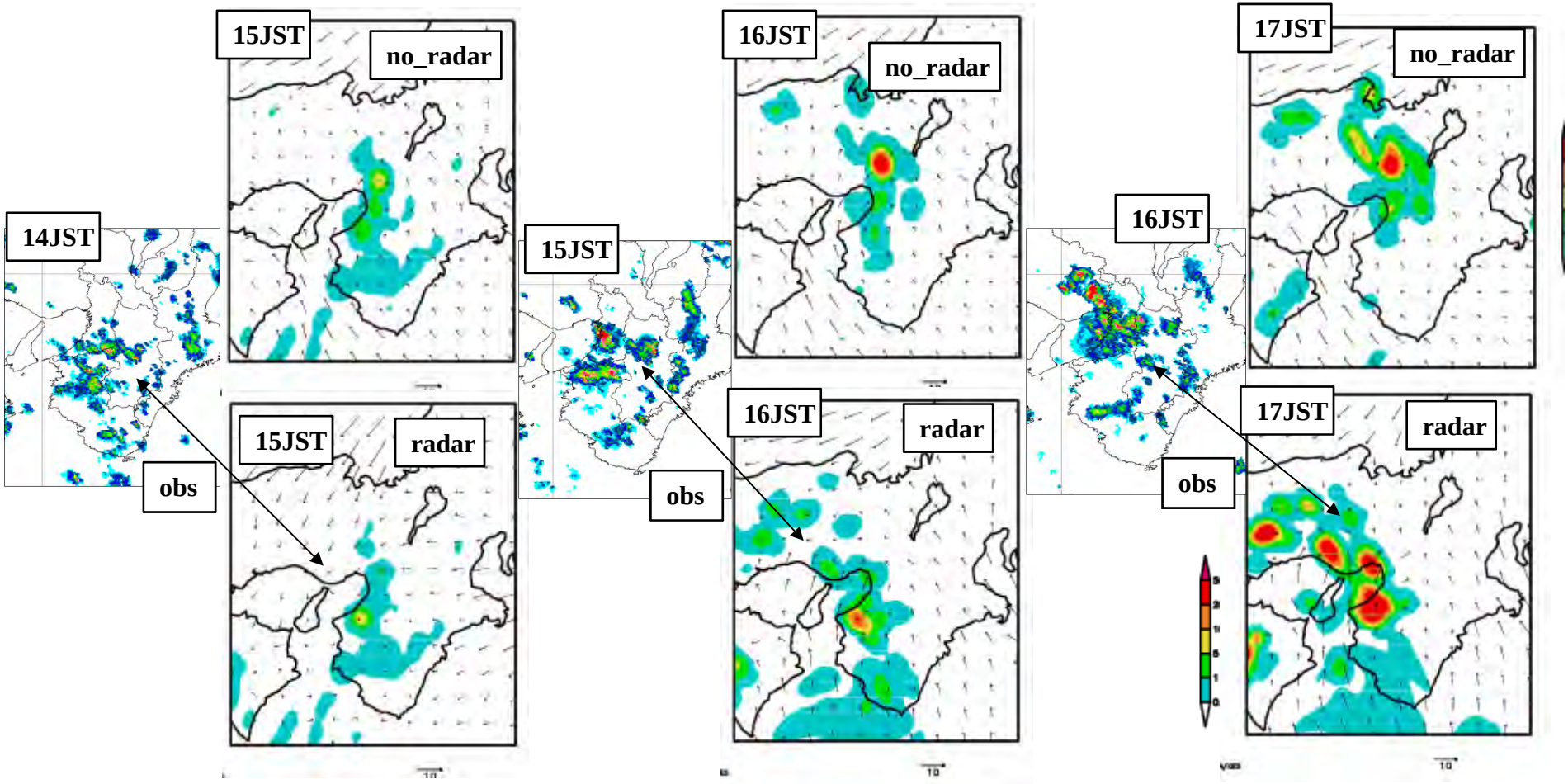


LETKF

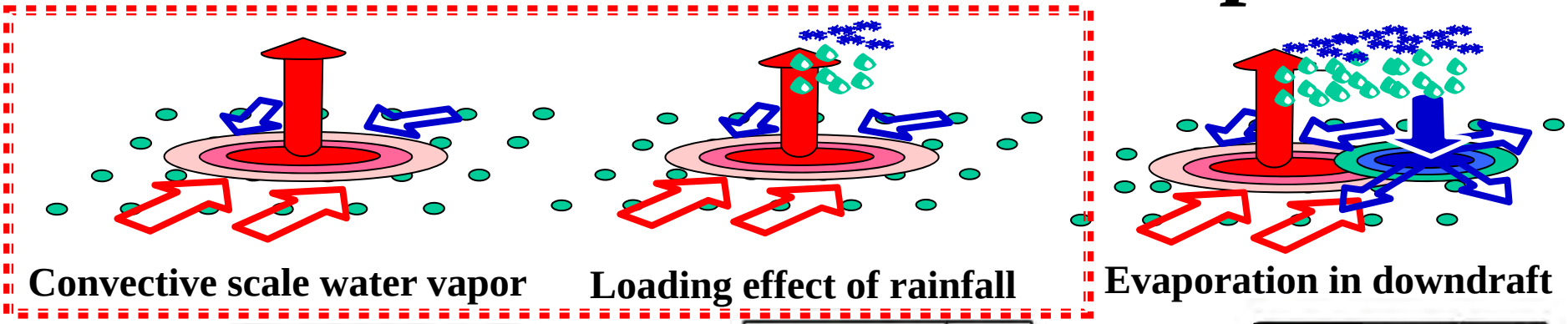


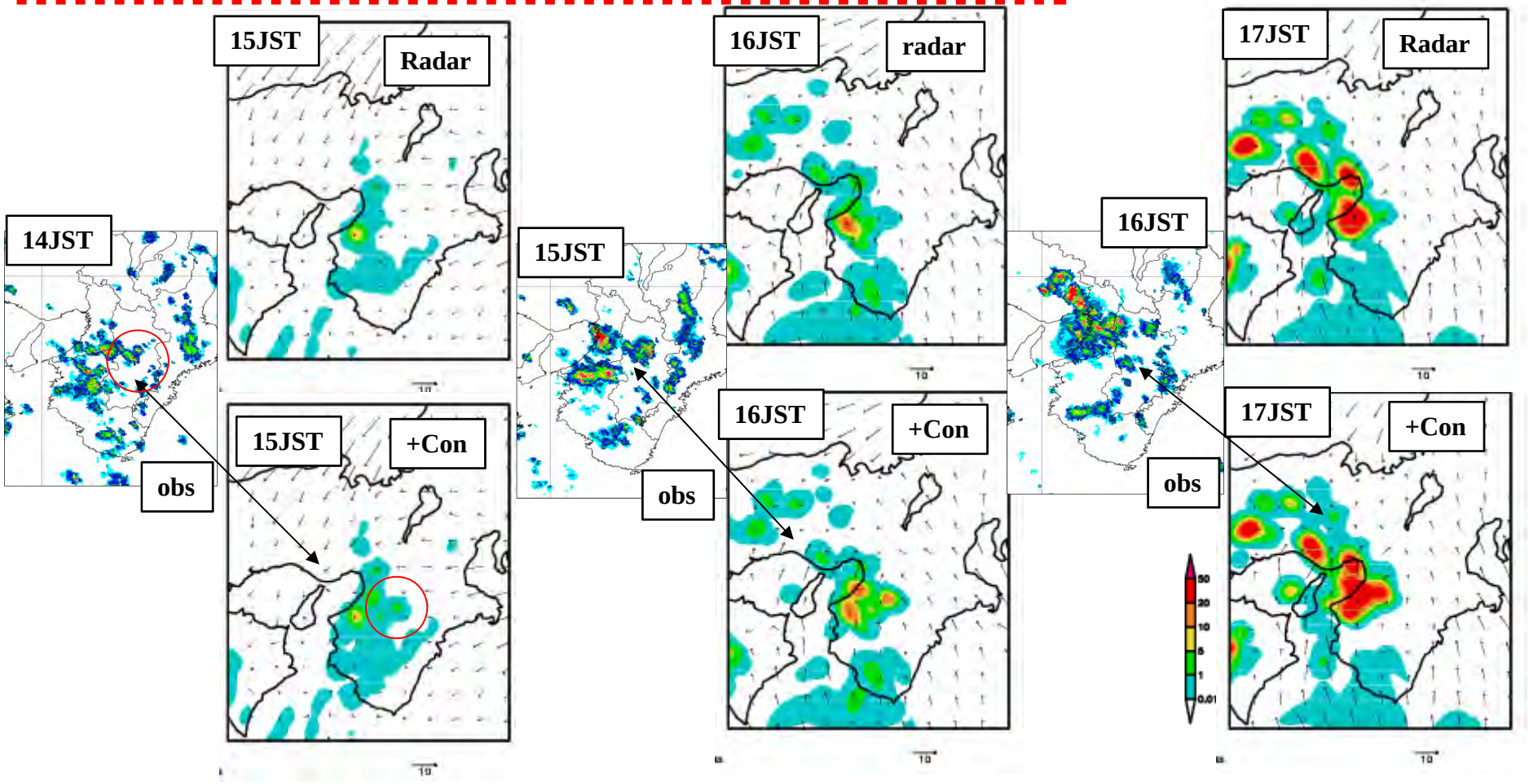
NHM-3DVar

When Doppler radar data was assimilated, the location of local heavy rainfall was improved.

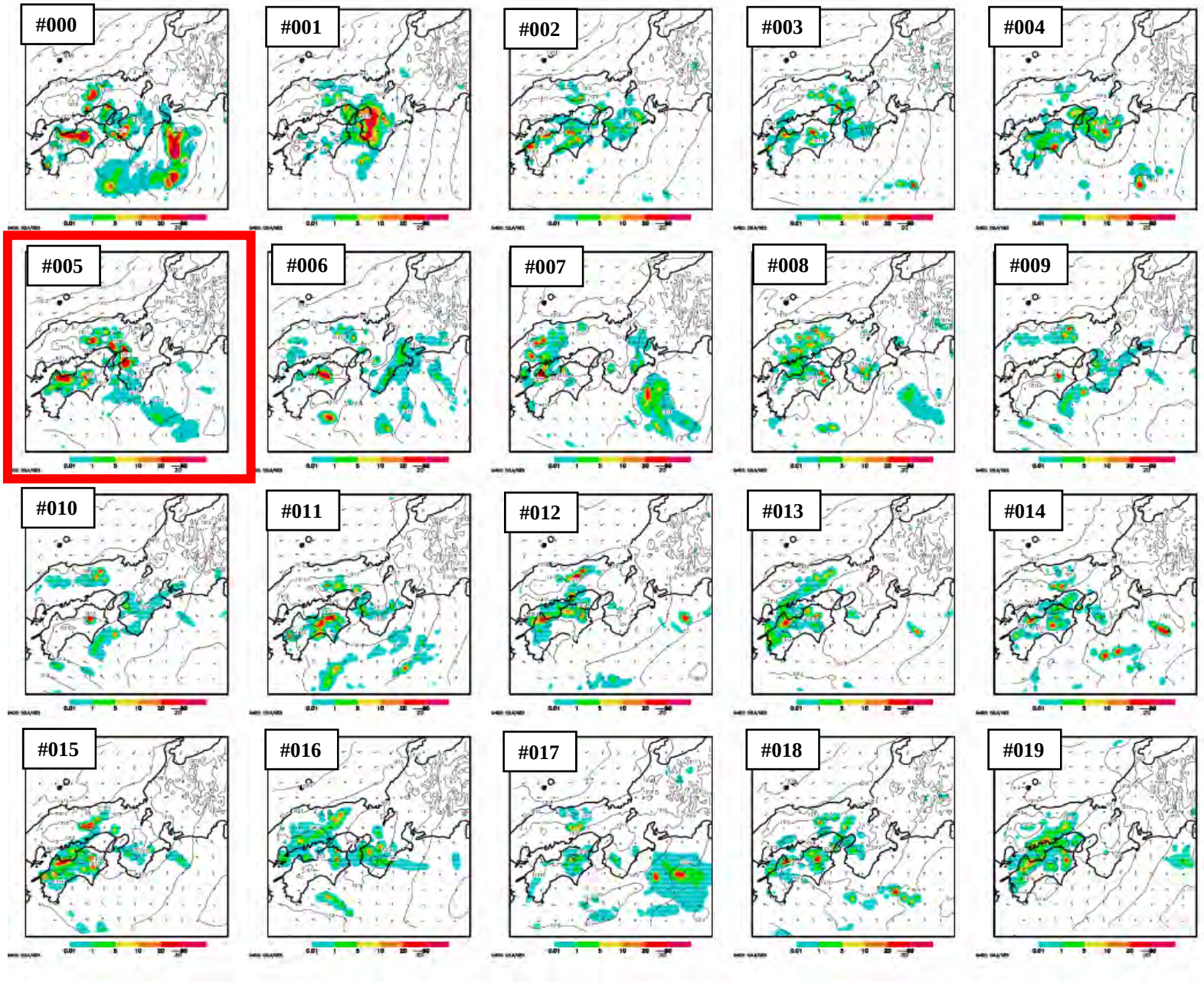


Convective scale water vapor





Forecast from assimilated fields (17JST)



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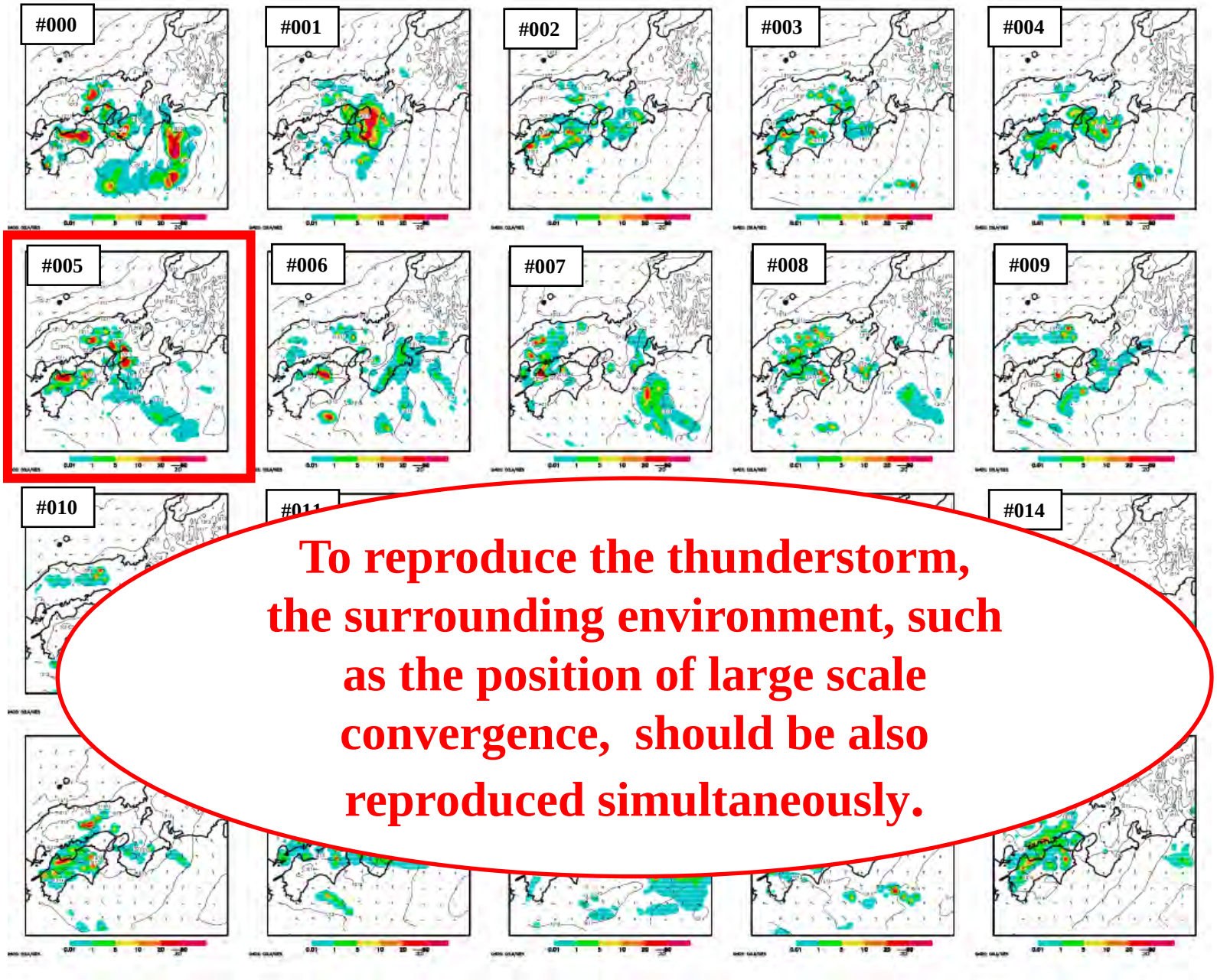
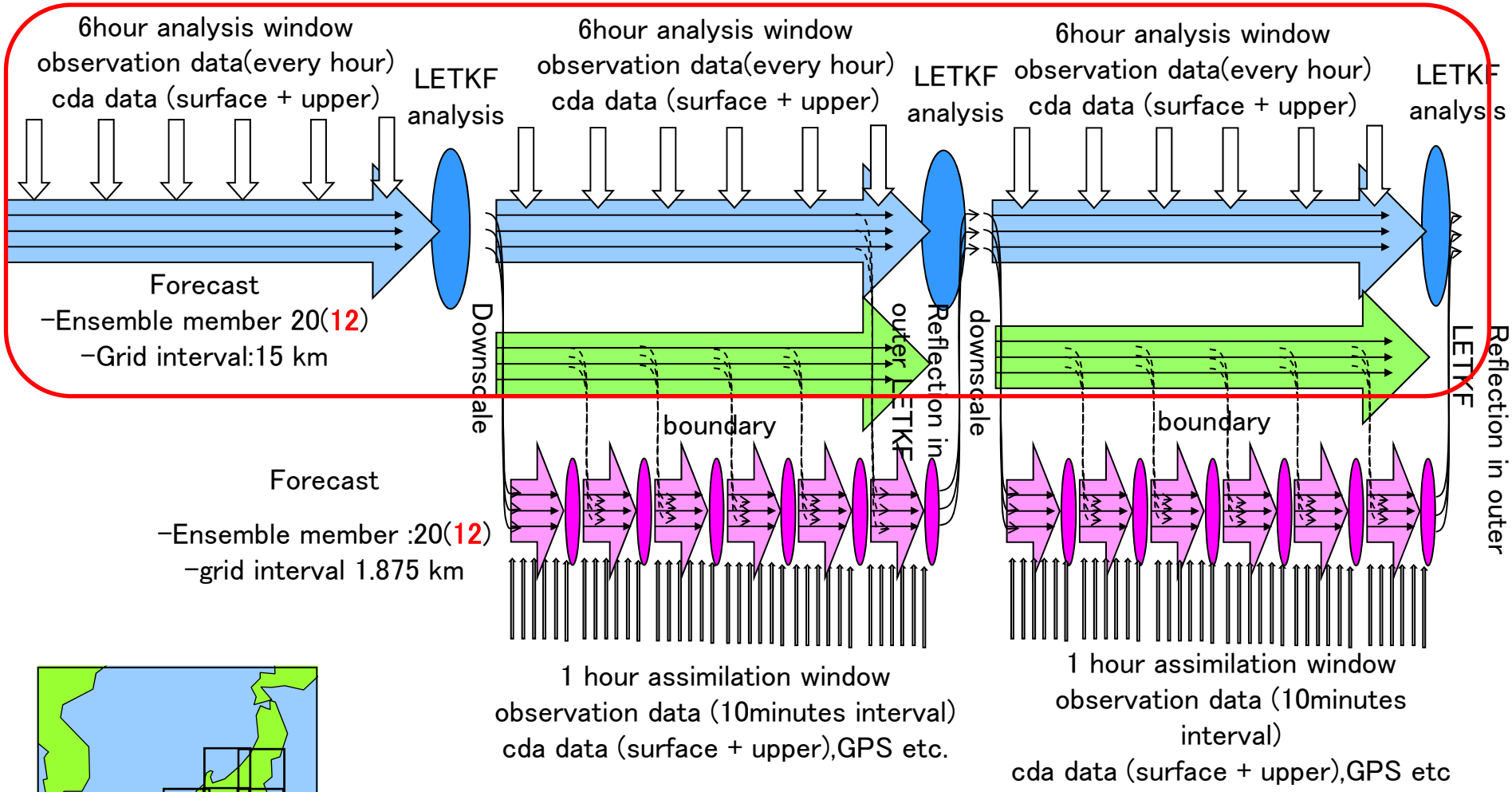
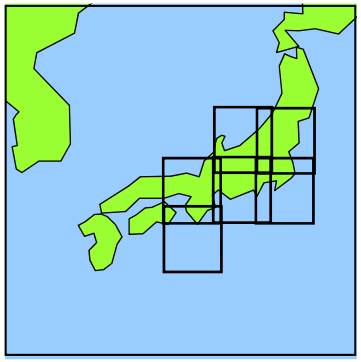


To reproduce the thunderstorm, the surrounding environment, such as the position of large scale convergence, should be also reproduced simultaneously.

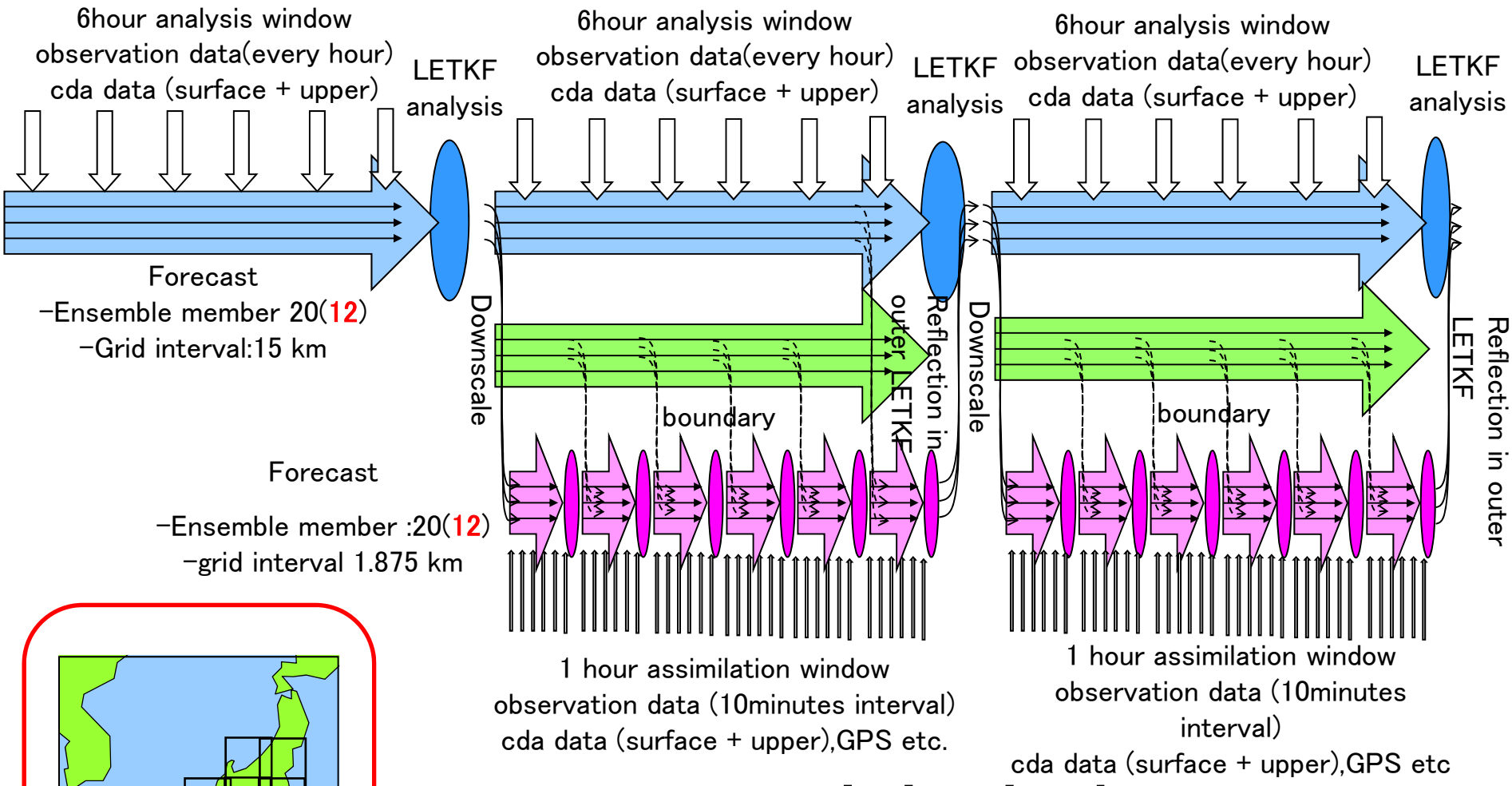
Schematic of nested LETKF system

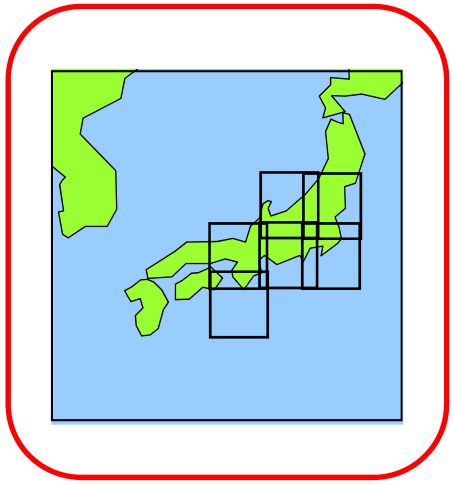




- The outer LETKF with a grid interval of 15 km assimilates the convectional data of Japan Meteorological Agency. Assimilation window was 6 hours.

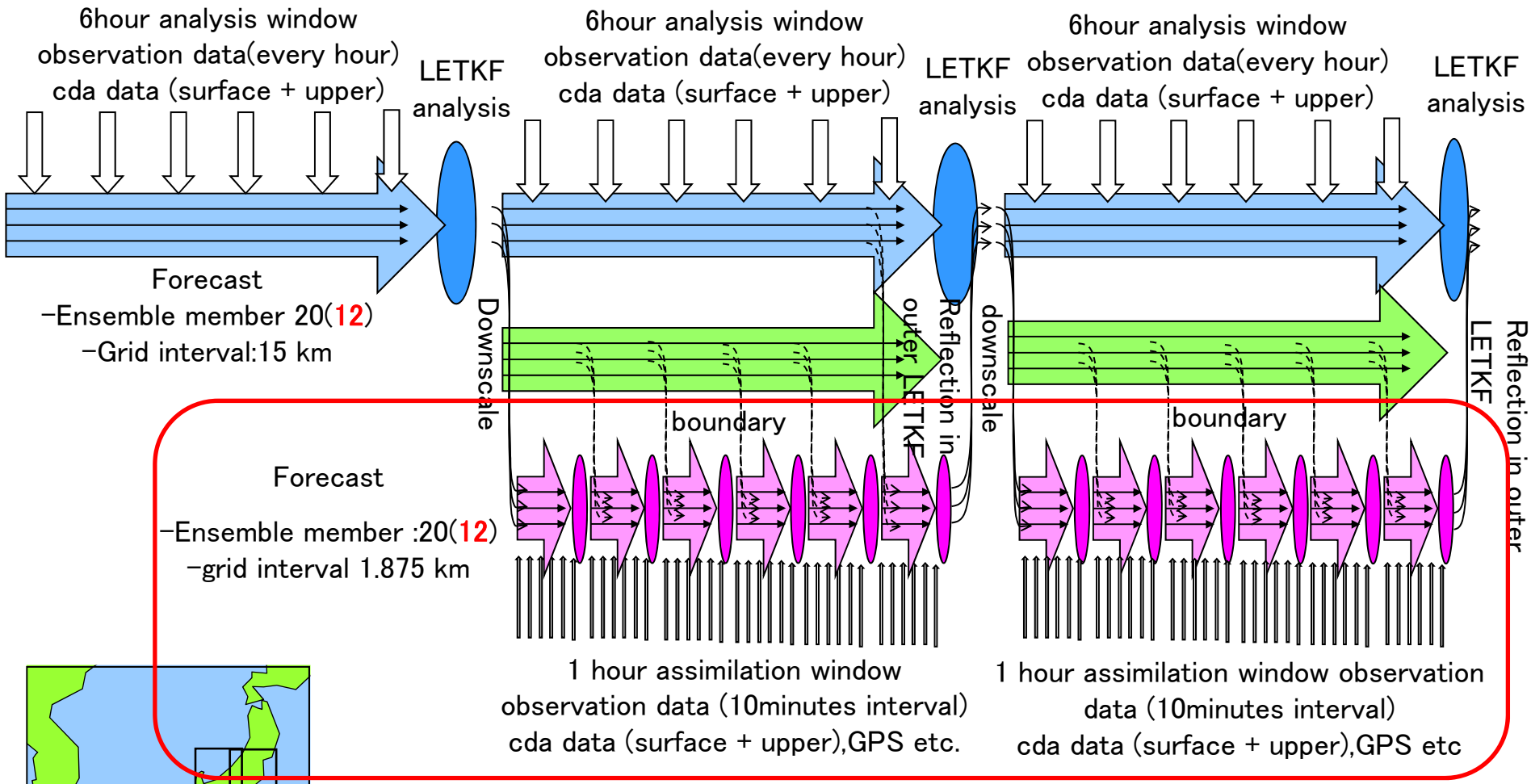
Schematic of nested LETKF system





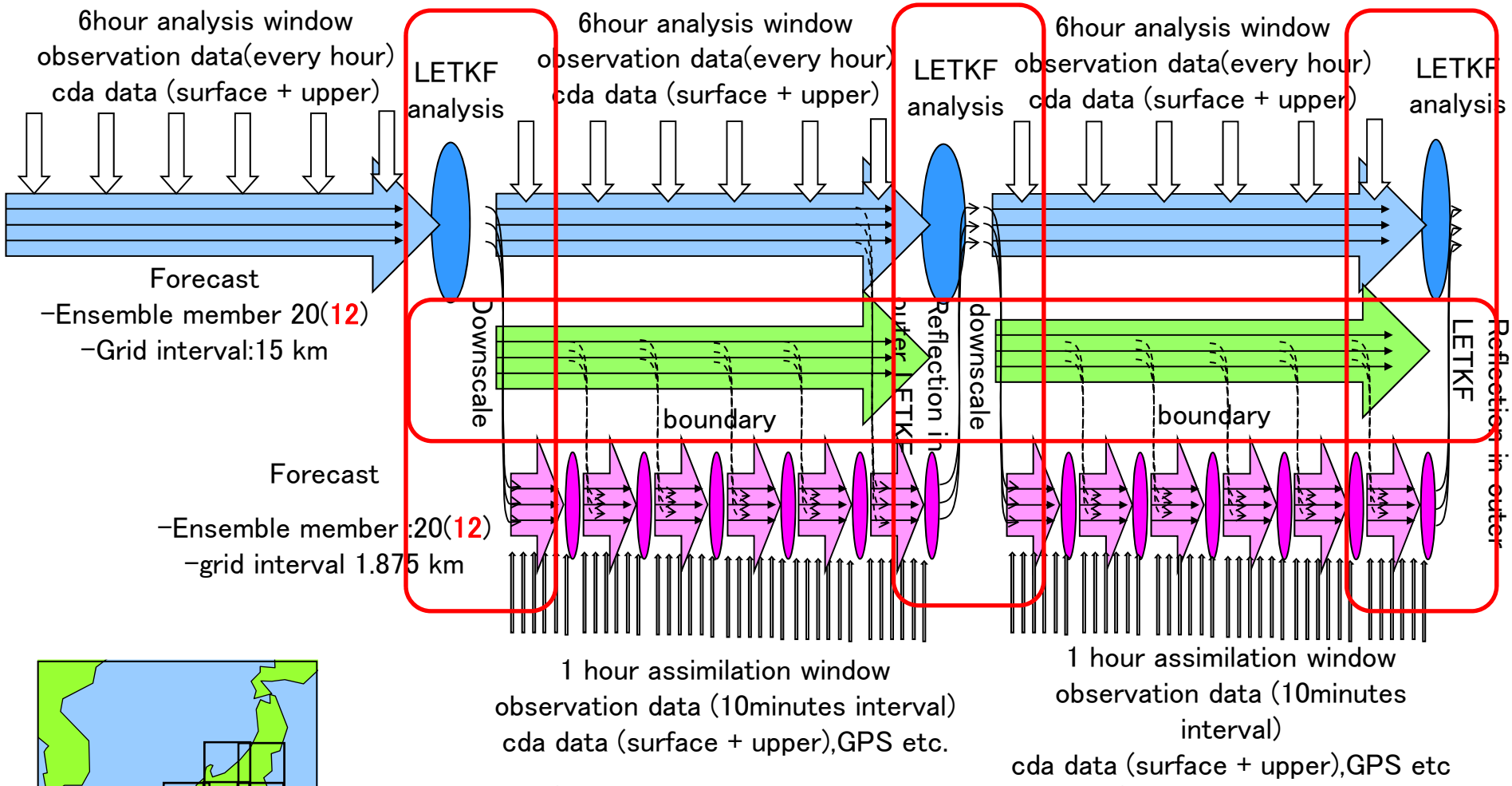
- Inner LETKFs were deployed in the outer LETKF.
- Boundaries of the inner LETKFs were overlapped to reduce the regions that were determined by the outer LETKF.

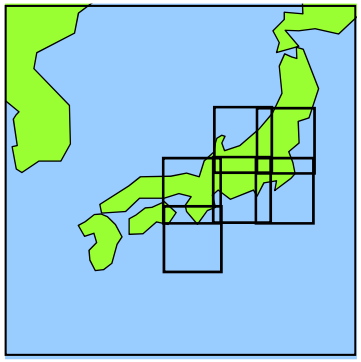
Schematic of nested LETKF system



- The grid interval of the inner LETKF with grid interval is about 2 km. The inner LETKF assimilated the convectional data and high resolution data. Assimilation window was 1 hour.

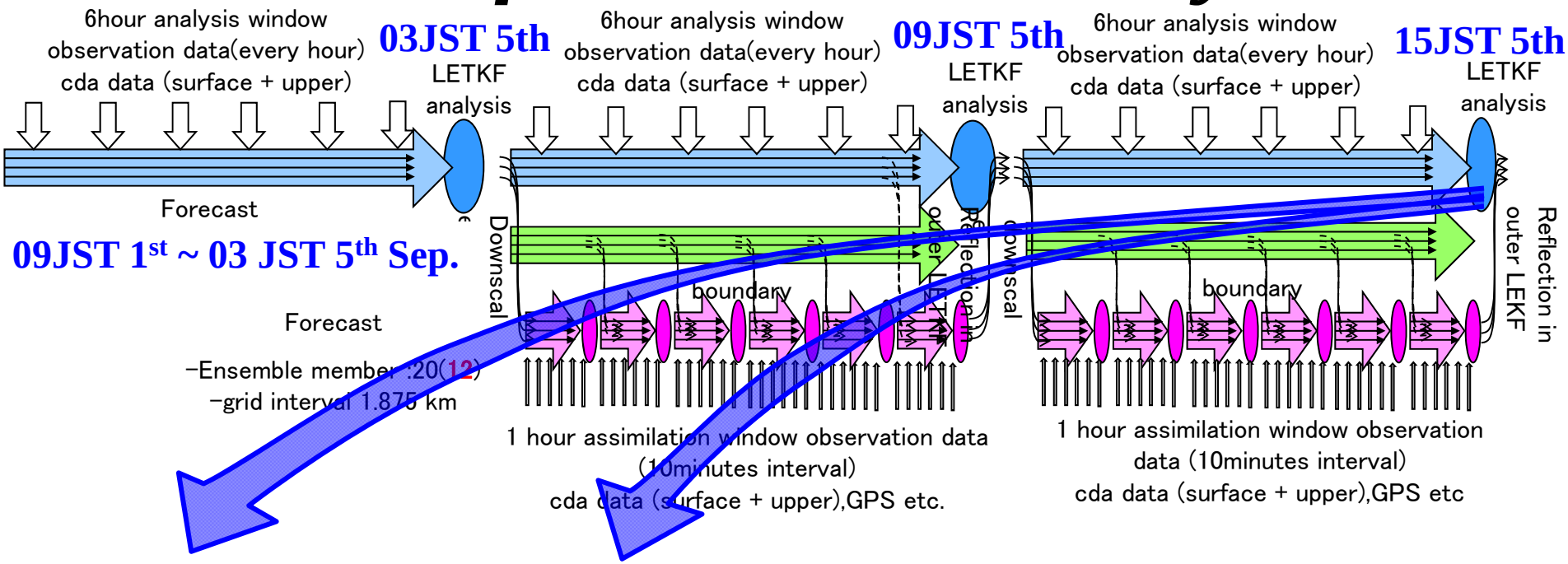
Schematic of nested LETKF system



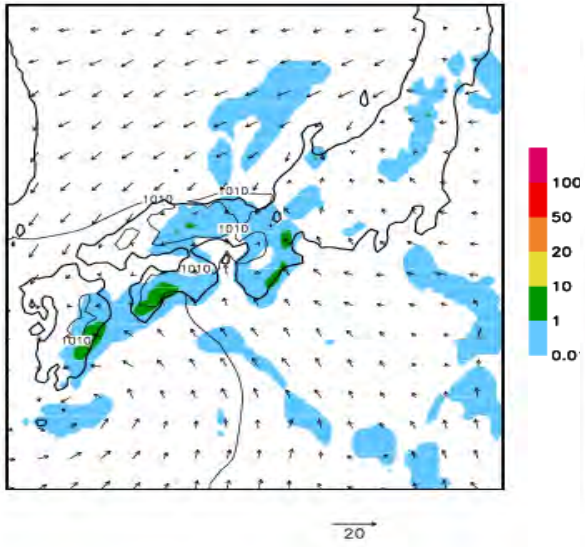


- Results of the inner LETKFs were reflected in the outer LETKF every 6 hours.
- Initial boundaries of the inner LETKFs were produced from forecasts of the outer LETKF.

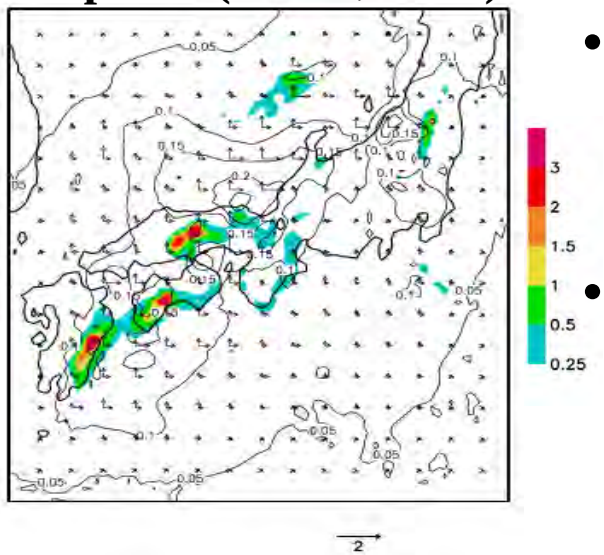
Results of nested LETKF system



Ensemble mean (15JST,15km)

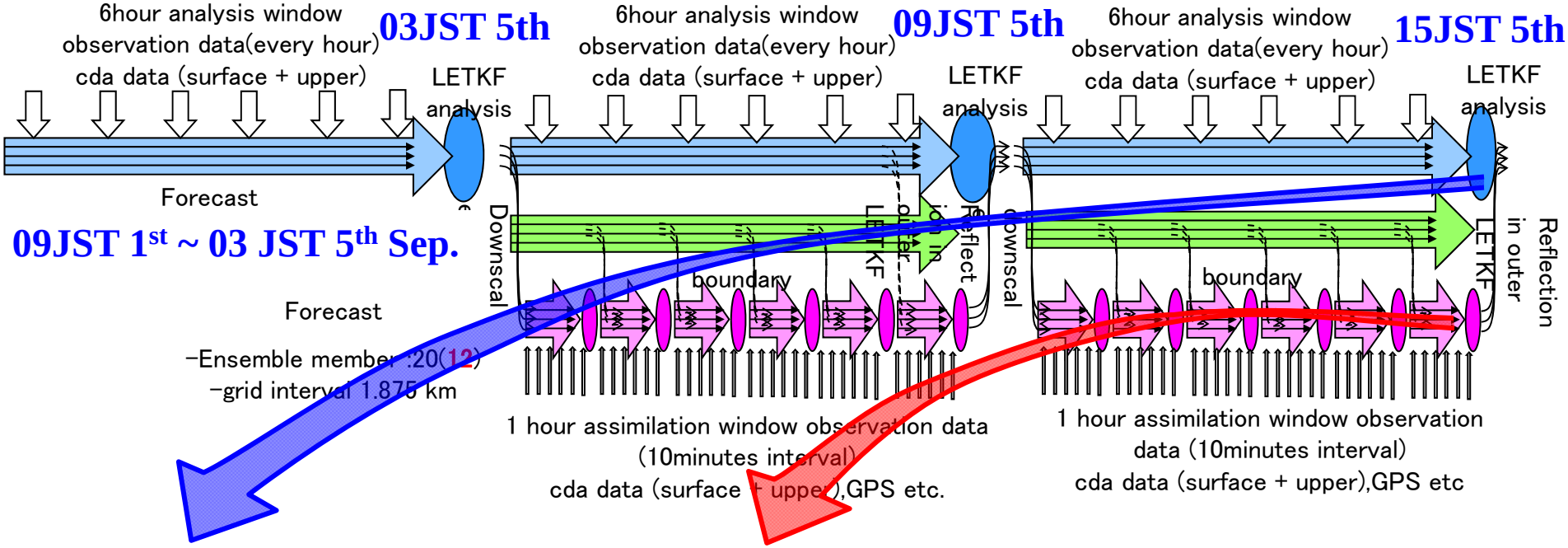


Spread (15JST,15km)

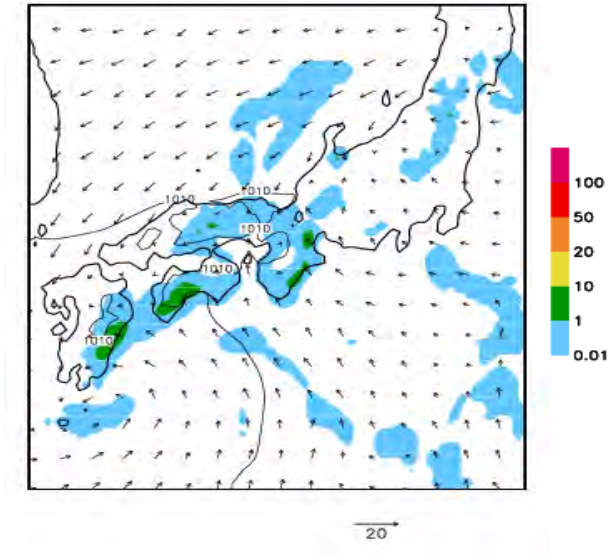


- Spread at the center of the domain was relatively large.
- So we deployed the inner LETKF at the center of the domain.

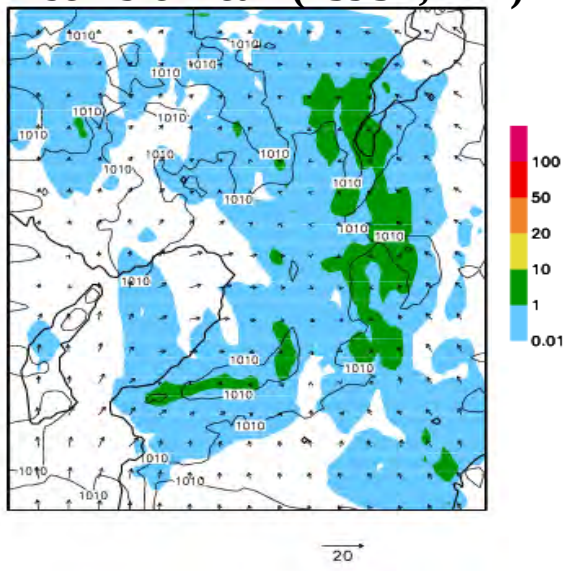
Results of nested LETKF system



Ensemble mean (15JST,15km)

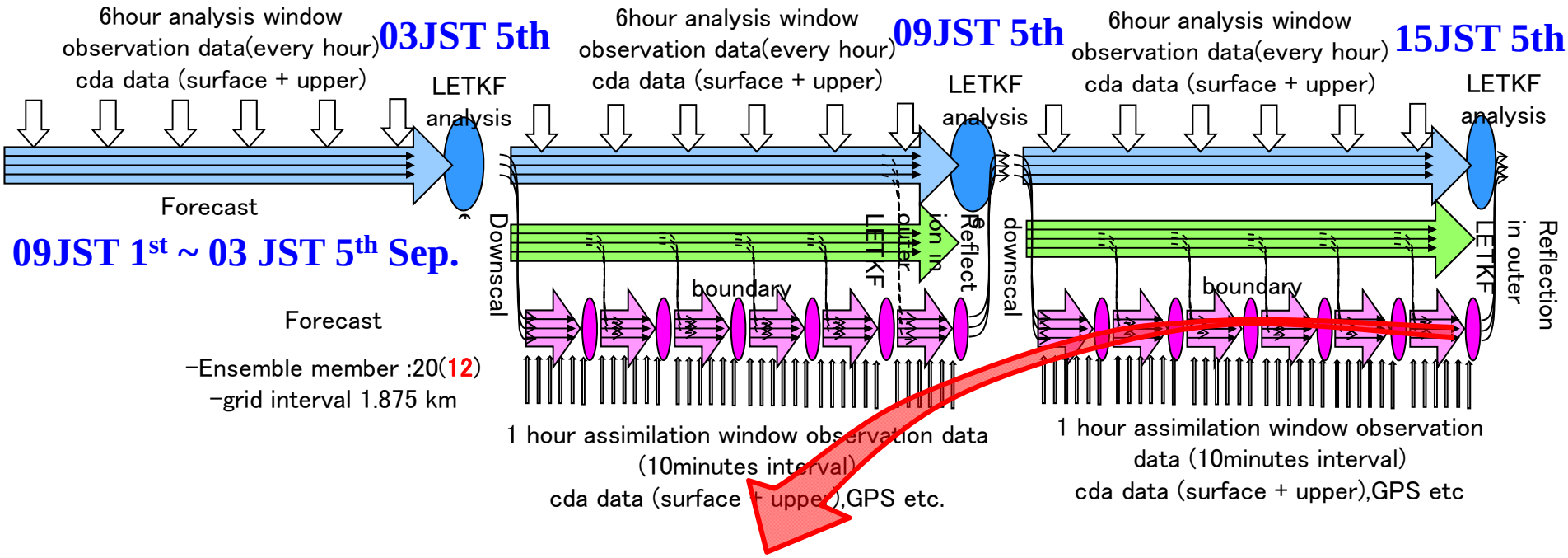


Ensemble mean (15JST,2km)



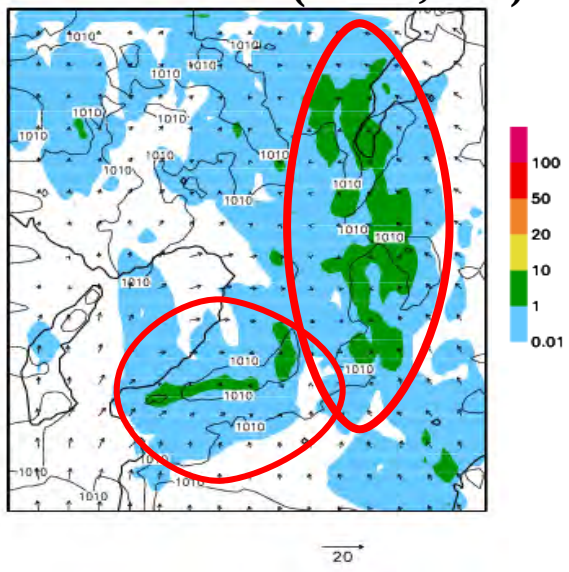
- Detailed structures were produced by the inner LETKF with a grid interval of 2 km.

Results of nested LETKF system

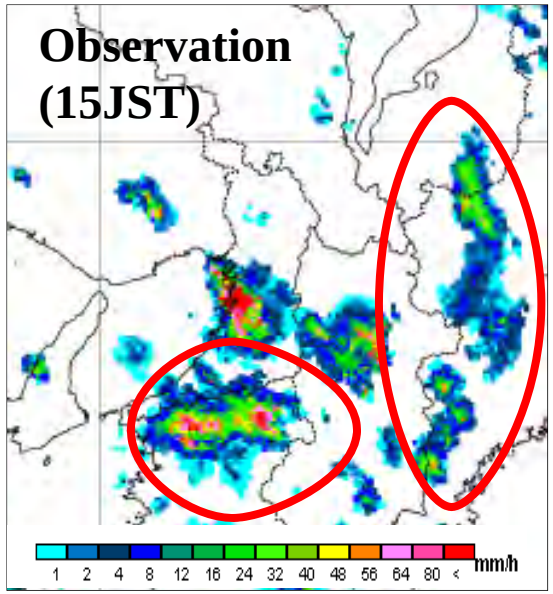


- Rainfall regions were similar to the observed ones. (Rainfall regions were produced over the mountain areas)

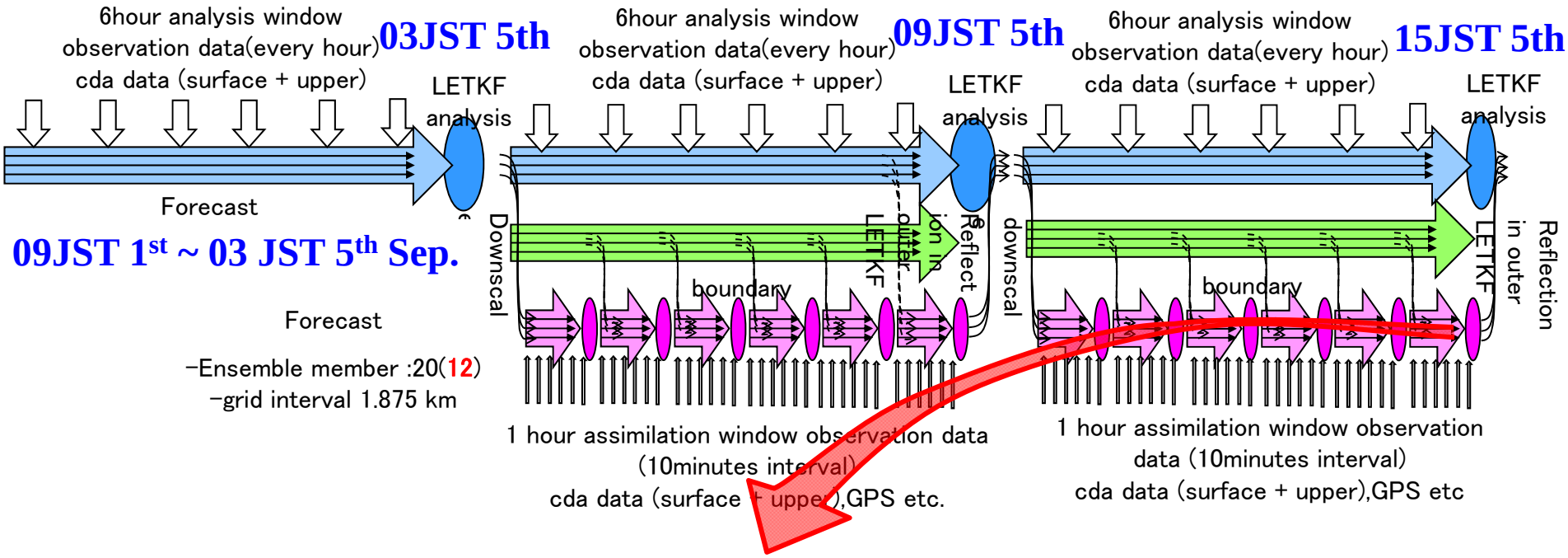
Ensemble mean (15JST,2km)



Observation (15JST)

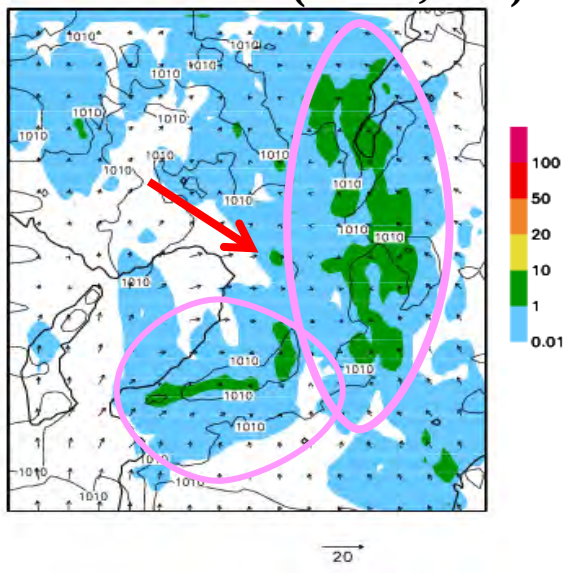


Results of nested LETKF system

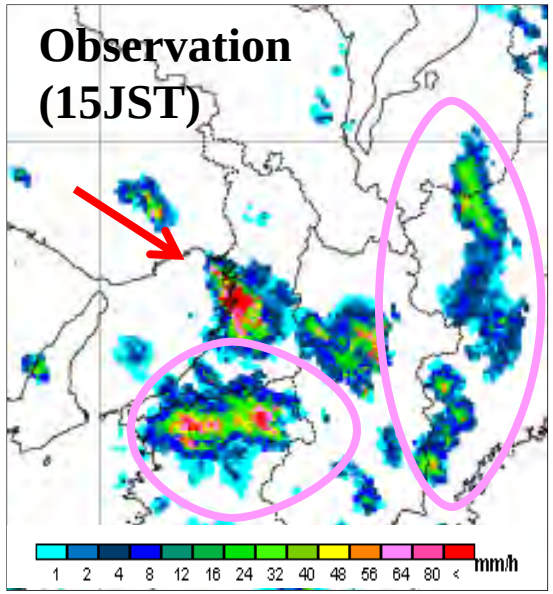


- However, the rainfall that developed into the Sakai intense rainfall was too small.

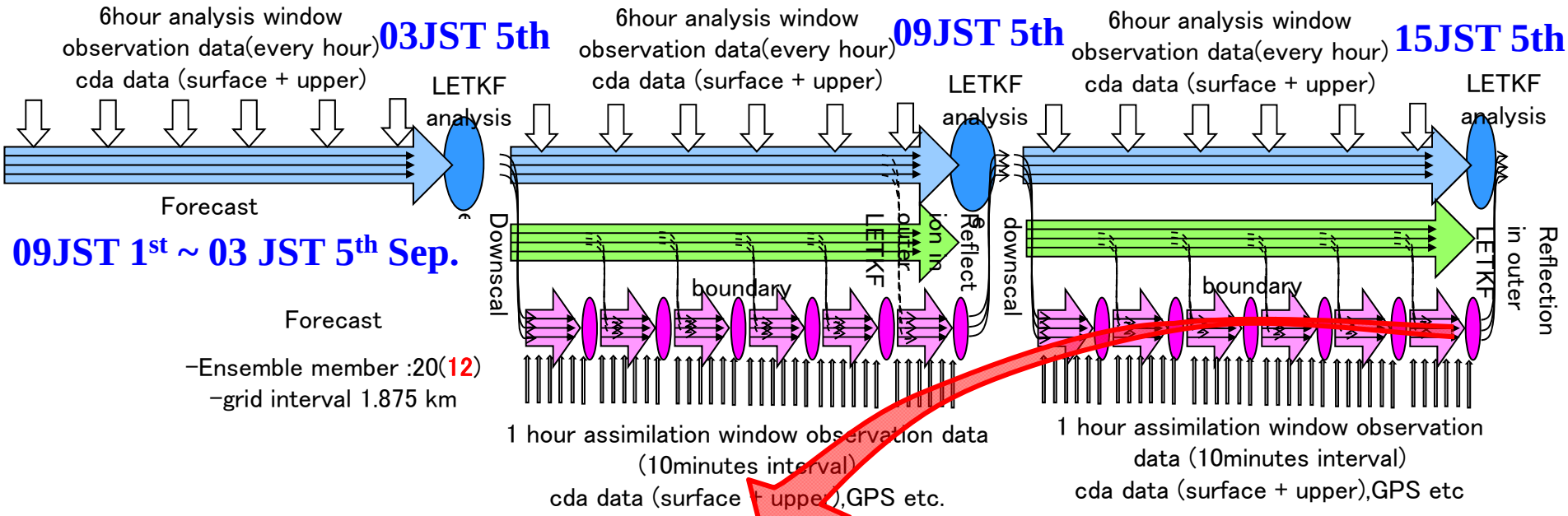
Ensemble mean (15JST,2km)



Observation (15JST)

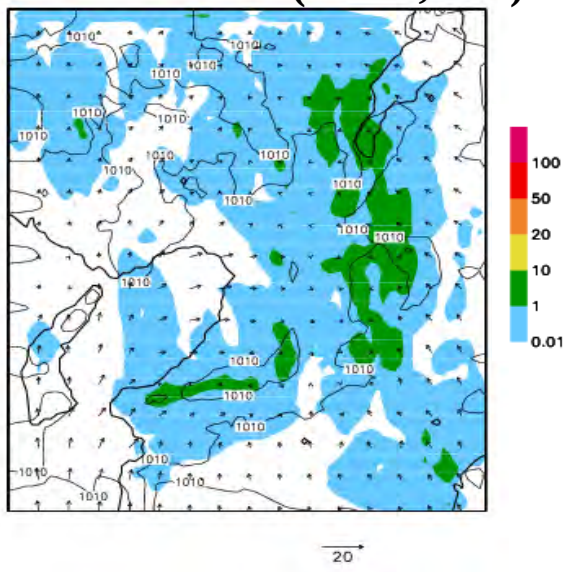


Results of nested LETKF system

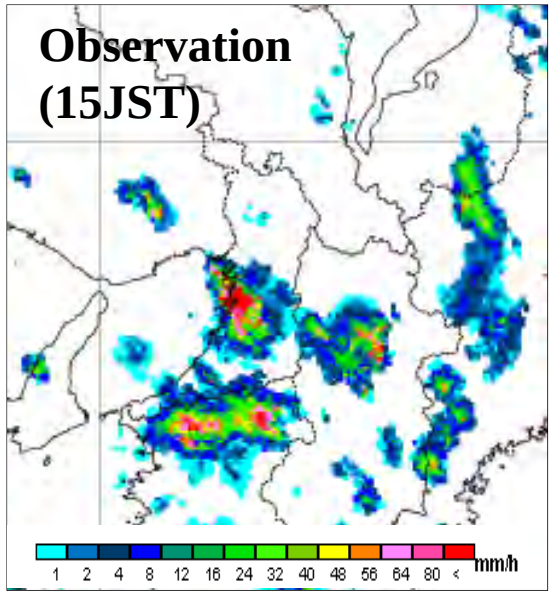


- To be similar to the observed distribution, higher resolution data, such as GPS PWV and Doppler radar data, are needed.

Ensemble mean (15JST,2km)

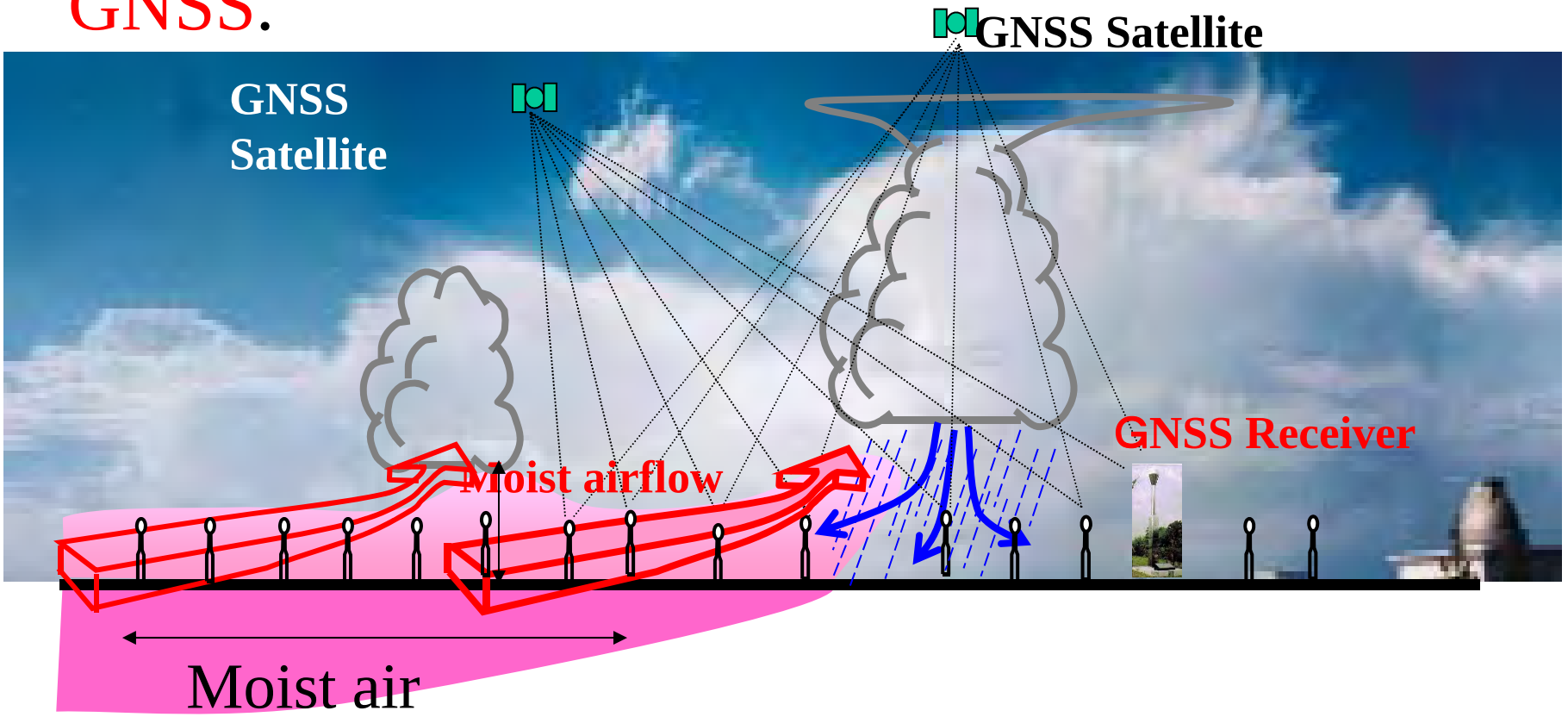


Observation (15JST)



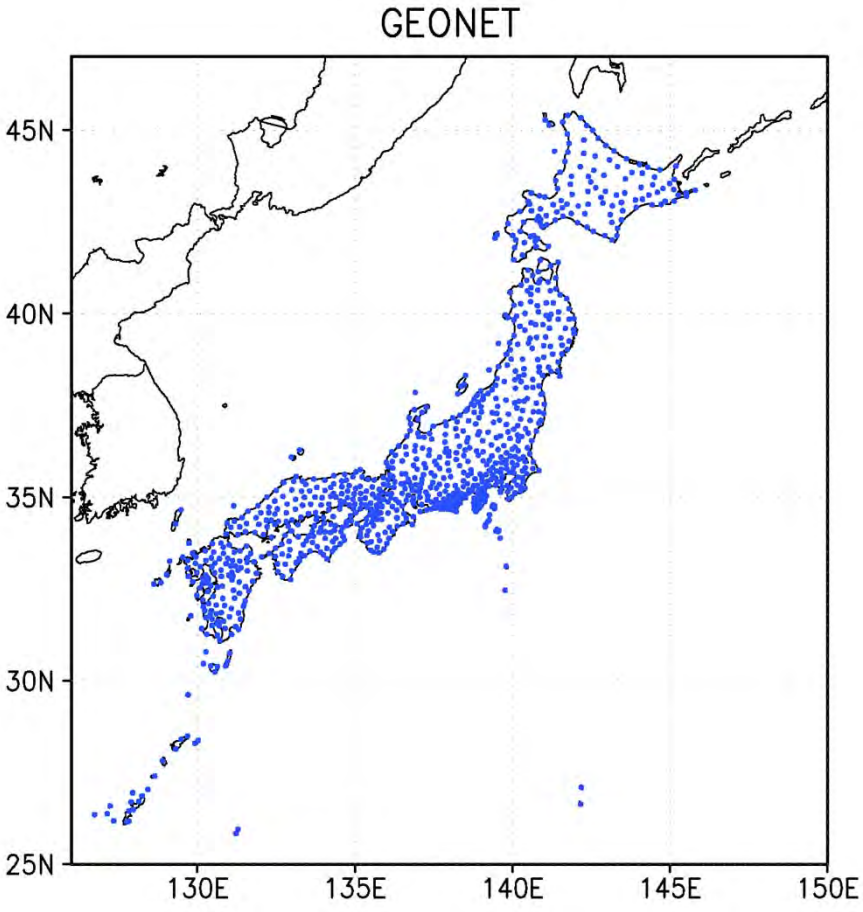
Low-level convergence of water vapor

- To improve convergence of **water vapor**, we want to assimilate the precipitable water vapor (PWV) and horizontal wind data .
- PWV can be obtained from delays of signals from GNSS.

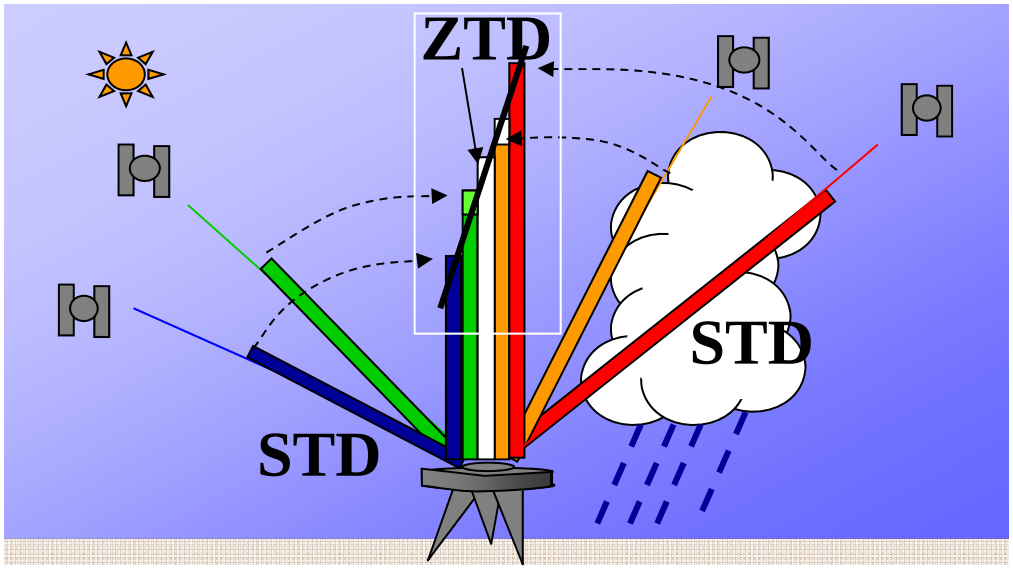


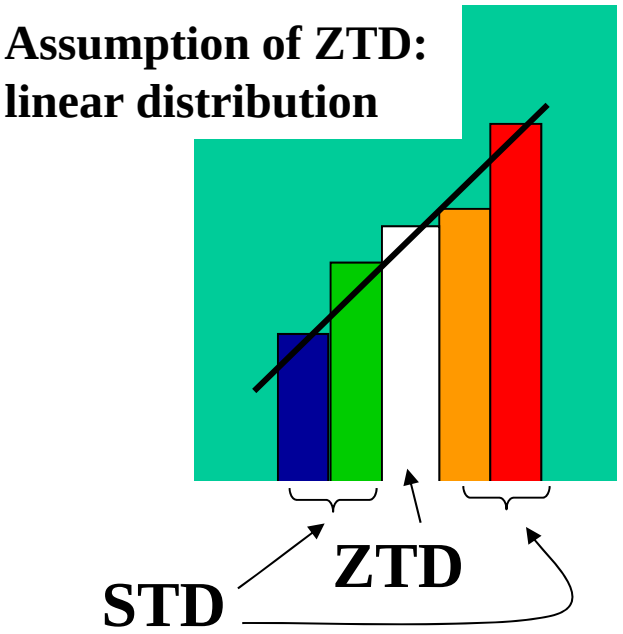
How to estimate PWV data

- **A GPS network (GEONET) has been established in Japan.**
- **Horizontal distances of GPS receivers are about 25 km.**
- **GEONET provides high resolution data of PWV that can express the environments of local heavy rainfalls.**



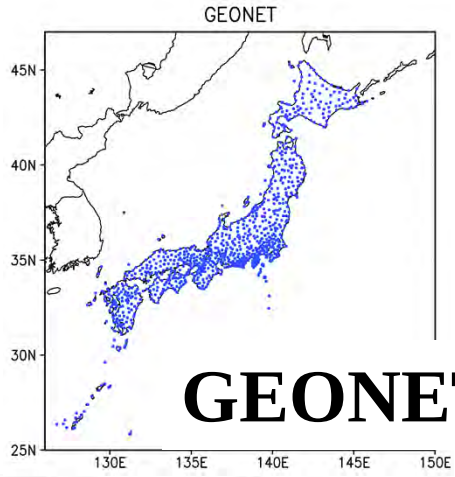
How to estimate PWV data





- Signals from GNSS satellites are delayed by water vapor in the atmosphere. Delay along the path between GNSS satellites and receivers is called the Slant Total Delay (STD).
- The Zenith Total Delay (ZTD) is estimated from the STDs by multiplying the mapping function of the elevation angles.
- The Precipitable Water Vapor (PWV, vertically integrated amount of water vapor) is estimated from the ZTDs.

Accuracy of GPS-PWV data observed by GEONET



GEONET

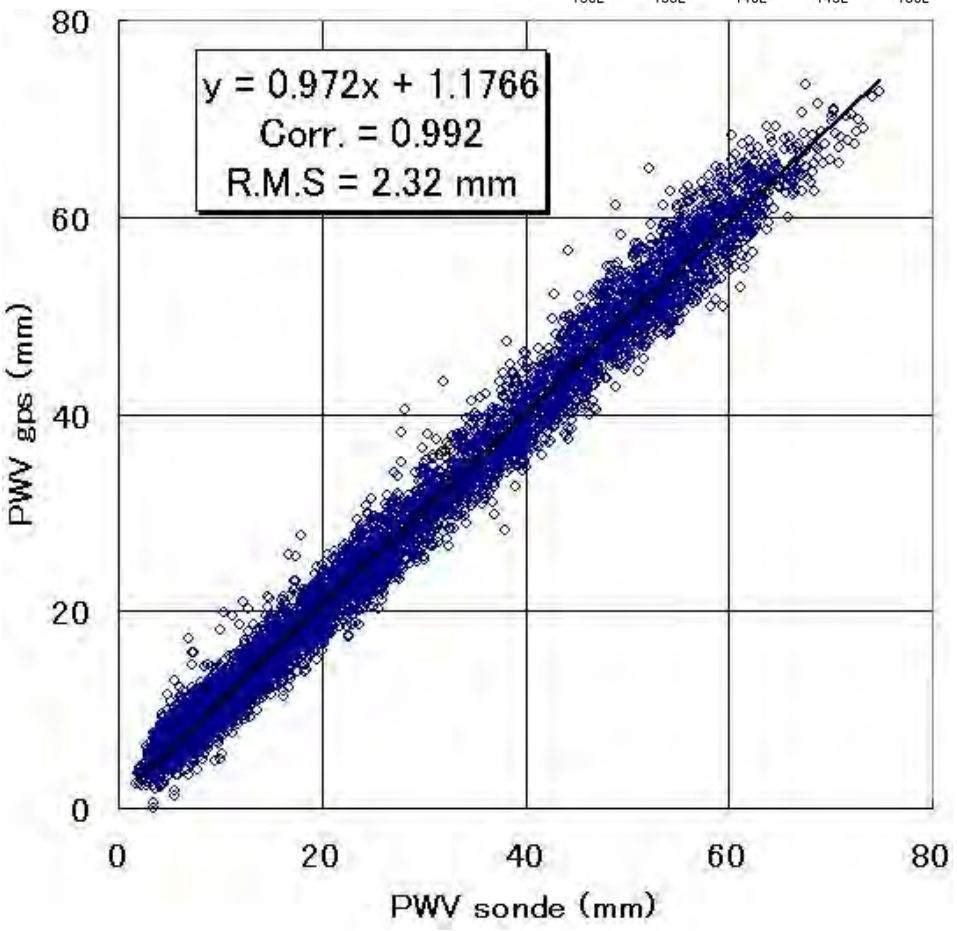
Comparison with GPS-PWV and sonde-PWV（Period Jun. 1999 ～ May 2000）. Distances between GPS-PWV and sonde-PWV were less than 10km horizontally and 20m vertically.

高層観測点	GPS点	水平距離 (km)	高度差 (m)
47420/根室	0006	7.5	−6.0
47580/三沢	0539	2.7	11.3
47590/仙台	0037	7.3	−11.3
47600/輪島	0053	1.0	0.1
47646/舘野	0584	6.6	0.0
47681/浜松	3050	9.8	−6.8
47744/米子	0654	1.0	3.9
47918/石垣島	0750	0.9	12.5
47945/南大東島	0497	0.6	1.2

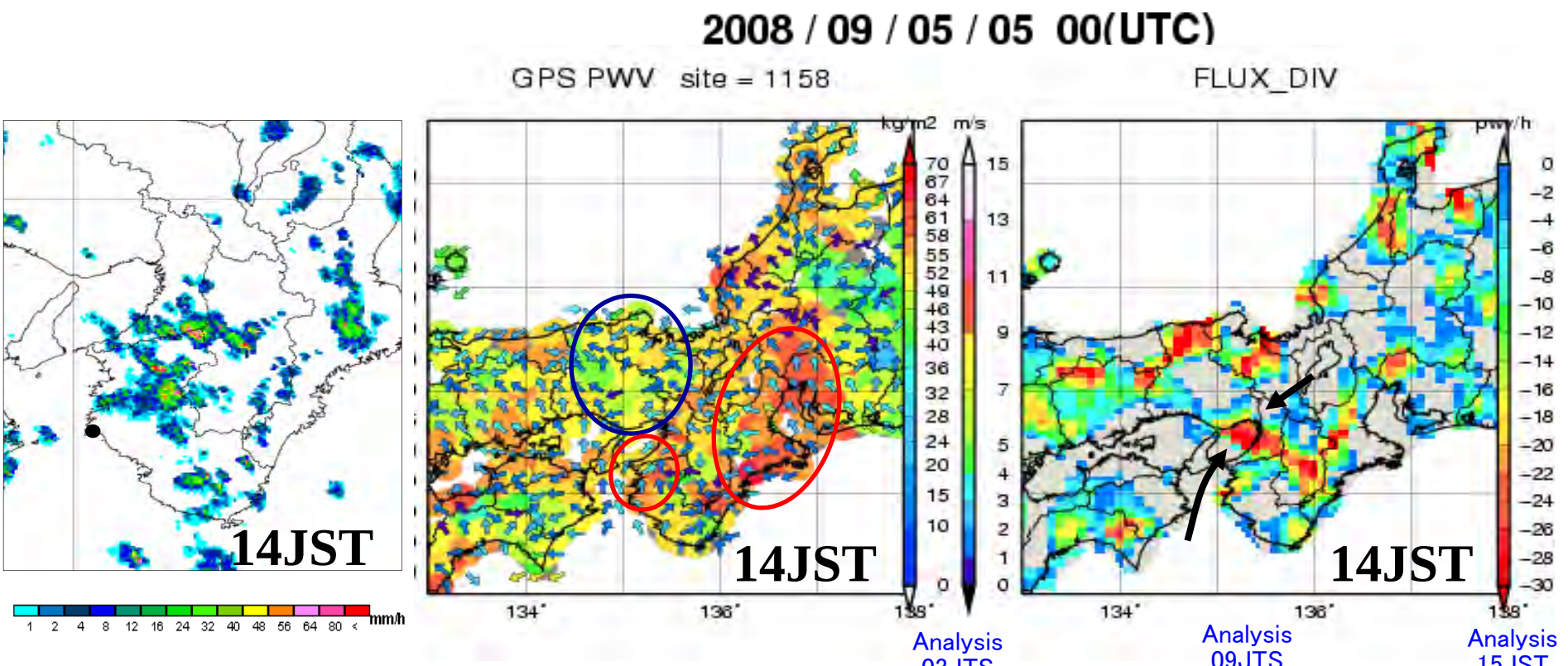
*高度差＝GPS点標高－高層観測点標高

RMS = 2.3mm

（Precise orbit was used in the estimation of GPS-PWV.）



Observed GPS-PWV



Rainfall distribution at 14JST on 5th Sep. and GPS-PWV and convergence of water vapor.

GPS-PWV were assimilated from 9 to 15 JST very 10 minutes.

Assimilation method GPS-PWV

Observation data :GPS-derived PWV

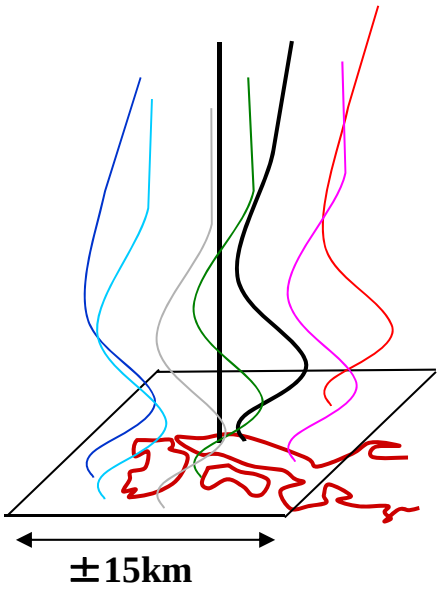
Difference between the GPS receivers' altitude and model topography <50 m.

First guess and statistical value obtained by NHM-LETKF

Vertical profiles of T, RH and the spread of RH within the range of ±15 km from GPS receivers.

RH profiles were produced. (Input data of LETKF)

Thinning of the vertical layer in the profiles was performed, because of the vertical correlation of the observation error.

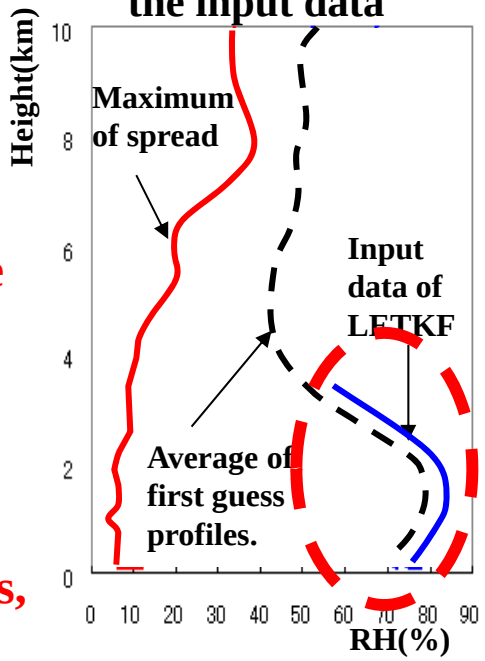


Assumption: the difference between analysis and first guess is larger at the layer with a wider spread of RH.

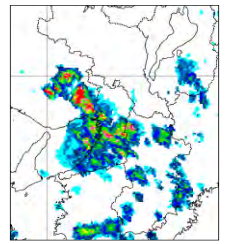
Water vapor was should be modifies only at the layer of which the correlation with PWV was large.

Input RH data of the LETKF was produced by increasing of average of first guess value in proportion to maximum spared of RH at layers, of which the correlation with PWV was large.

Example of the input data

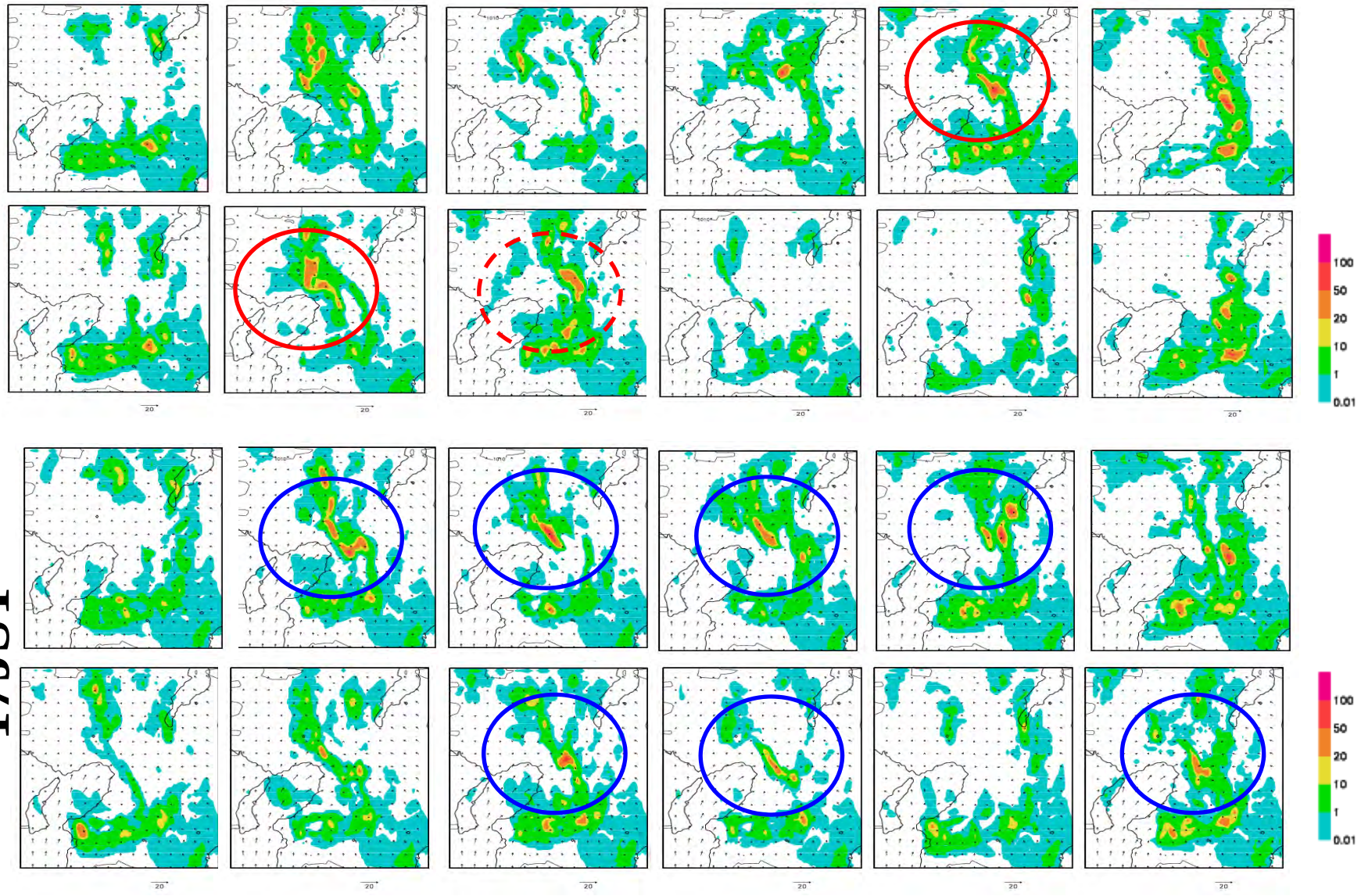


Assimilation of GPS-PWV data

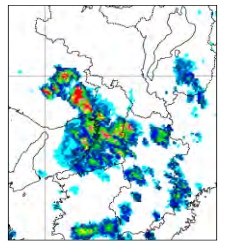


CNTL 17JST

GPS_PWV_2
17JST



Assimilation of GPS-PWV data



CNTL 17JST

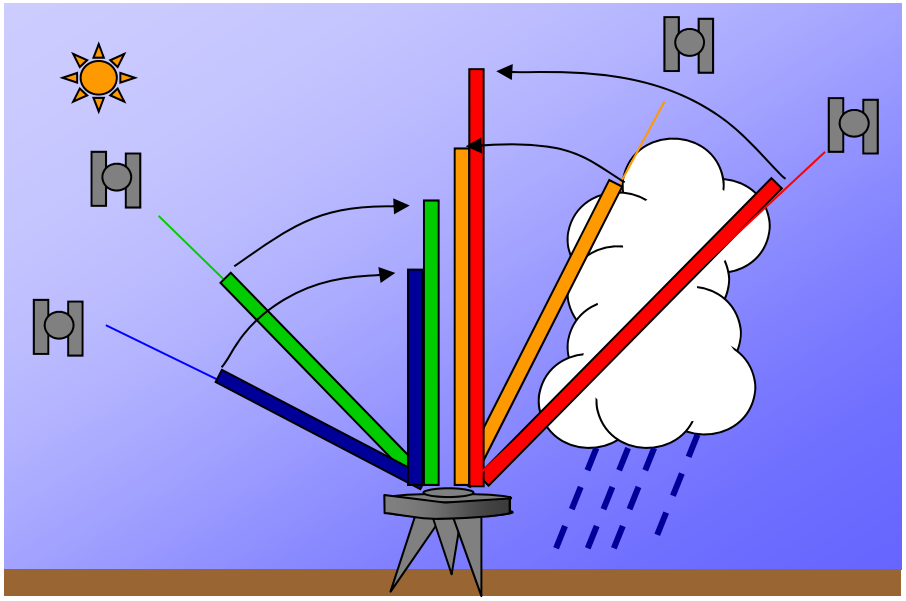
GPS_PWV 17JST

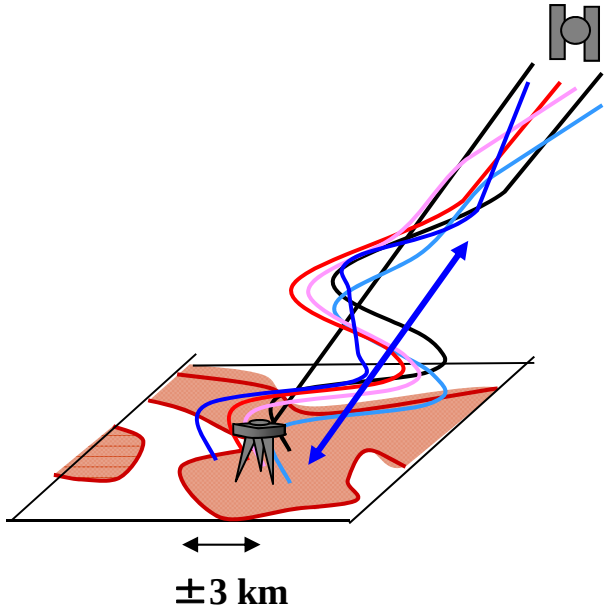
The number of ensemble forecasts in which Sakai thunderstorm was reproduced is increased.

100
50
20
10
1
0.01

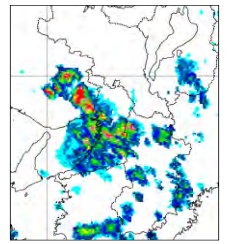
GPS-slant water vapor (SWV) data

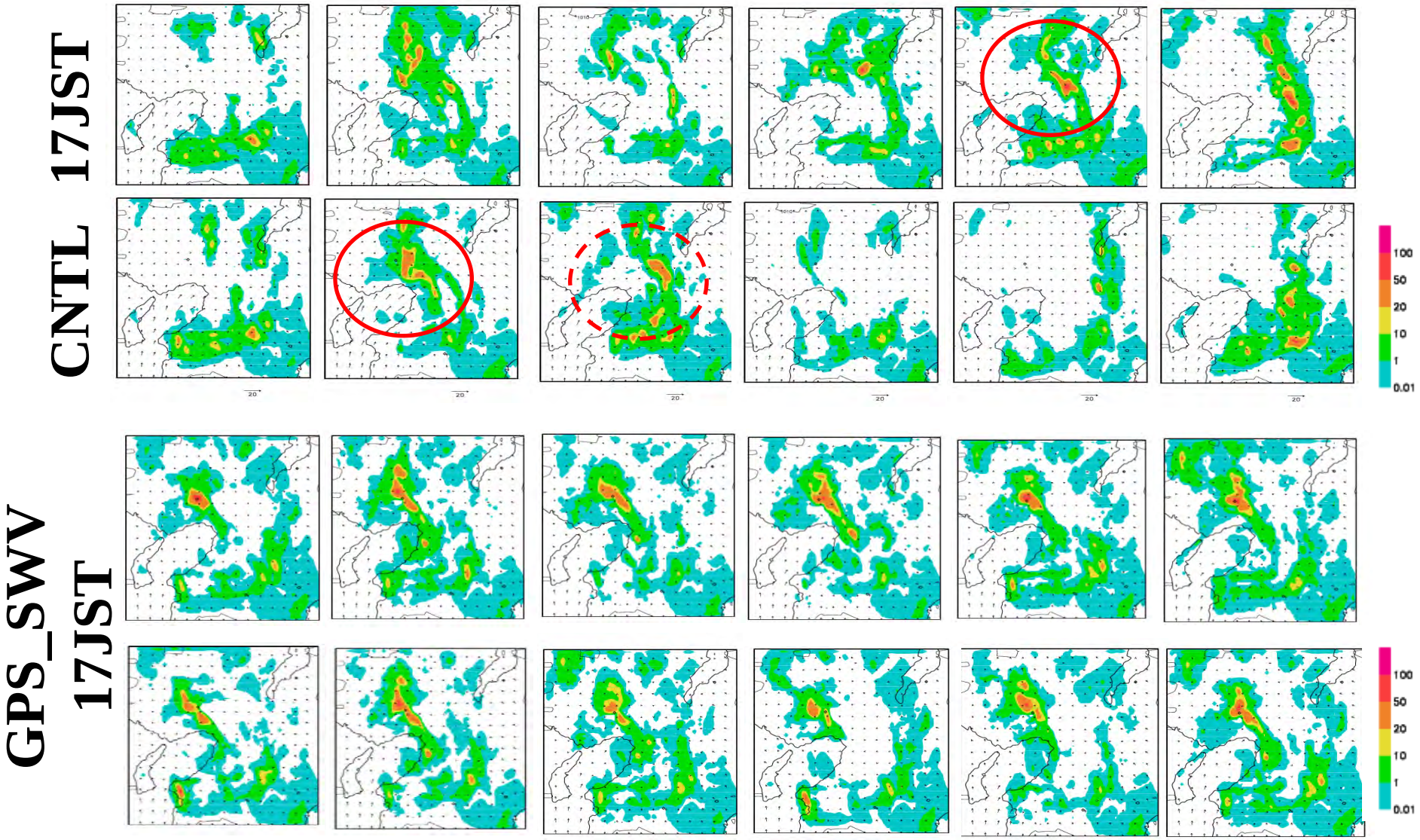
- Slant water vapor (SWV) was the water vapor amount along the path from GPS satellite and GPS receivers
- SWV was retrieved from PWV, gradient and residual, and surface meteorological data, such as T and P.
- **SWV was assimilated by using the same method of PWV, except the paths were slanted.**



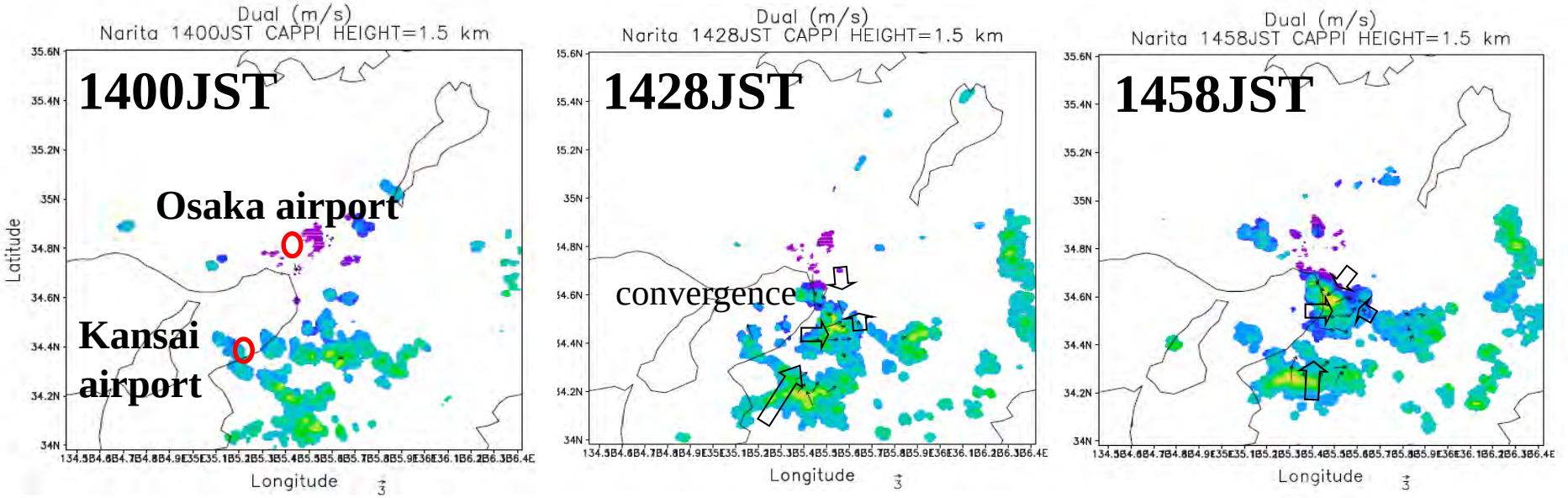


Assimilation of GPS-SWV data



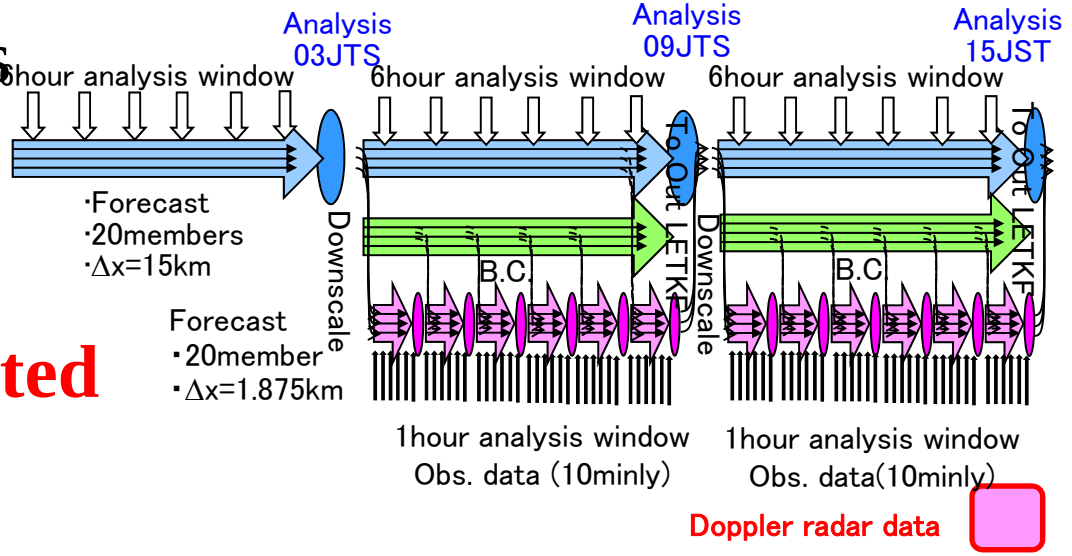


Horizontal wind obtained from Doppler radars

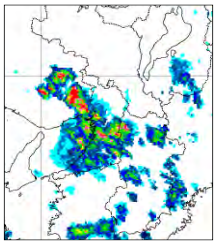


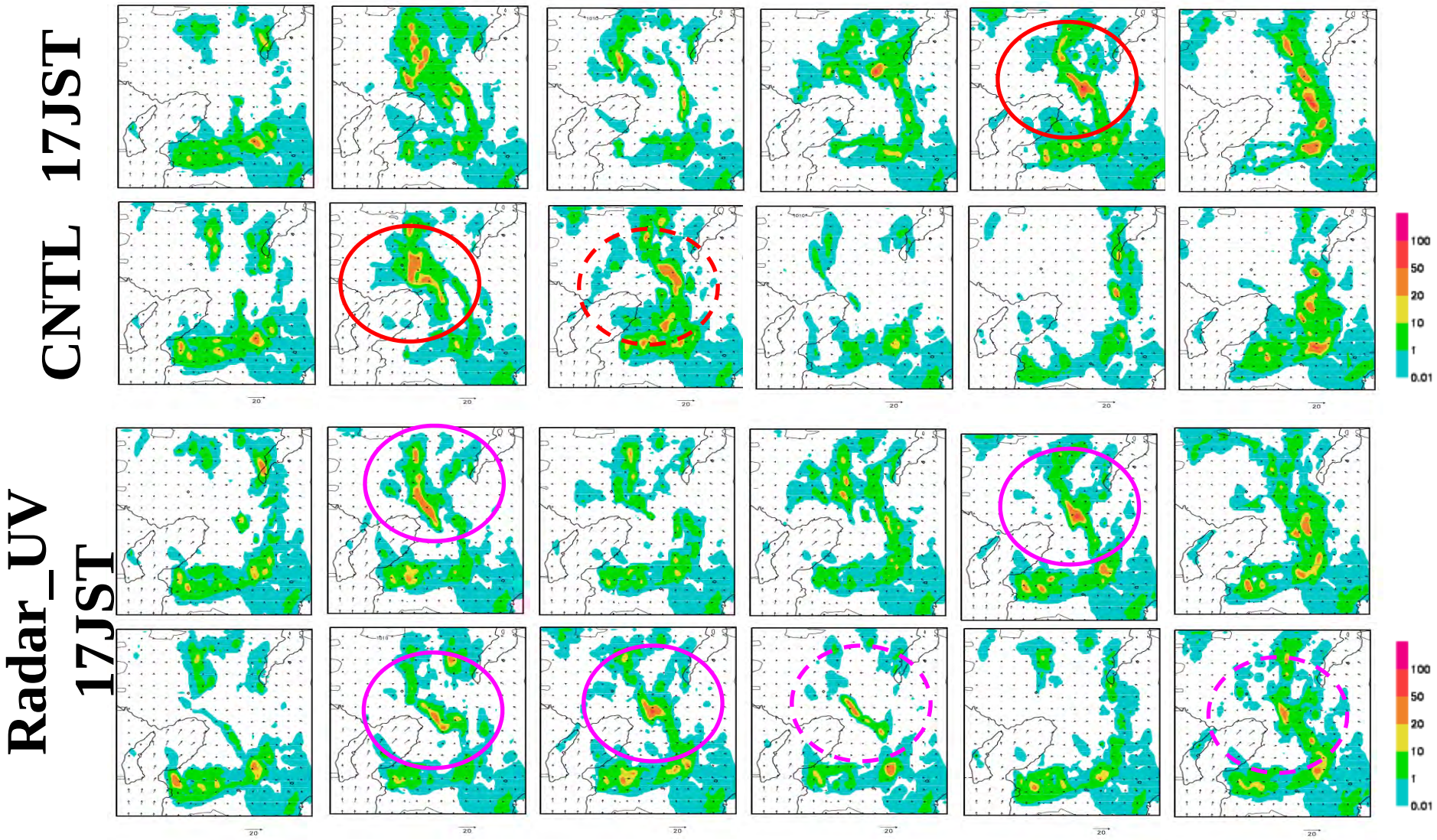
Horizontal winds were estimated from the radial winds of Kansai and Osaka airports using dual analysis.

Radial wind from 14 -15JSTwere assimilated every 10 minutes.

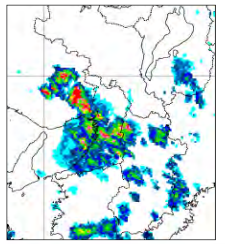


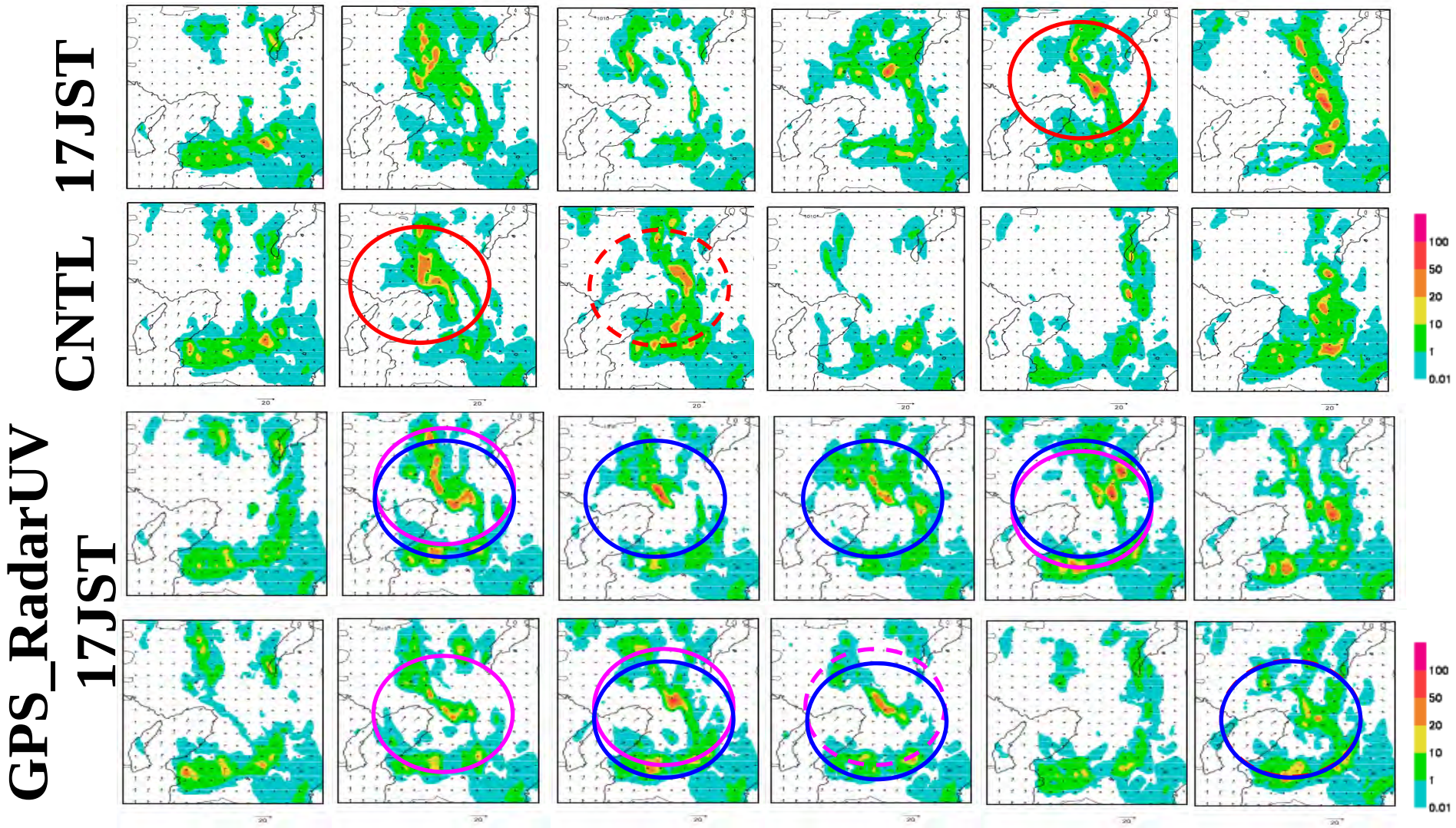
Horizontal wind improves the rainfall forecasts,
although the impact was weaker than GPS-PWV.





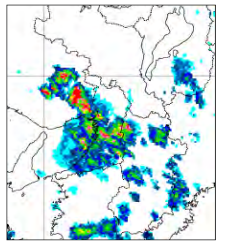
Both GPS-PWV and horizontal wind were assimilated simultaneously, number of the improved member were increased.

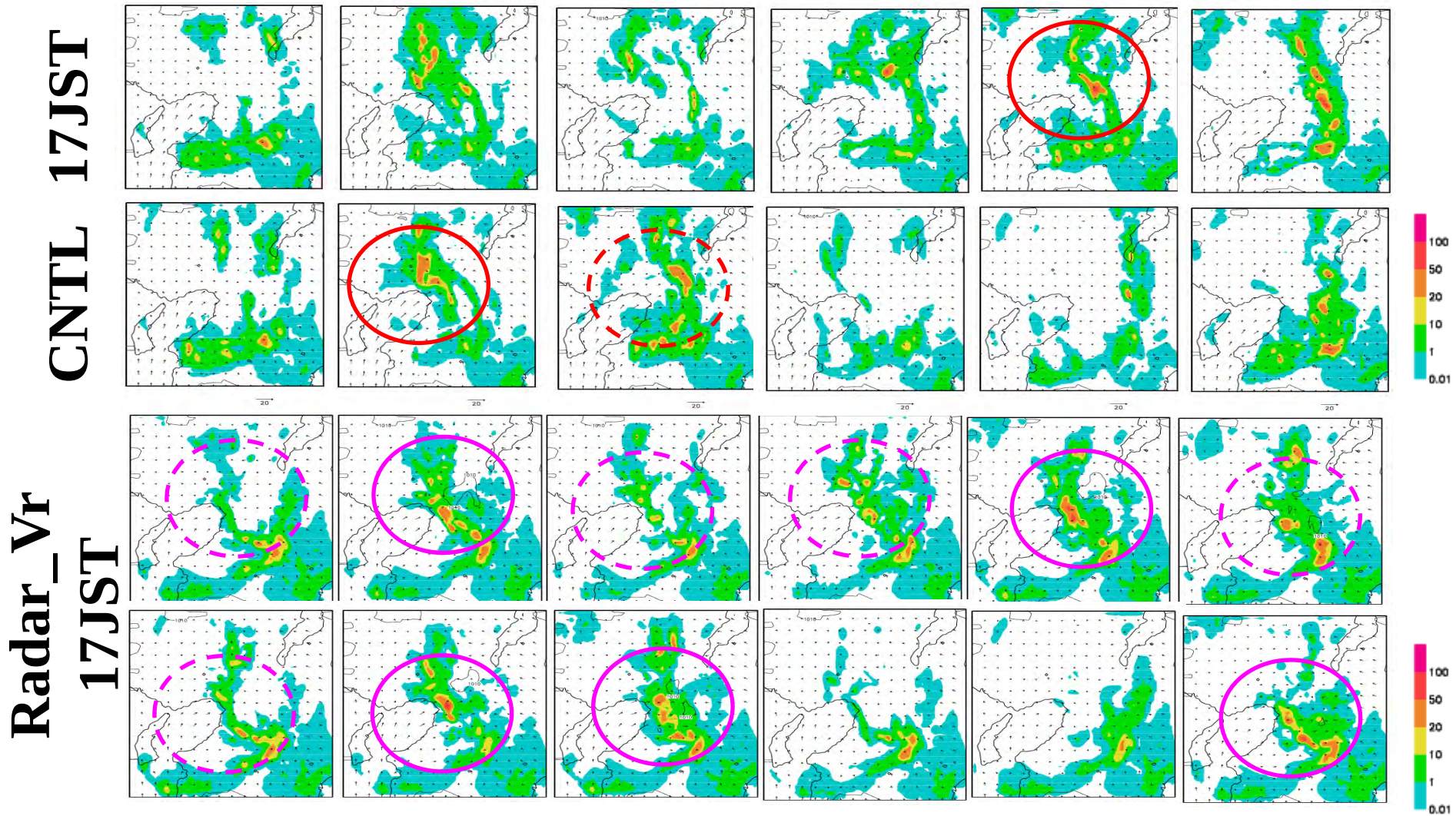




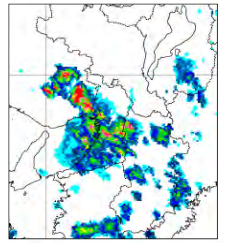
Blue and pink circles indicate the rainfalls improved by GPS and radar data

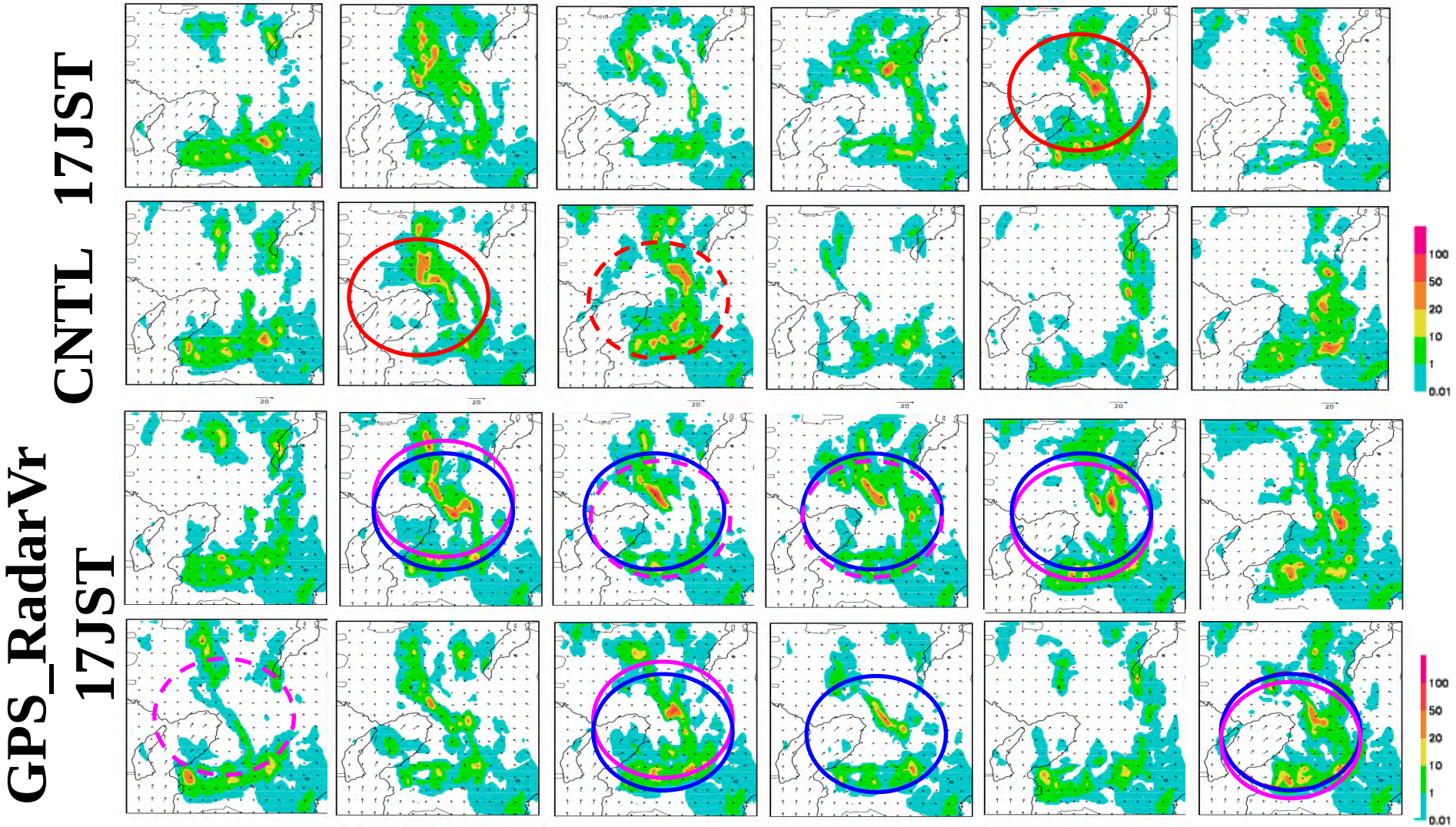
Radial winds of Doppler radar also improve the rainfall forecasts.





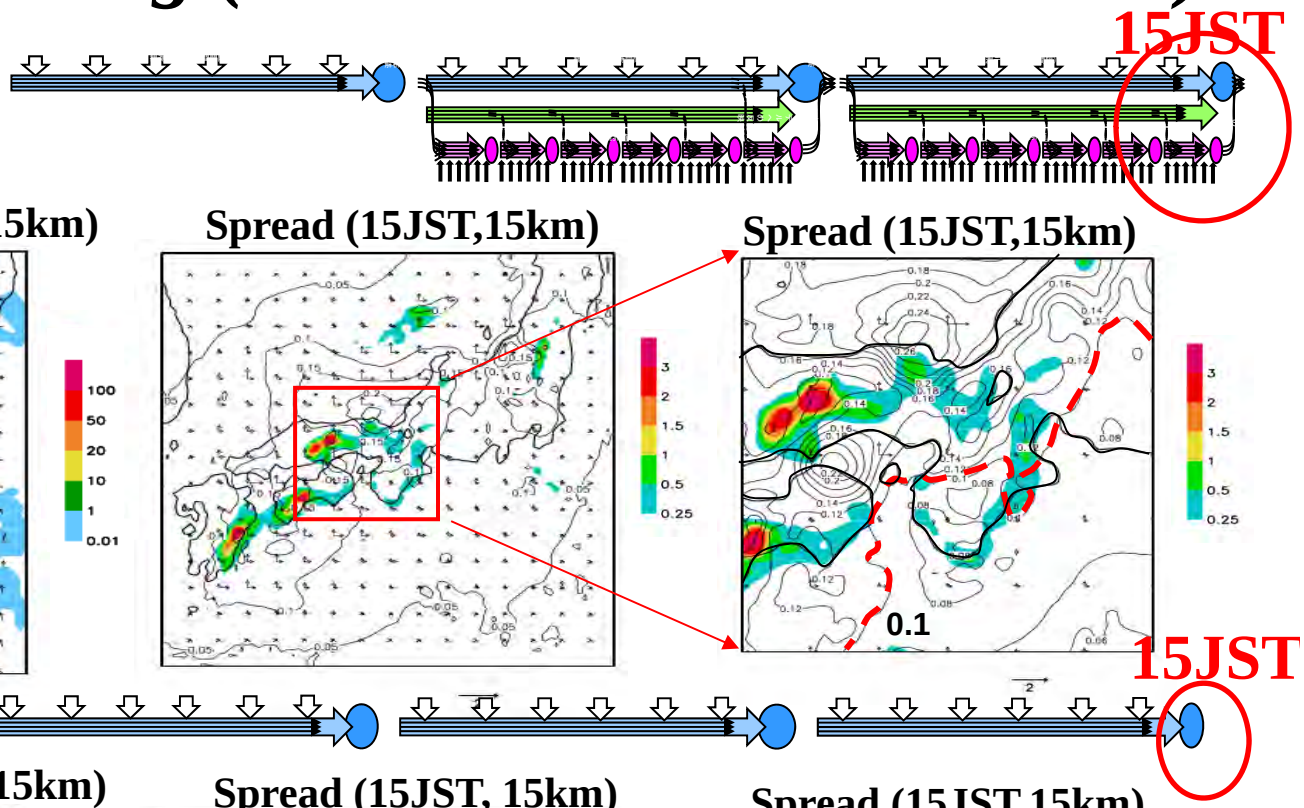
Both GPS-PWV and radial wind were assimilated simultaneously, the number of the improved members were increased.





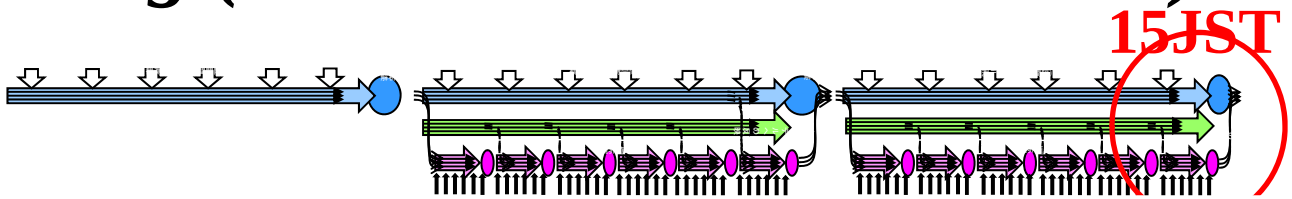
Blue and pink circles indicate the rainfalls improved by GPS and radar data

Influence of nesting (Feedback to outer LETKF)



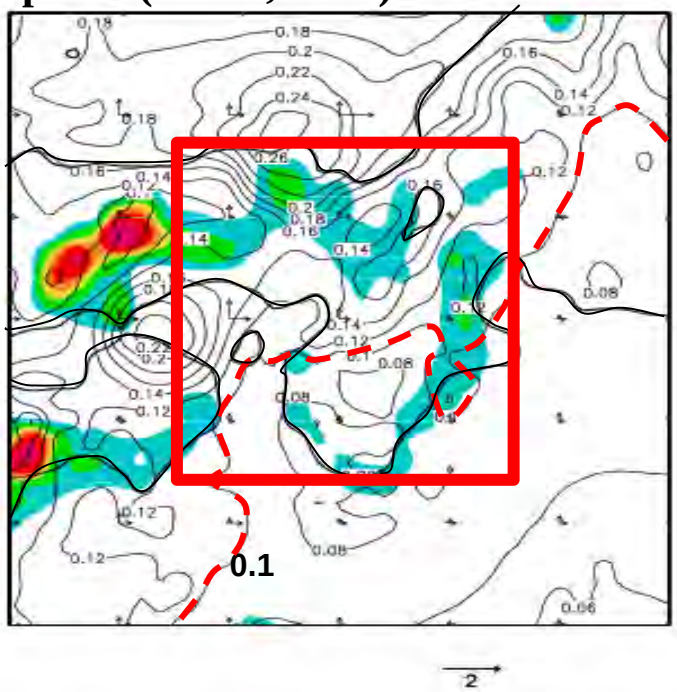
Spreads of with nest and w/o nest were compared.

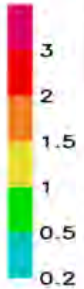
Influence of nesting (Feedback to outer LETKF)



with nest

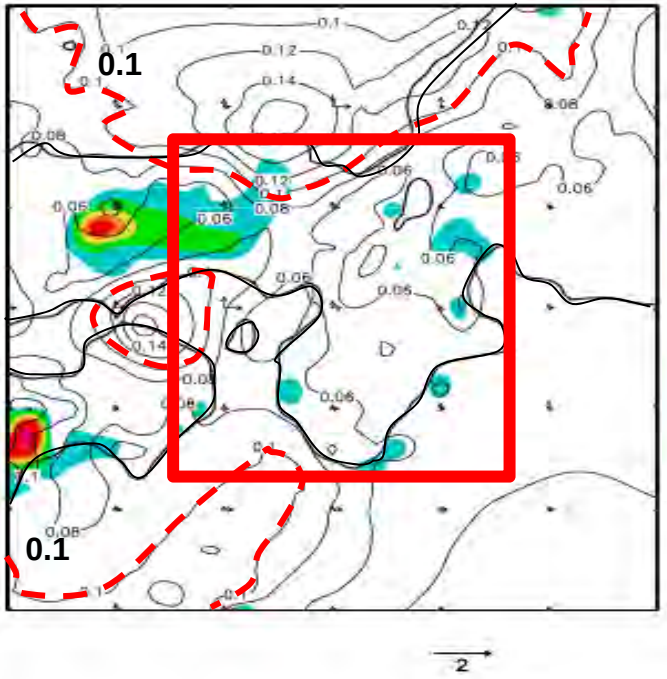
Spread (15JST,15km)





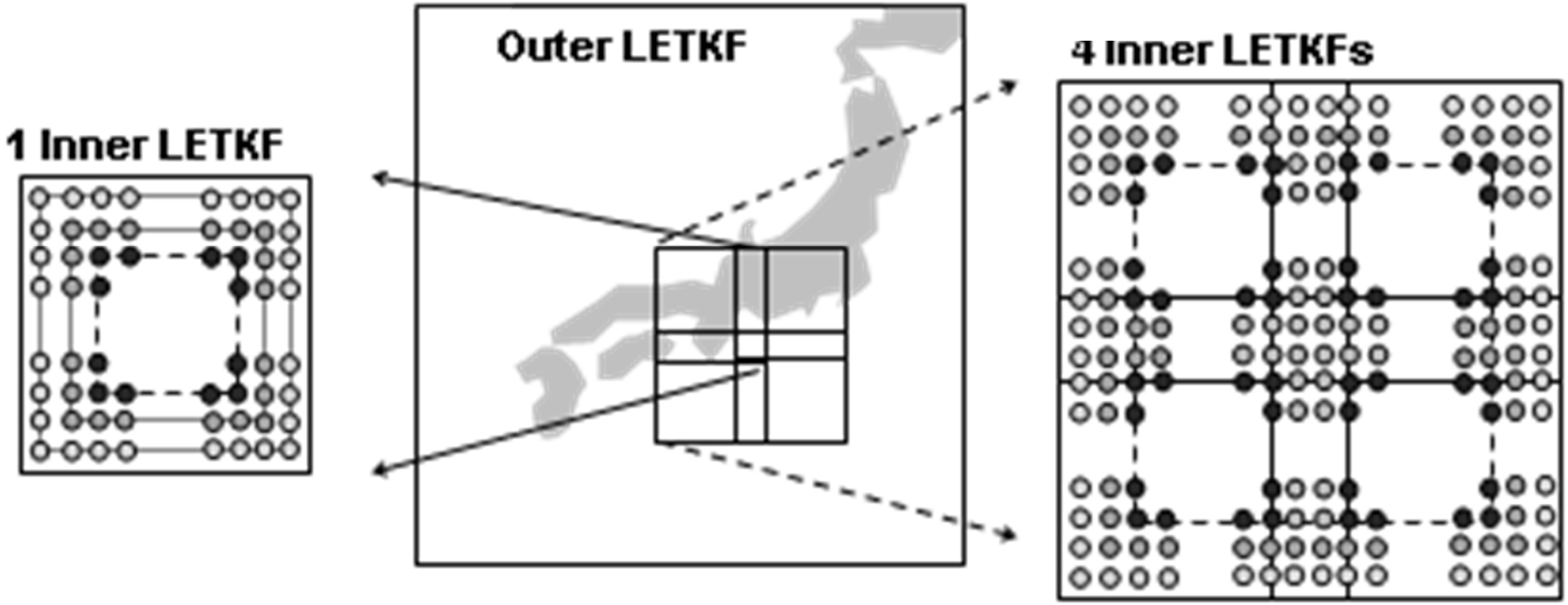
w/o nest

Spread (15JST,15km)



- Nesting increased the spread slightly in this case.
- Influence expanded into outer regions (pressure).
- More case studies are needed to obtain the conclusion.

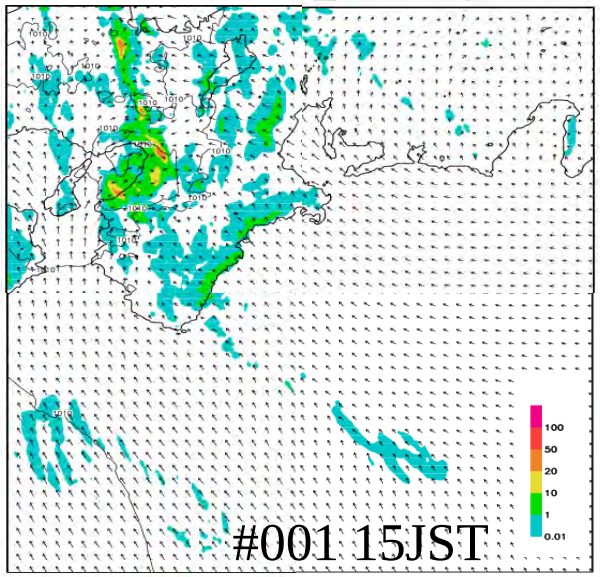
Multi inner LETKFs experiment

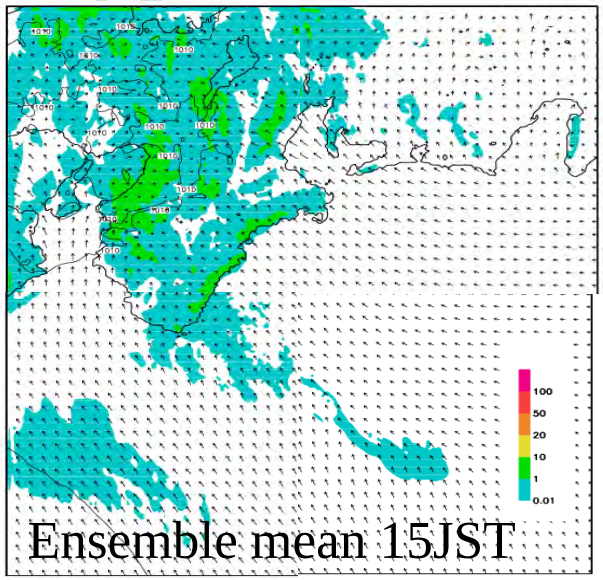


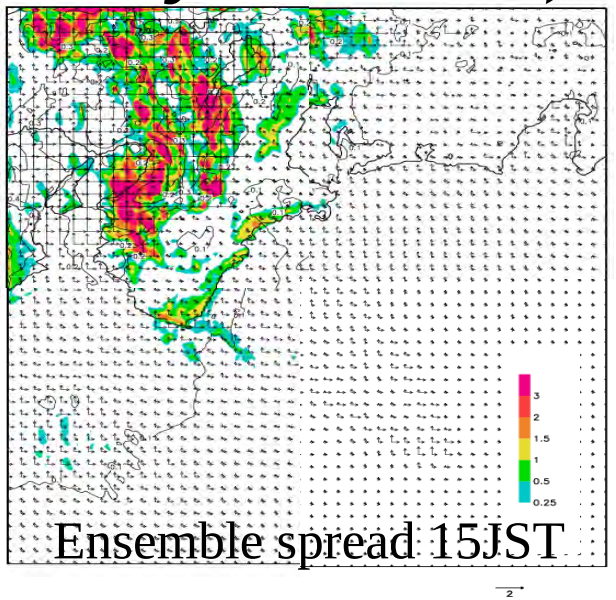
Four inner LETKFs were deployed in the outer LETKF.

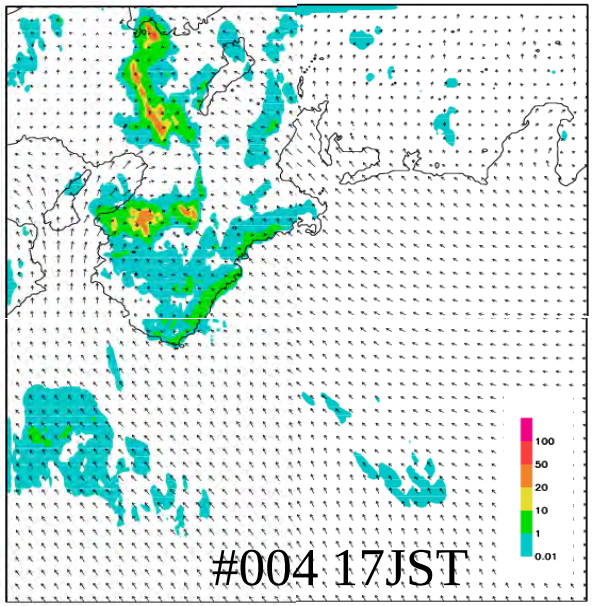
- **Weight was determined from the distance from the boundary of Inner LETKF.**
- **Inner LETKFs are not necessarily deployed next to each other**. (example. deployed at each radar sites)

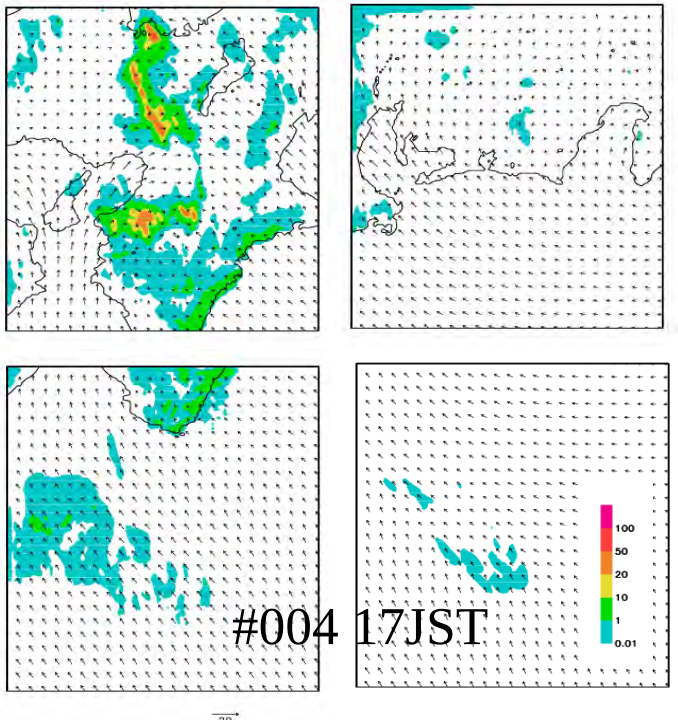
Overlap regions of patches (Boundary Problem)



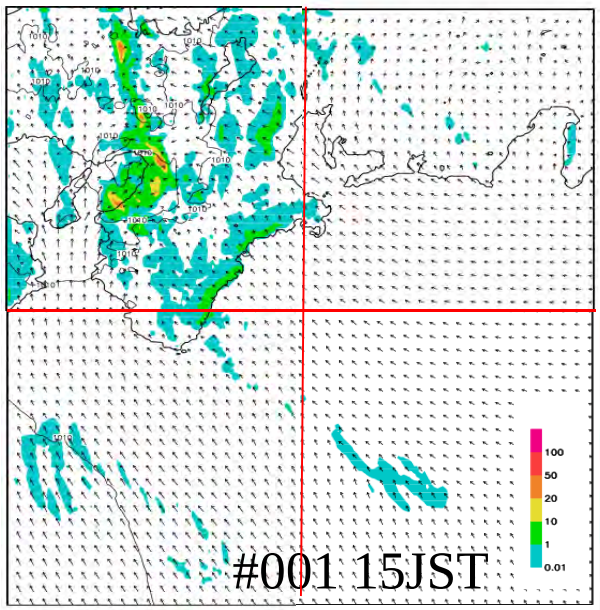


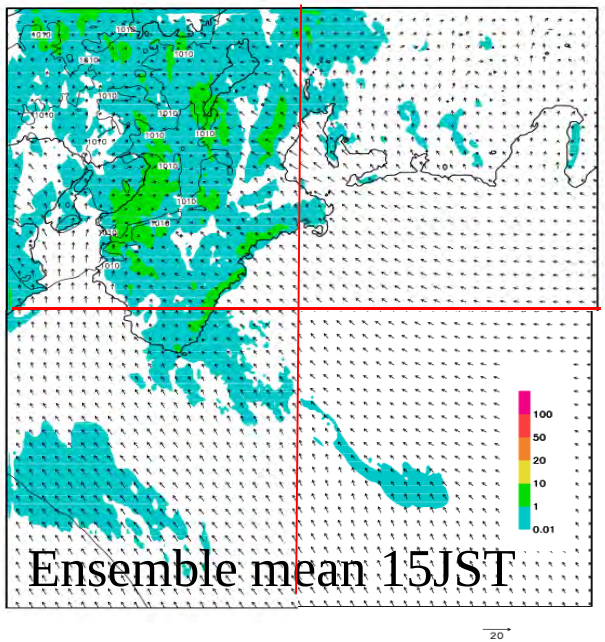


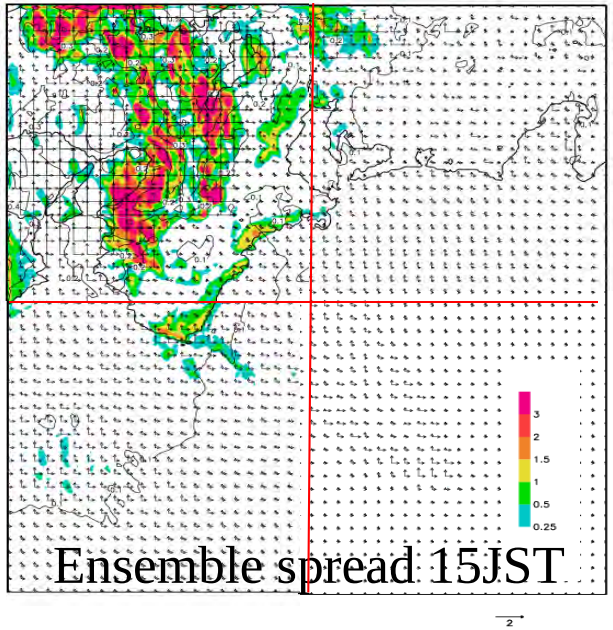


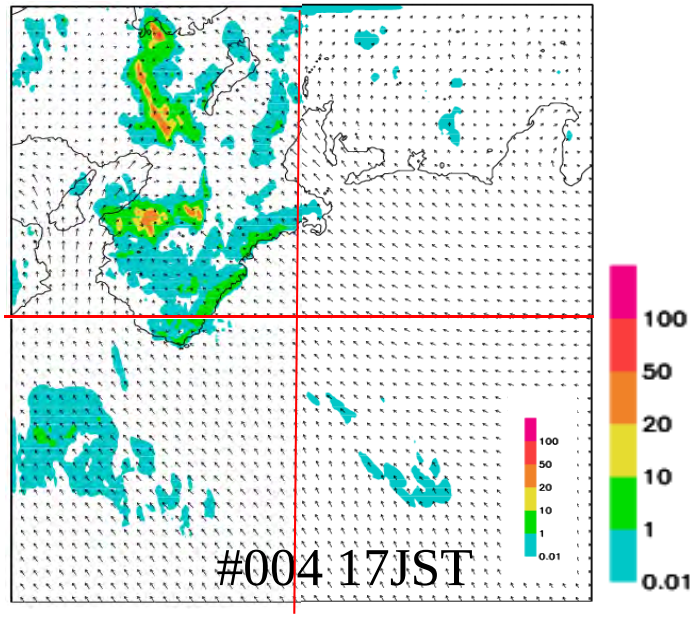


Overlap regions of patches (Boundary Problem)



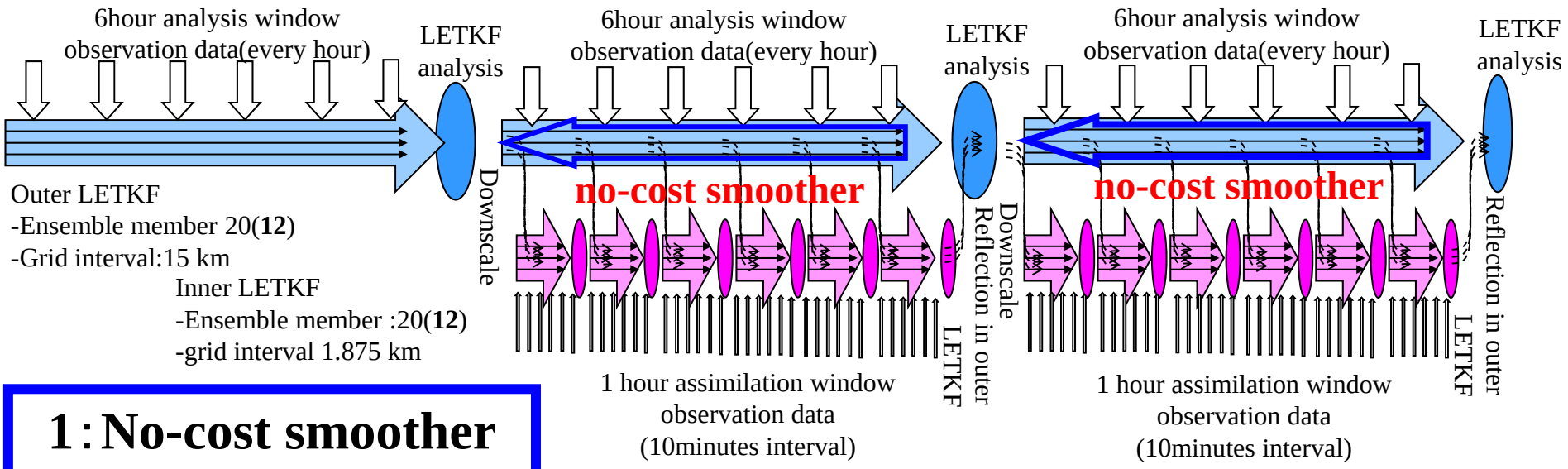




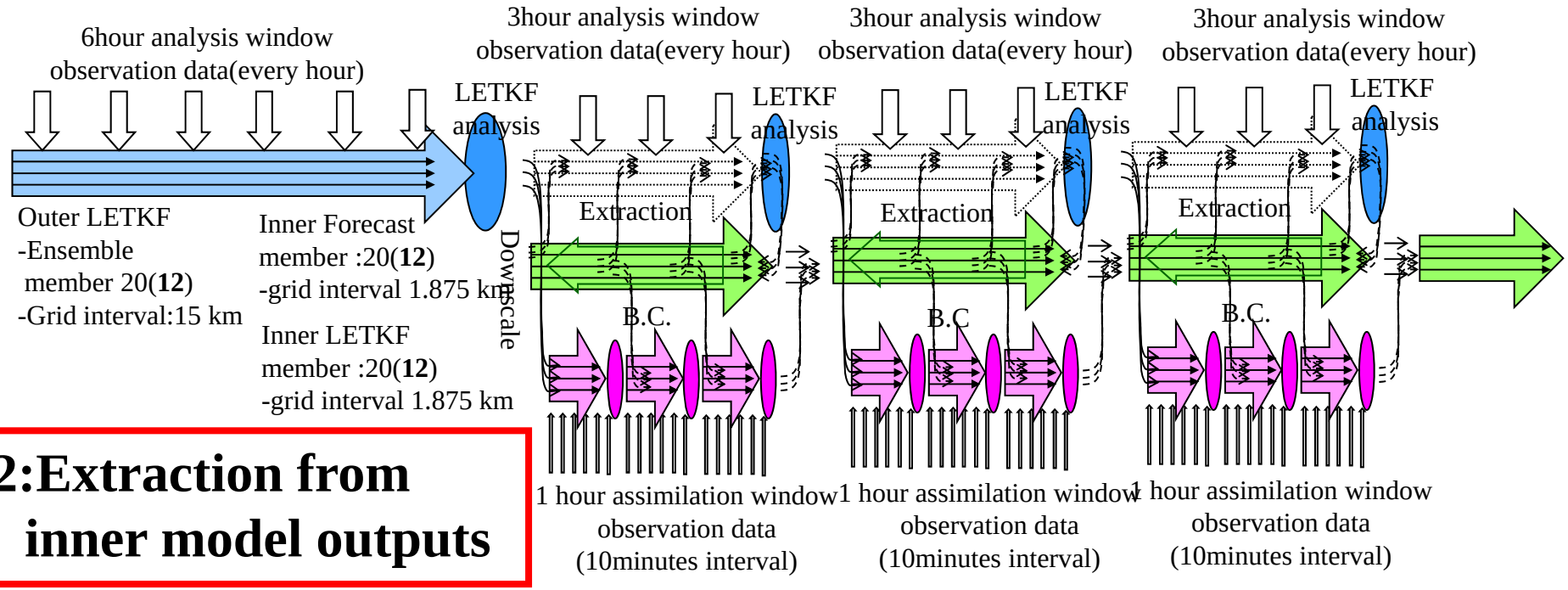


- Four inner LETKFs were deployed in the outer LETKF.
- **Unrealistic convection cells were not generated on the boundary.**

Further improvements

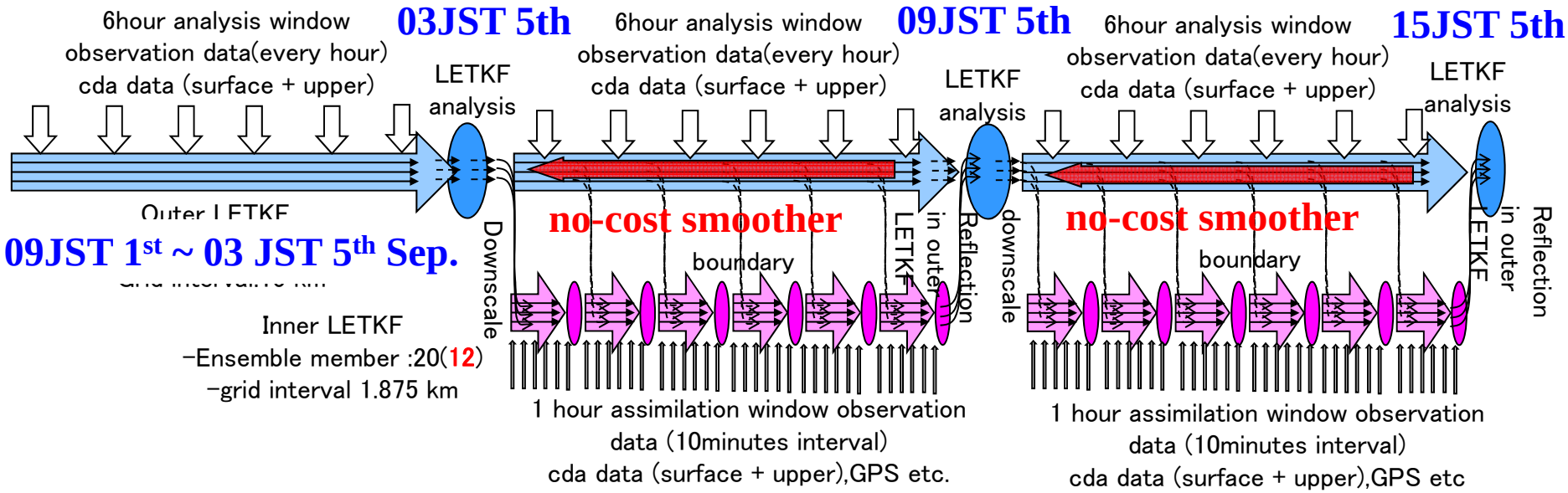


1 : No-cost smoother



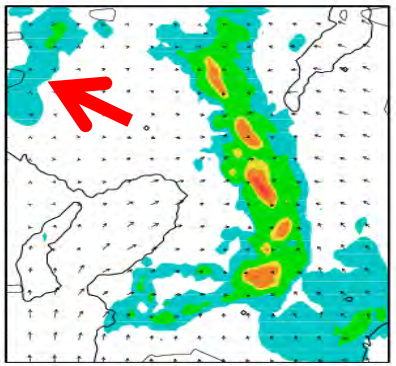
2:Extraction from inner model outputs

Utilization of no-cost smoother

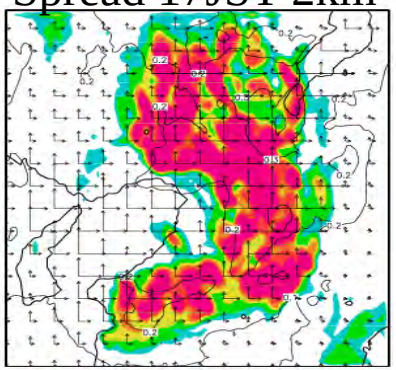


CNTL

#005 17JST 2km

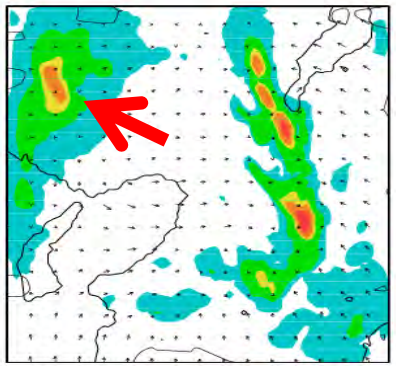


Spread 17JST 2km

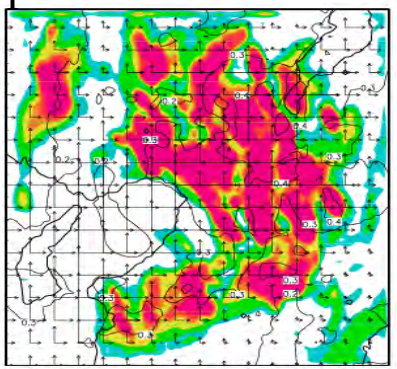


No-cost smoother

#005 17JST 2km



Spread 17JST 2km

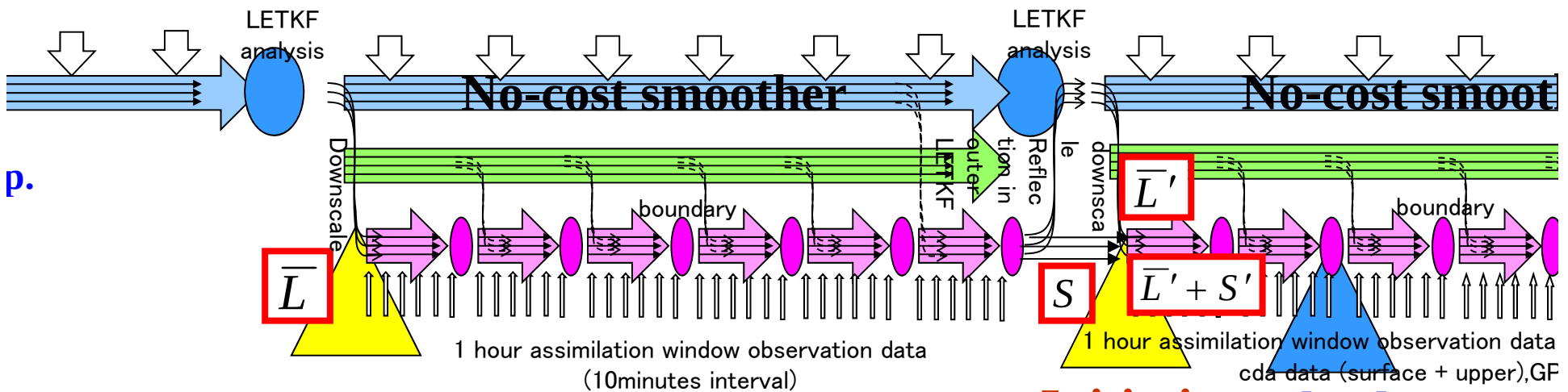


Rainfall region near the boundary was intensified.

Regions near the boundary were modified by no-cost smoother.

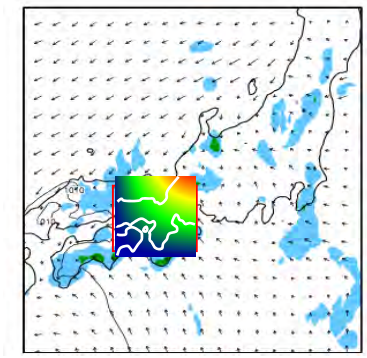
Influence of convective scale disturbances

03JST 5th **09JST 5th**



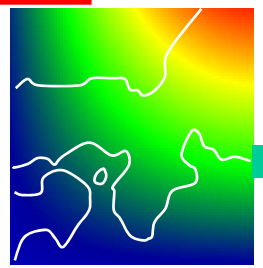
p.

Initiation Check

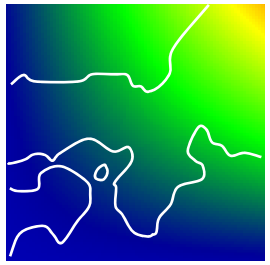


Outer LETKF

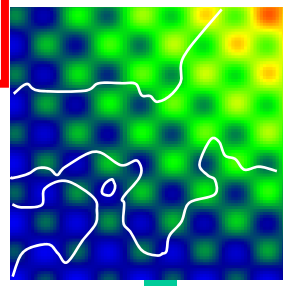
$\overline{L}'$

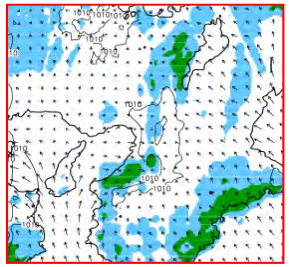


$\overline{S}$



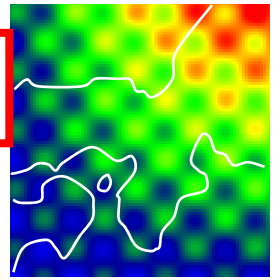
S



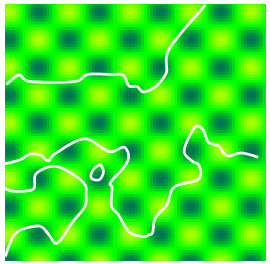


Inner LETKF

$\overline{L}' + S'$



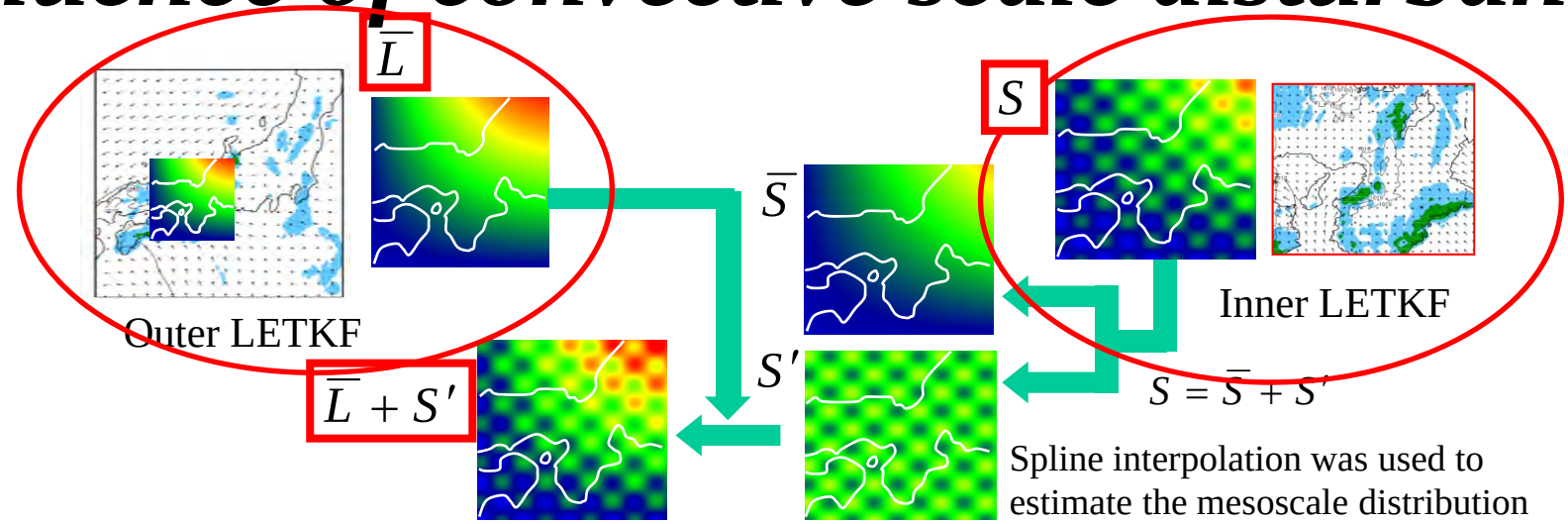
S'



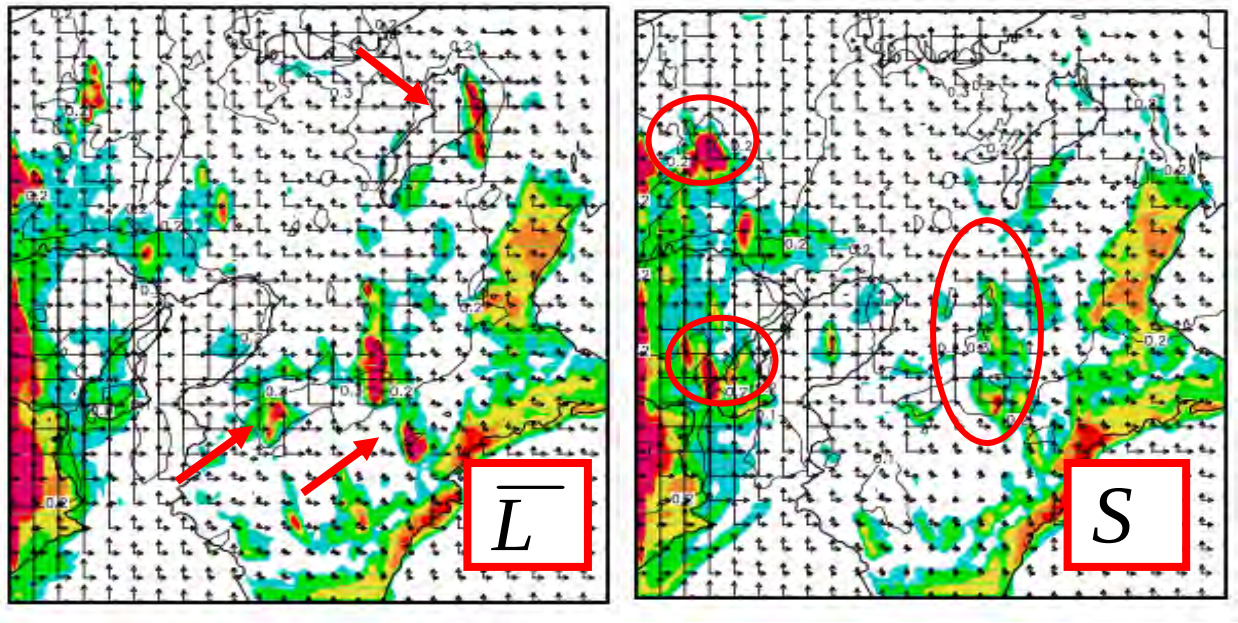
$S = \overline{S} + S'$

Spline interpolation was used to estimate the mesoscale distribution

Influence of convective scale disturbances



Spread of 11JST (2 cycles of Inner LETKF, 2km)

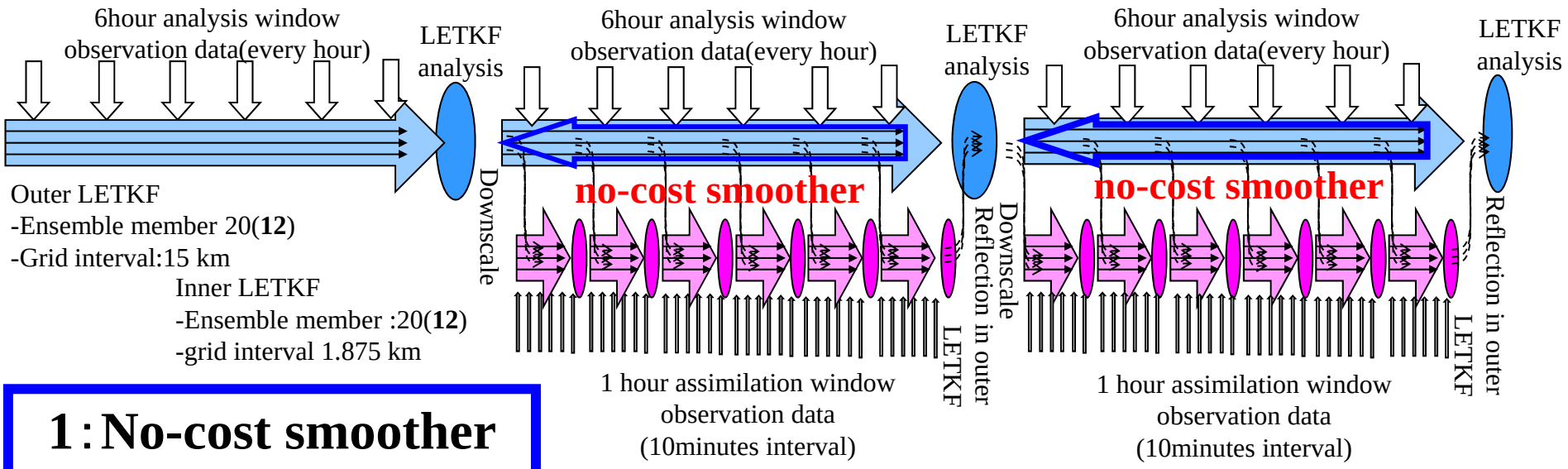


Large spread area in $\overline{L}$ corresponds to mountain ranges.

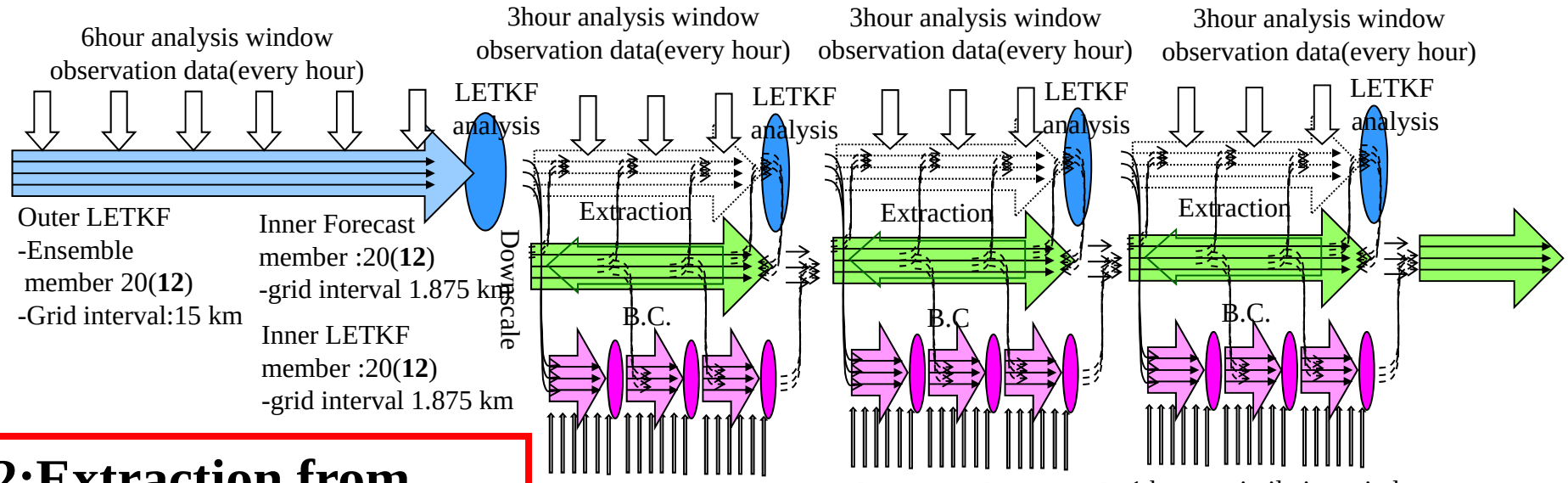
S different from $\overline{L}$.

S should be used because it contains ***small scale perturbations.***

Further improvements



1 : No-cost smoother

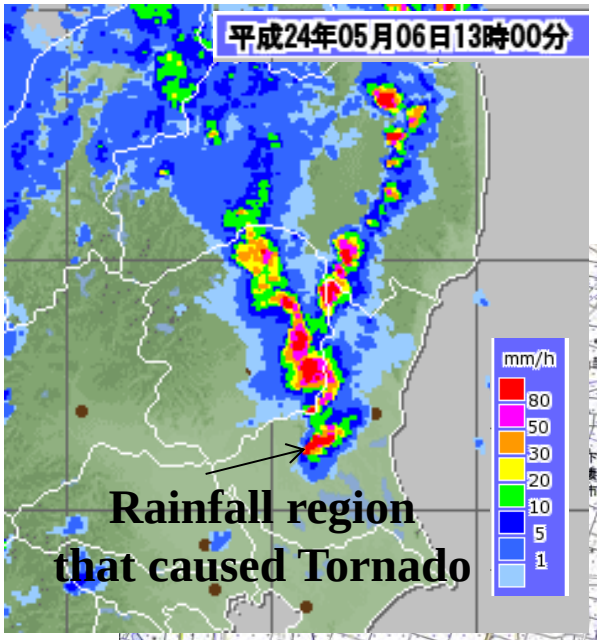


2:Extraction from inner model outputs

Summary and future plan

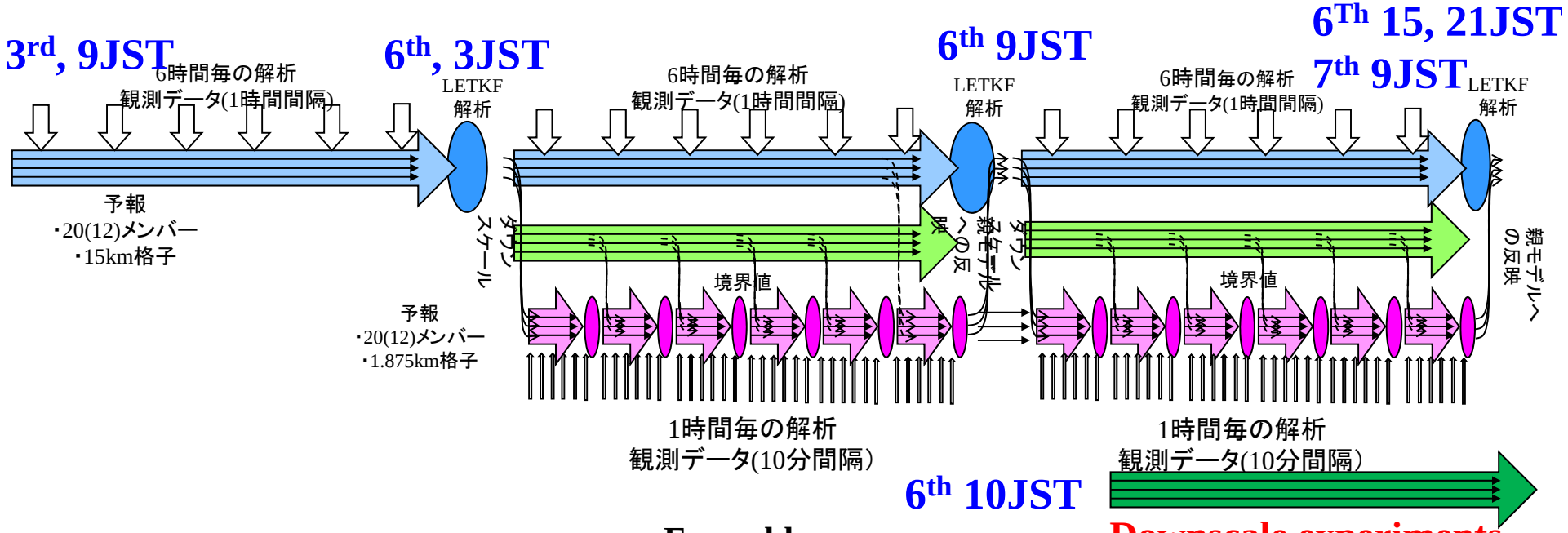
1. The nested LETKF system is under development to reproduce the environments and convection cells.
2. The Sakai intense rainfall on 5th Sep. 2008 was reproduced by the nested LETKF system.
3. GPS-water vapor data and the radial winds of the radar data increased the number of forecasts in which the thunderstorm was reproduced.
4. The number of kinds of assimilation data will be increased. Other improvements on the nested system will be implemented.

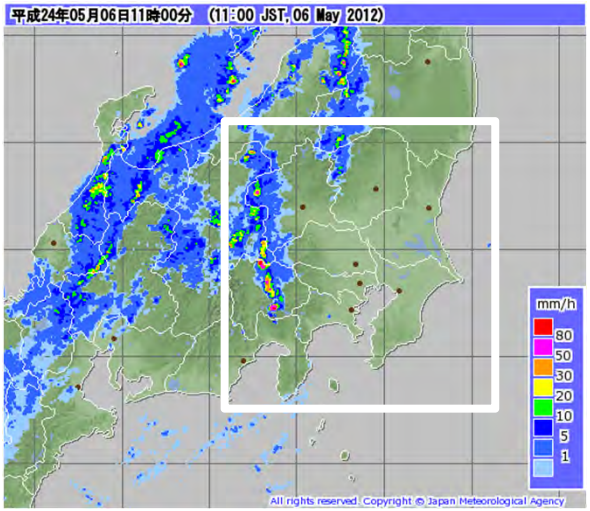
Tornado Occurred on 6th May 2012



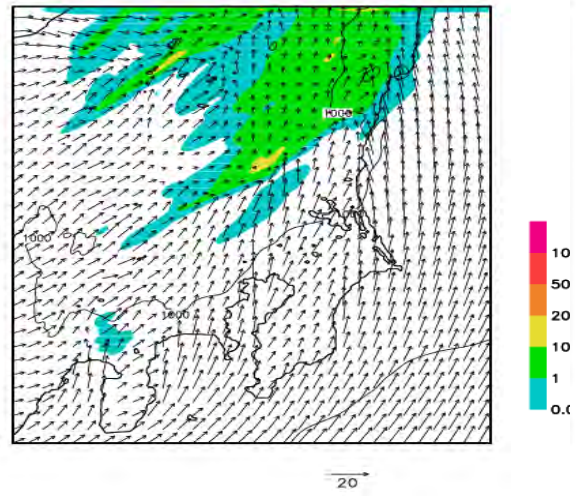
http://mainichi.jp

Tornado Occurred on 6th May 2012

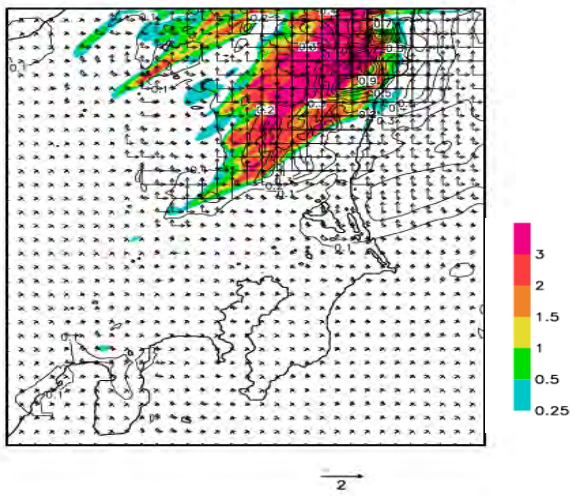


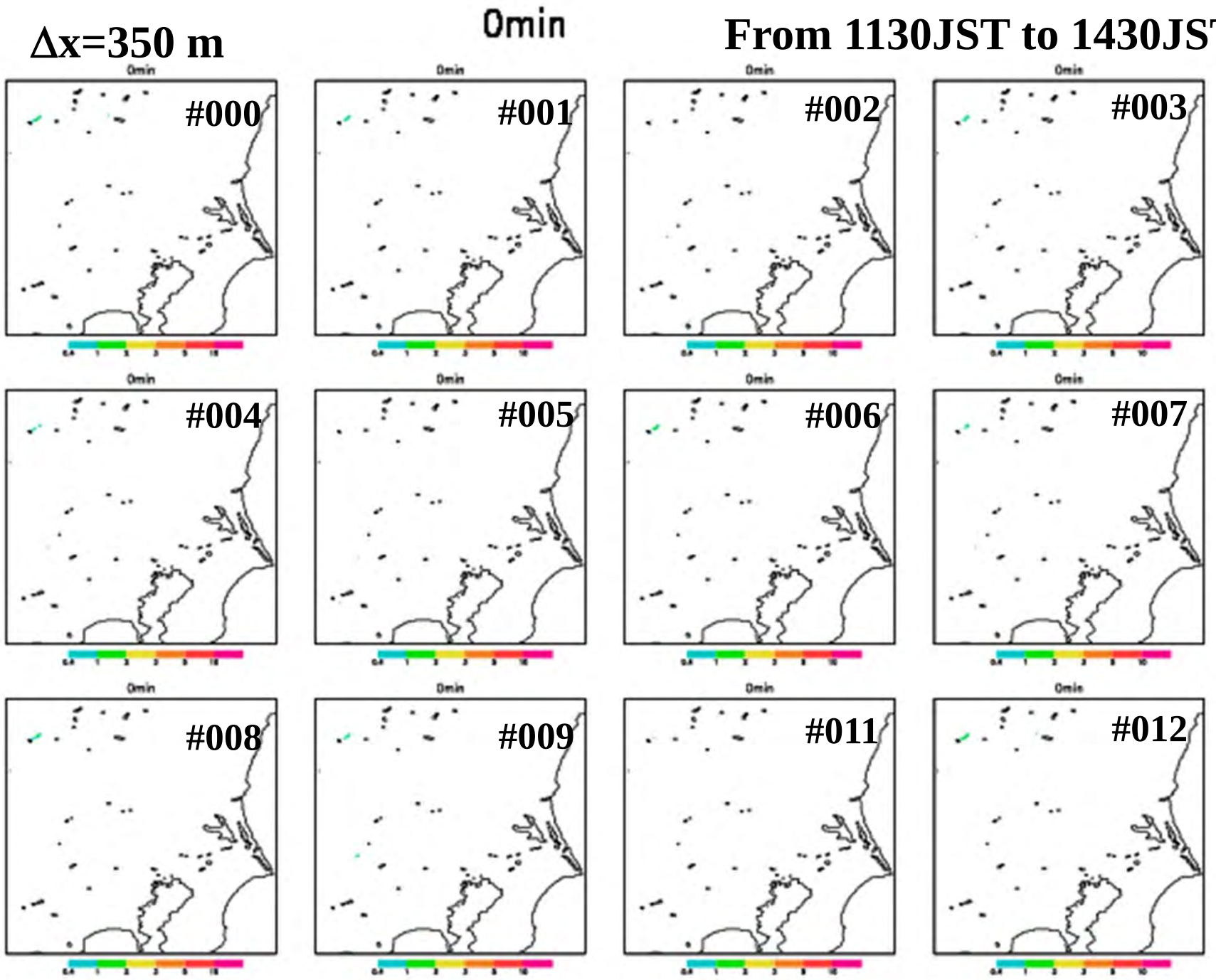


Ensemble mean of Inner LETKF at 12JST 1 hour rainfall



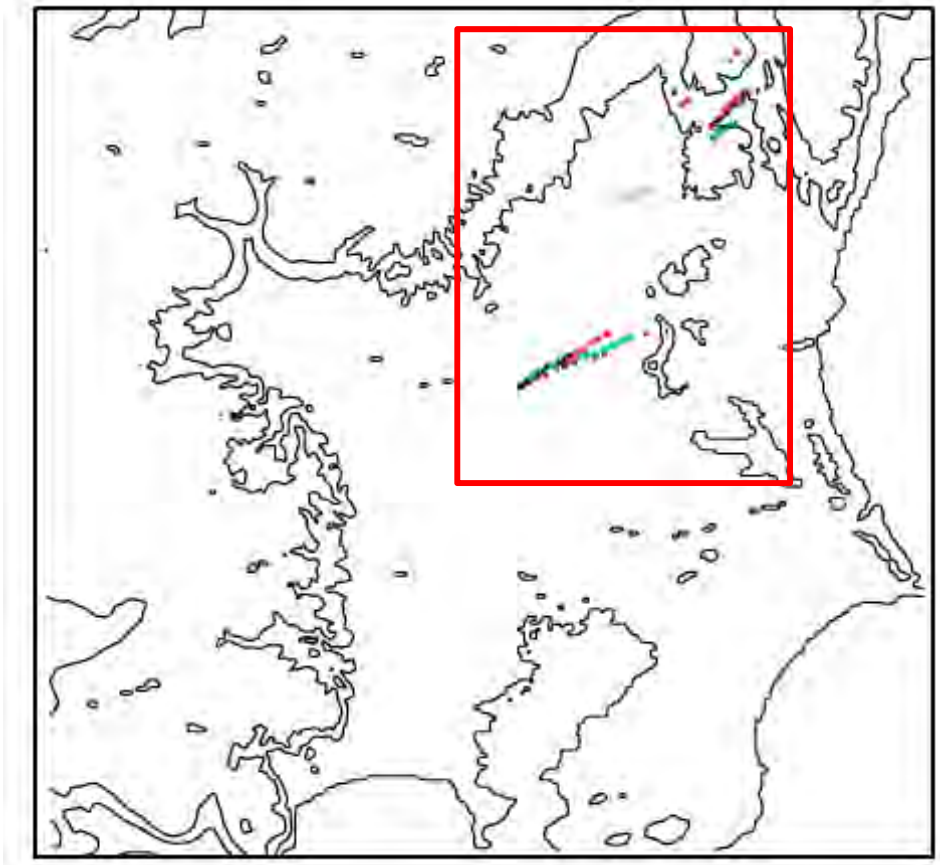
Spread at 12JST 1 hour rainfall

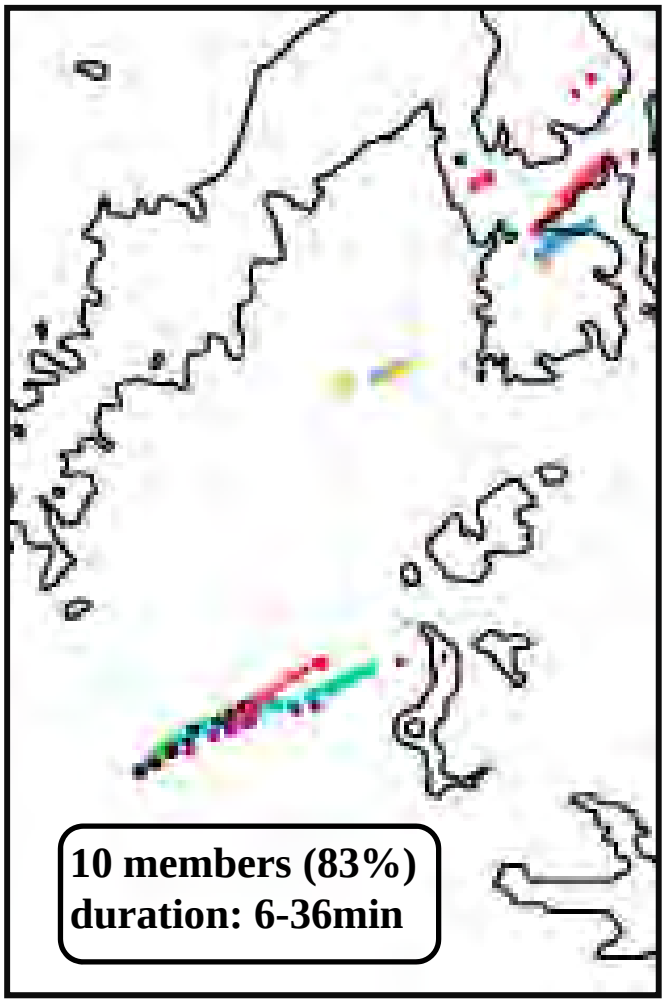



Δx=350 m
0min
From 1130JST to 1430JST
#000
#001
#002
#003
#004
#005
#006
#007
#008
#009
#011
#012

Downscale Experiments with Δx=350m

Positions of vortices more than 0.1(1/s)





- **Positions and durations depend on the ensemble members.**
- **Tornados occurred in three areas, which were the same as the observations though they were shifted northward by 10 km.**

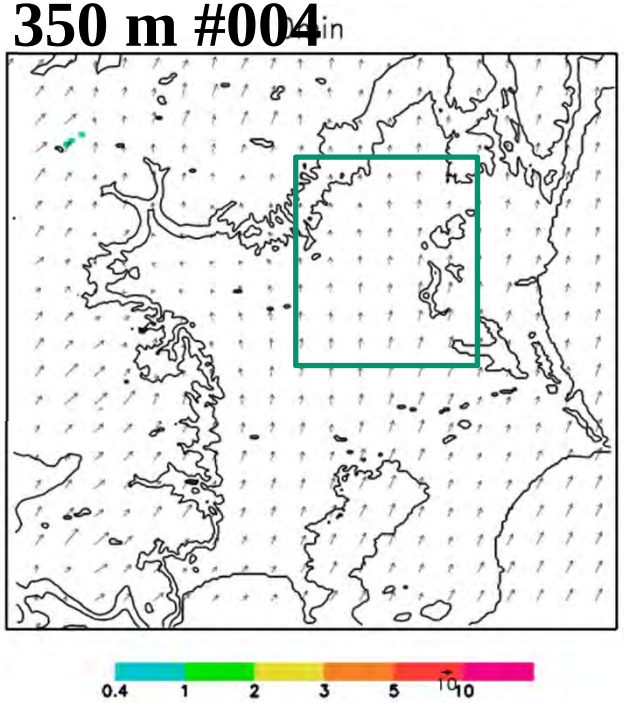
Downscale Experiments with Δx=350m

From 1130JST
to 1430JST

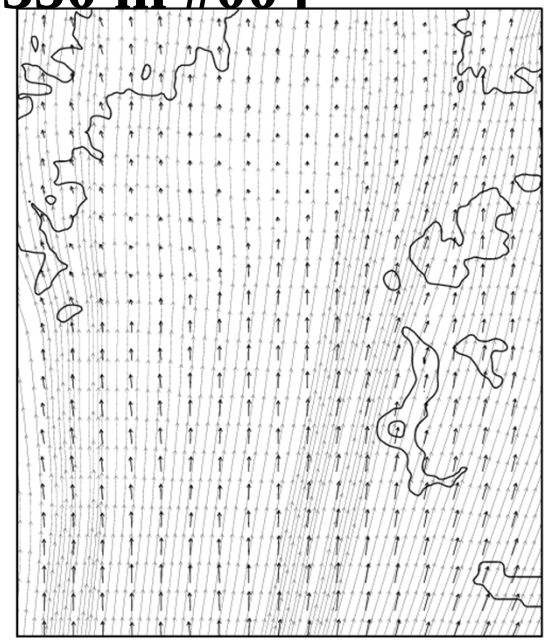
#004:
Intense vortex is maintained.

#007:
Intense vortex isn't generated.

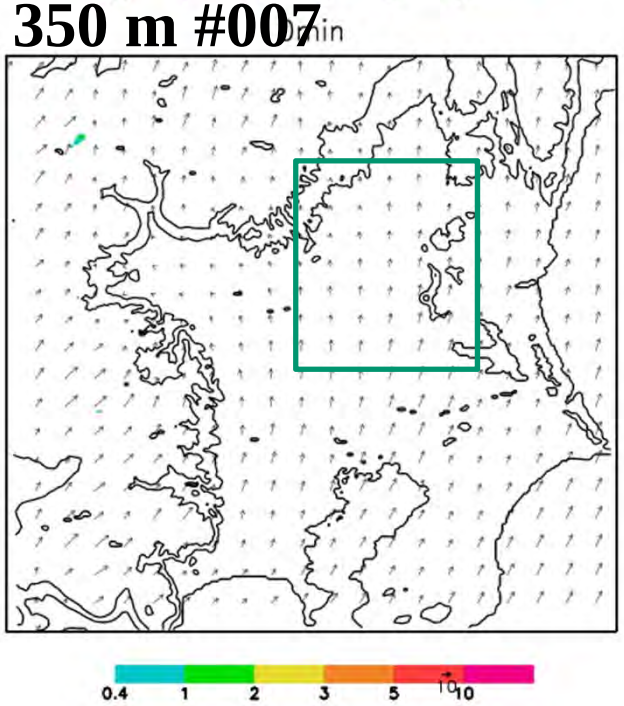
350 m #004



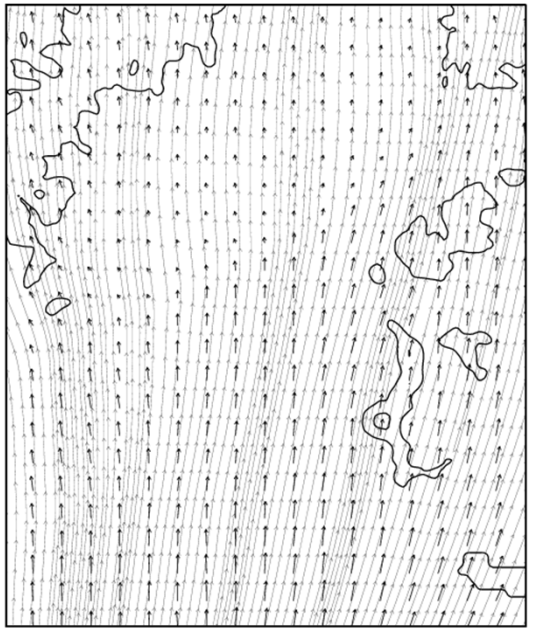
350 m #004

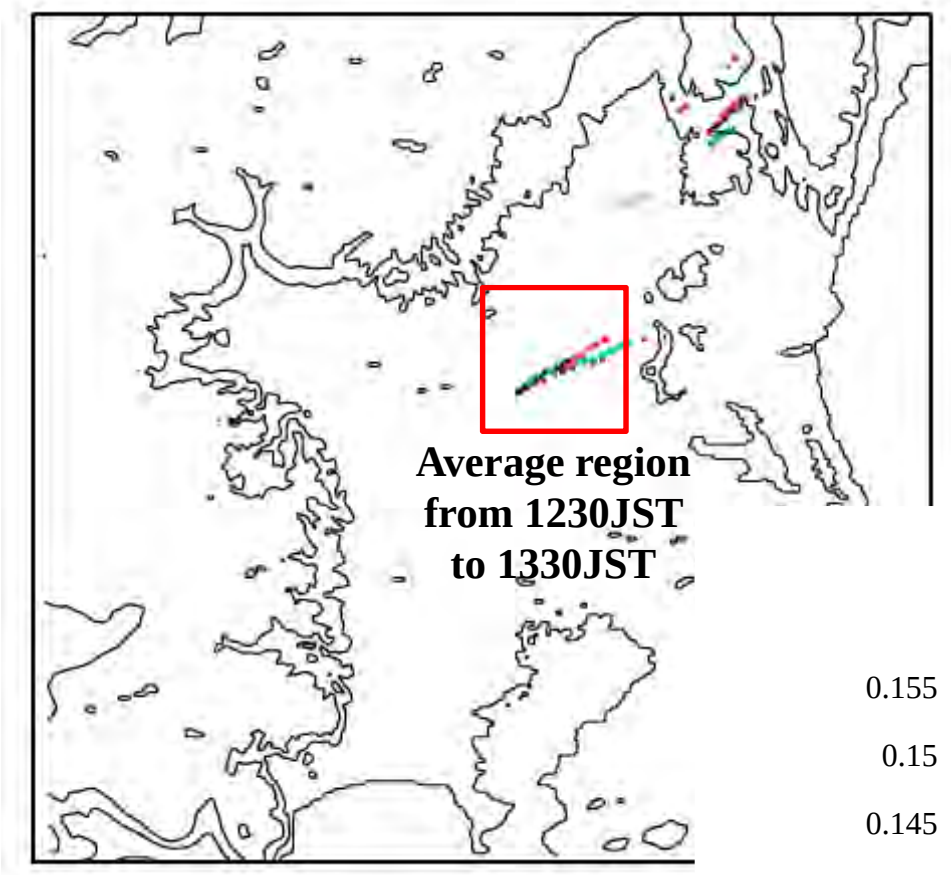


350 m #007

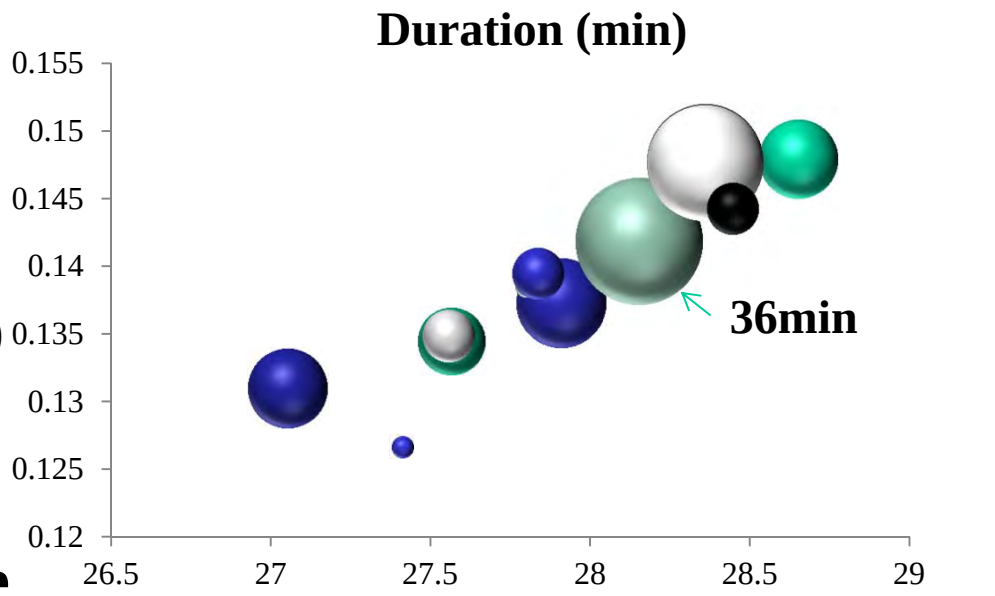


350 m #007



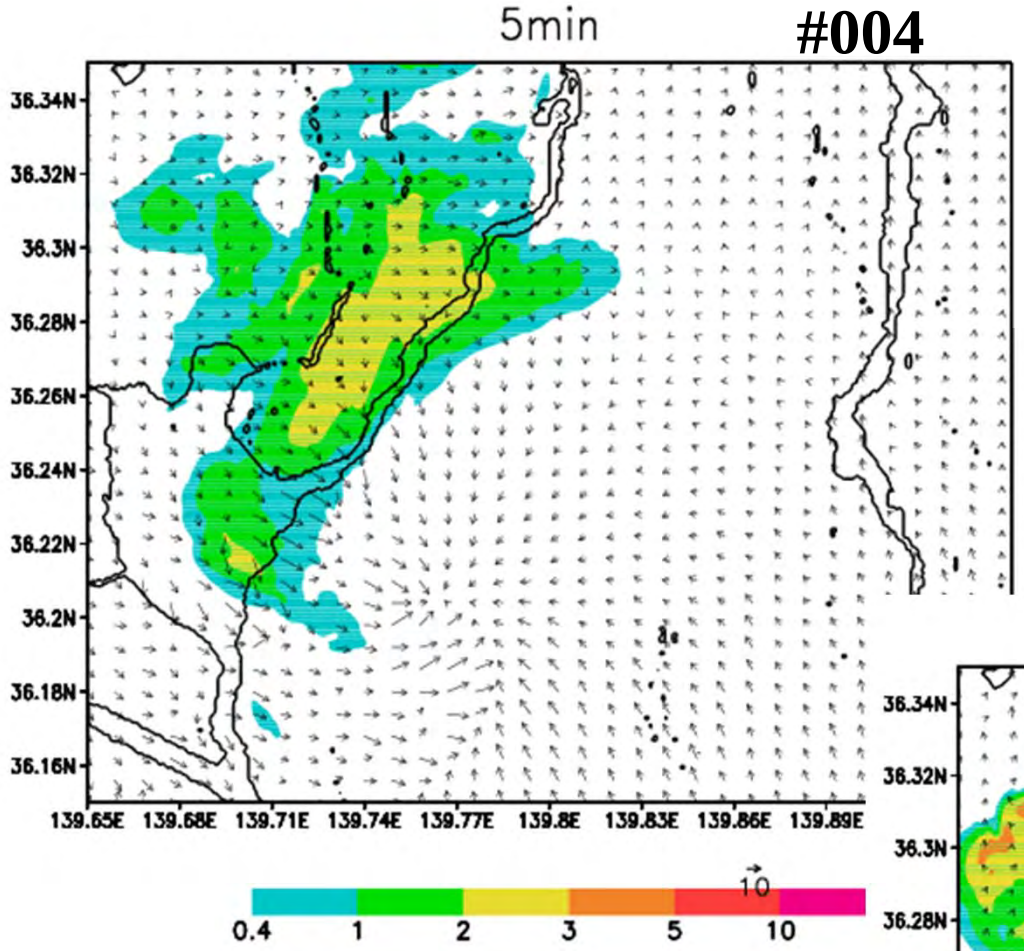


Downscale Experiments with Δx=350m

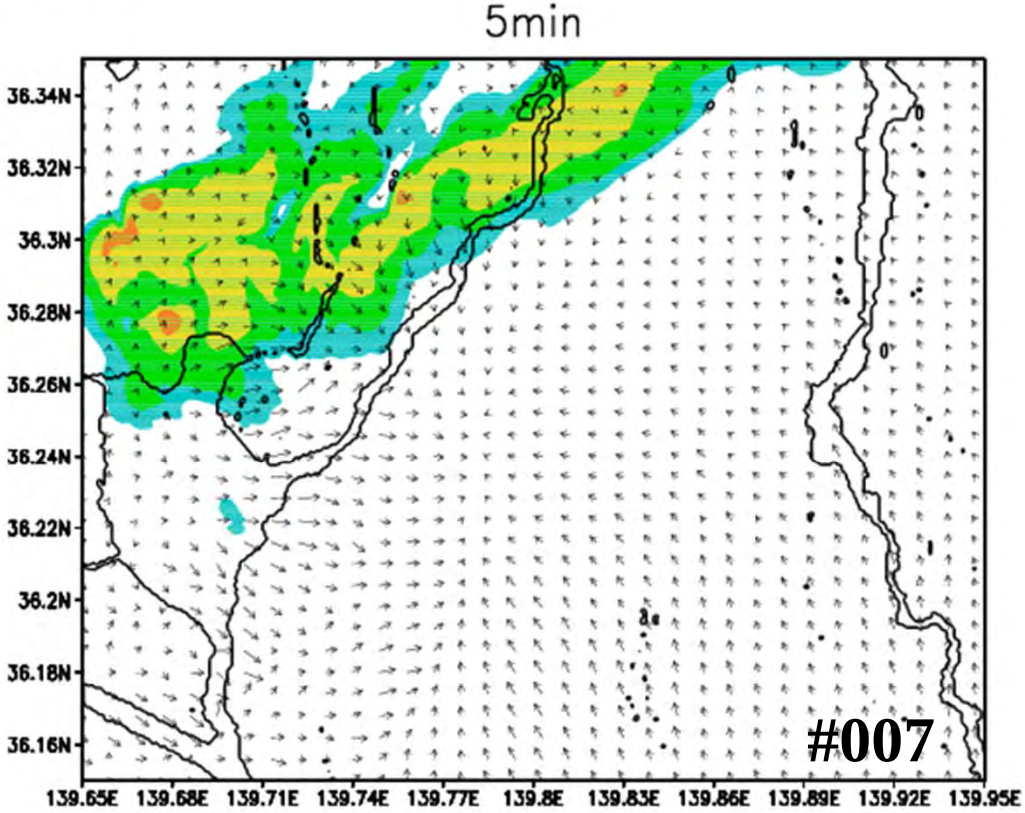


- Circles indicate the duration of tornados.
- Duration is long when water vapor at 550m height is large and vertical shear between 5km-0.5km was large.

Downscale Experiments with Δx=50m

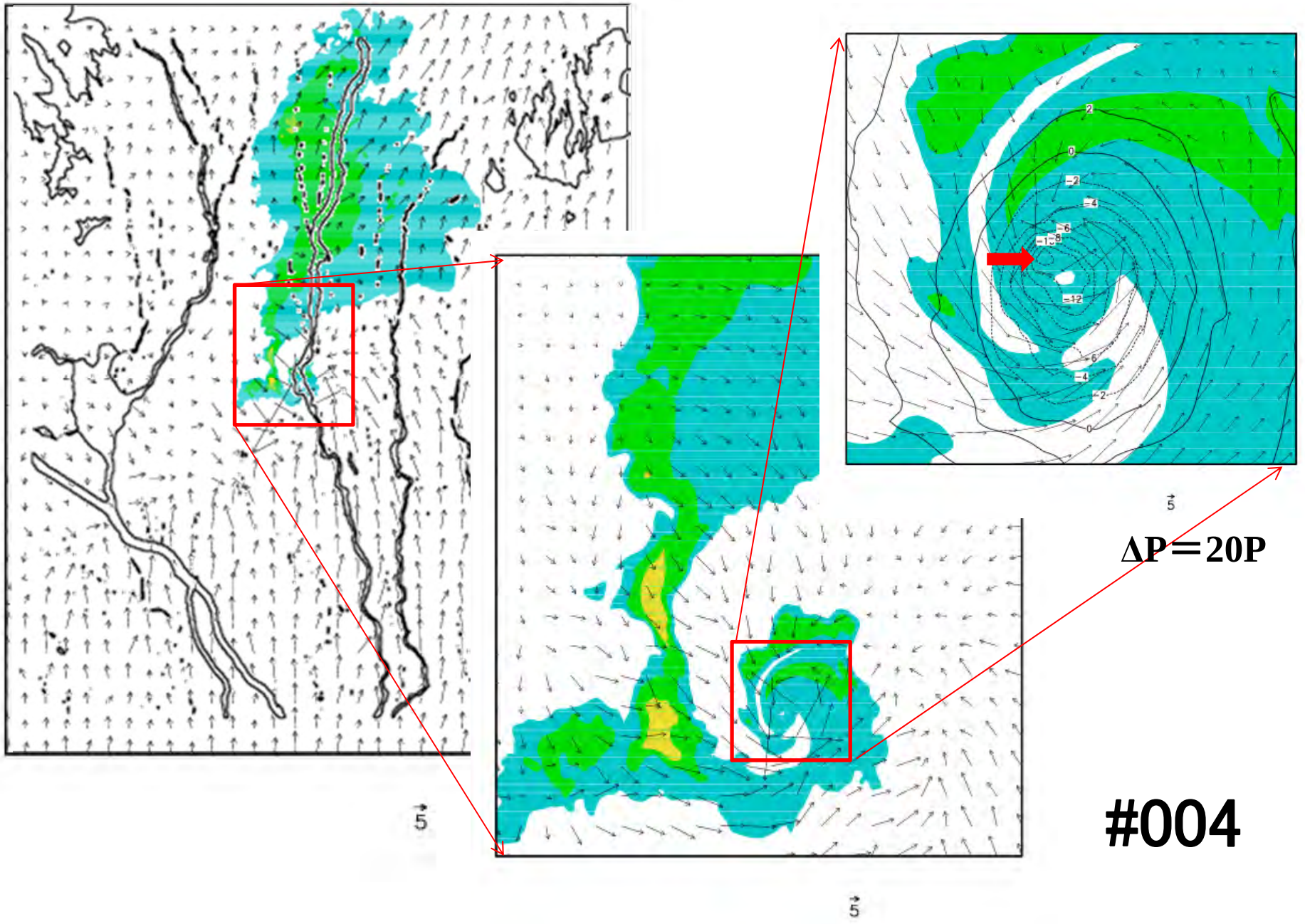


- From 1240JST to 1320JST
- Shifted northward.
- Vortex was intensified at 1250～1300JST.

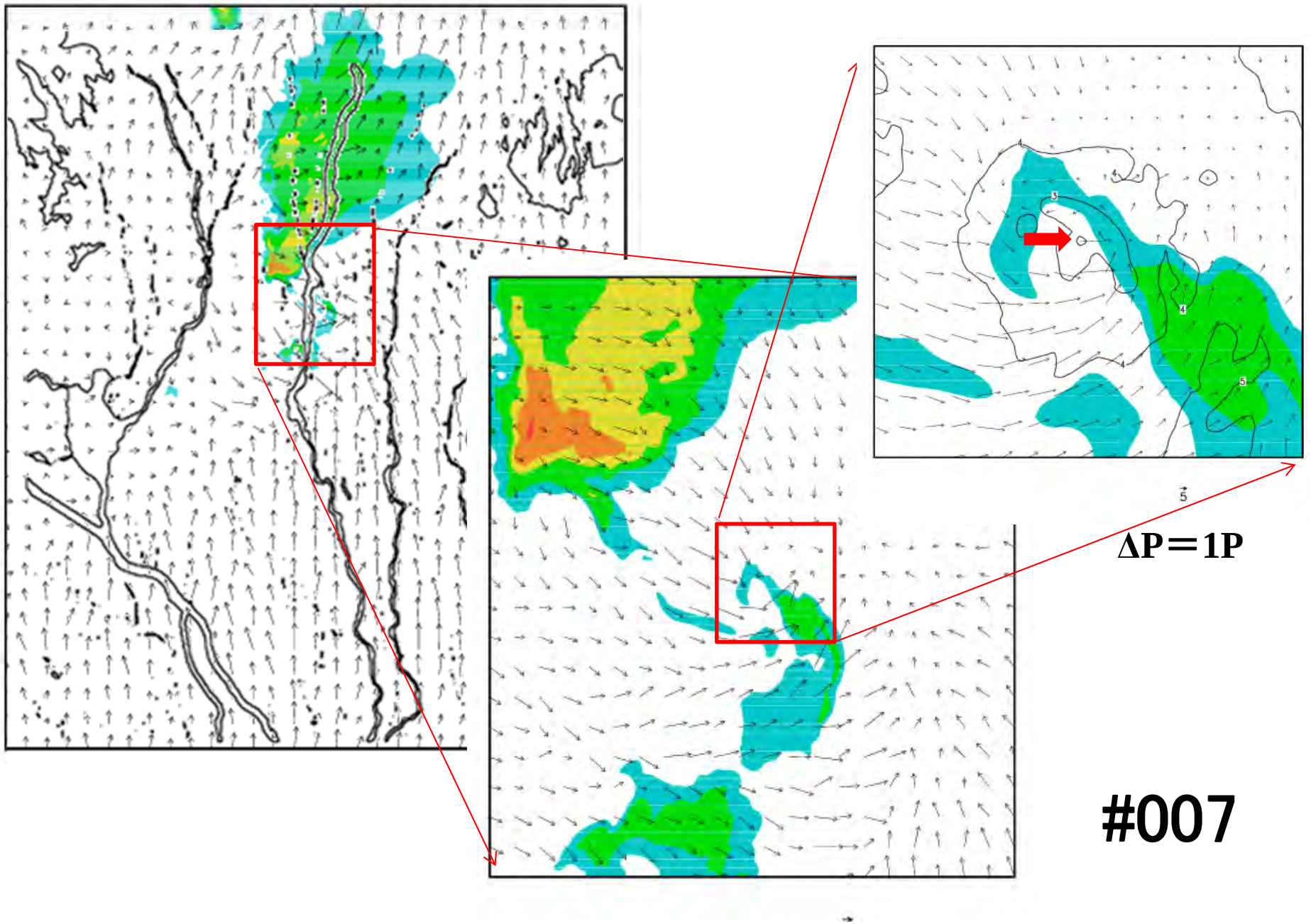


- Red points indicate vortices > 0.4 (1/s)
- Horizontal wind at 600 m height
- Rain at 20 m height.

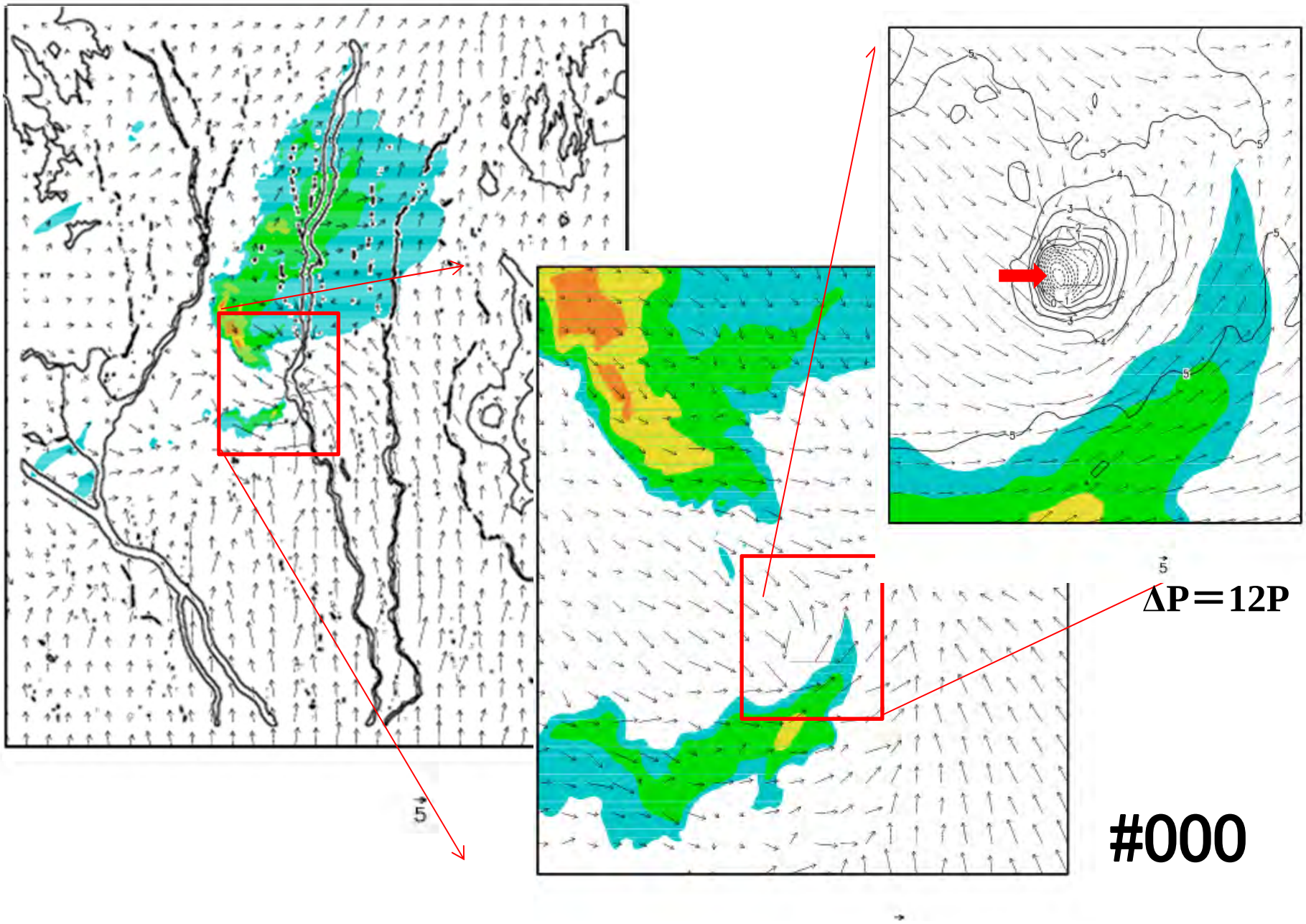
Downscale experiments Δx=50m



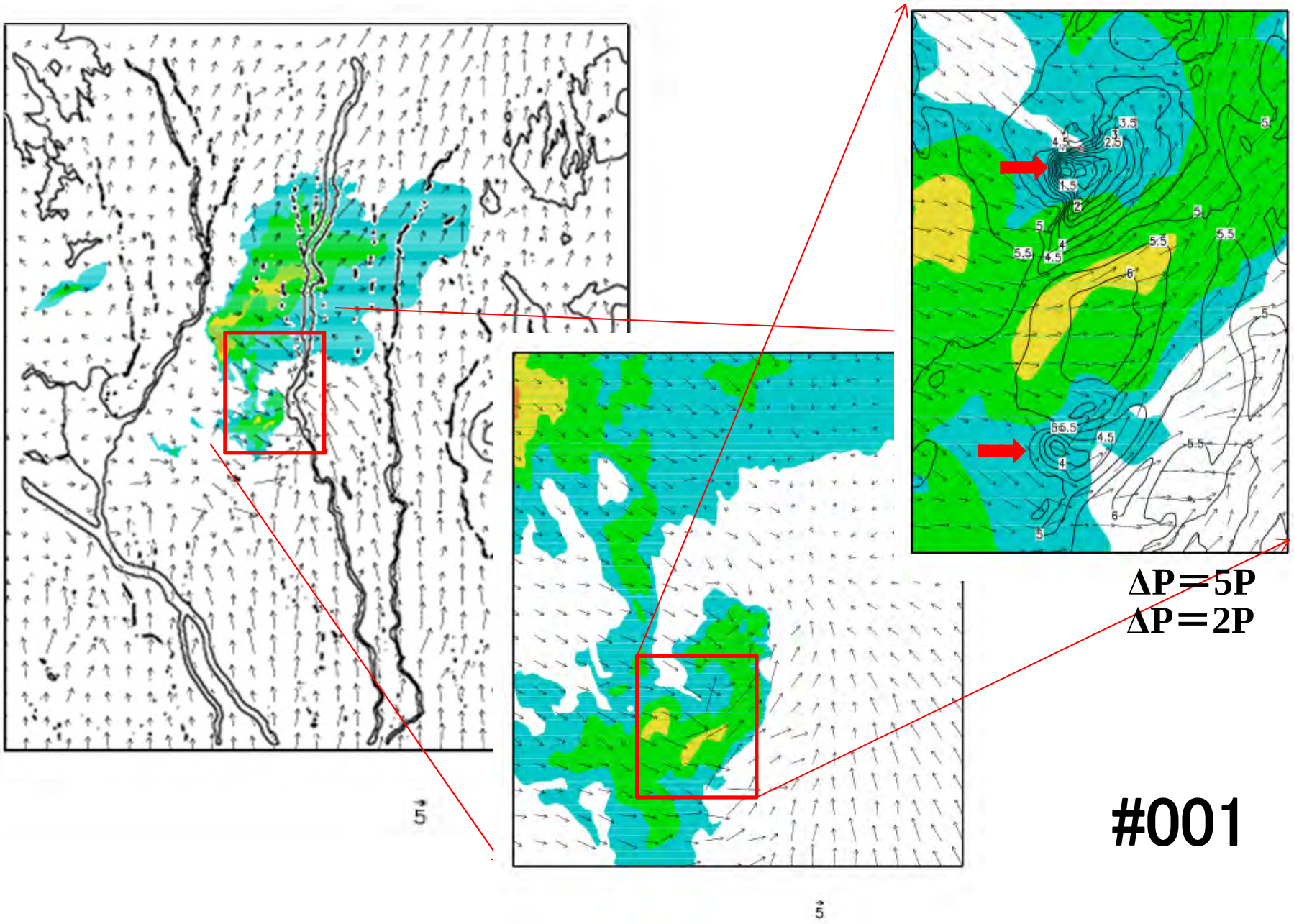
Downscale experiments Δx=50m



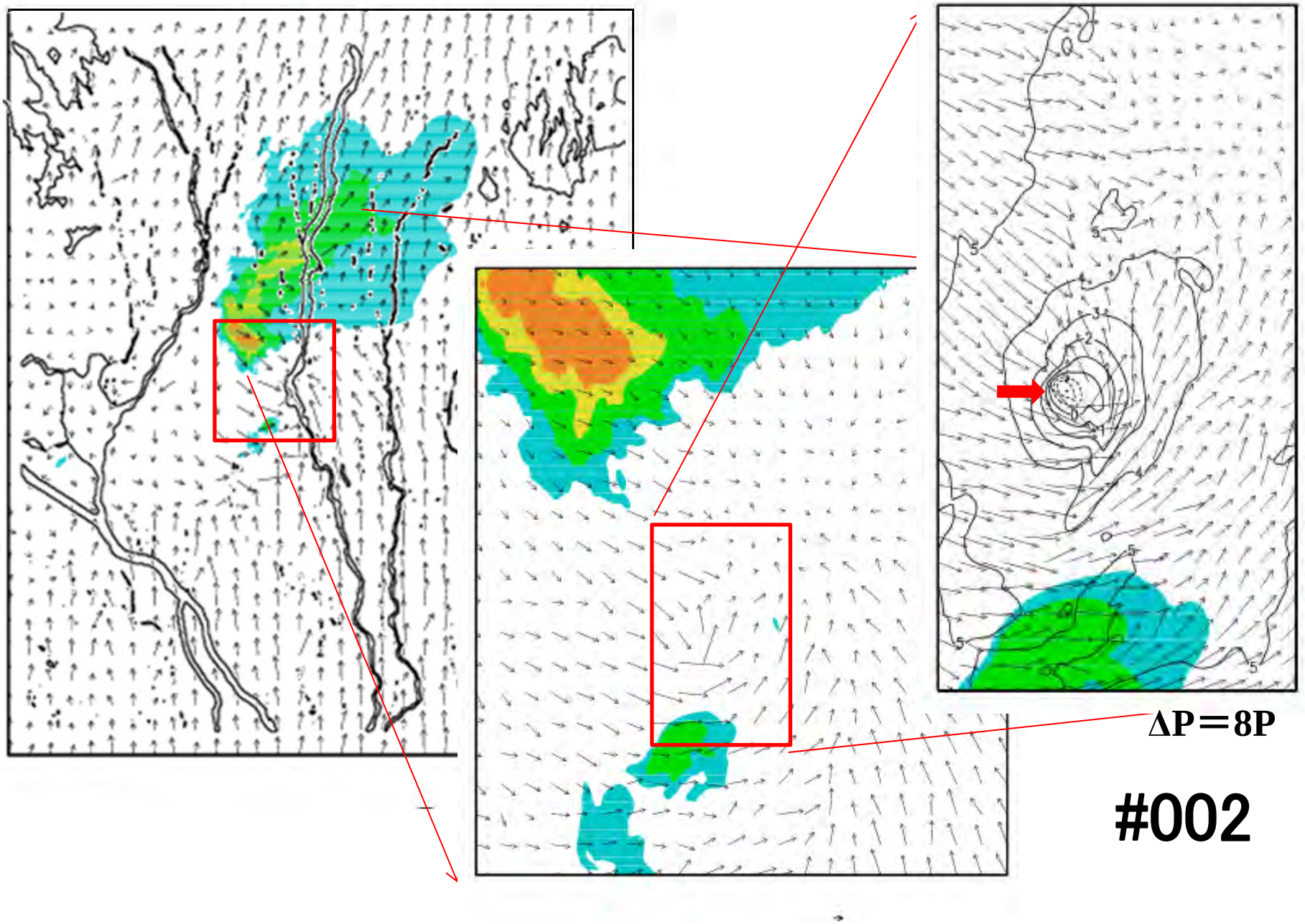
Downscale experiments Δx=50m



Downscale experiments Δx=50m



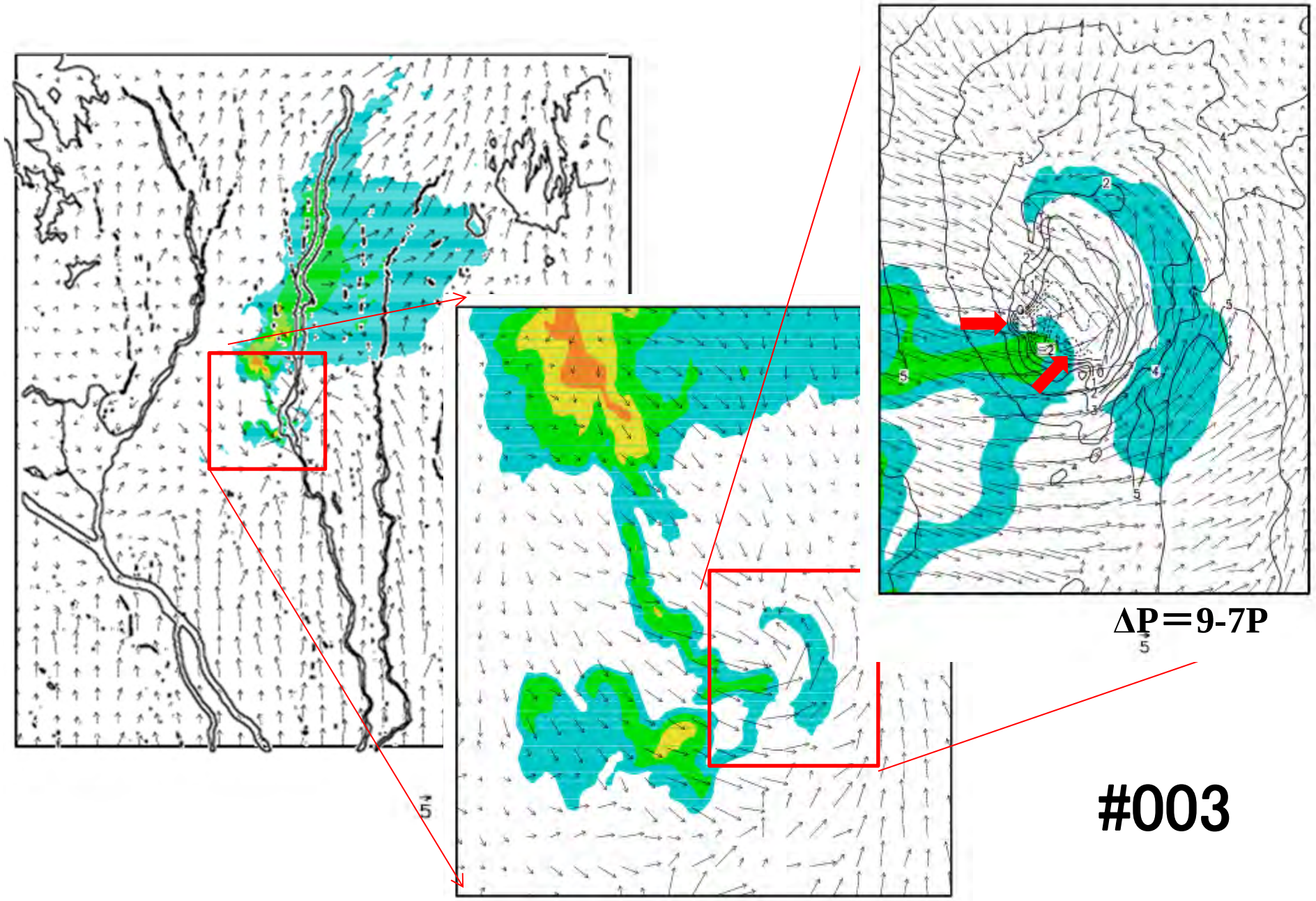
Downscale experiments Δx=50m



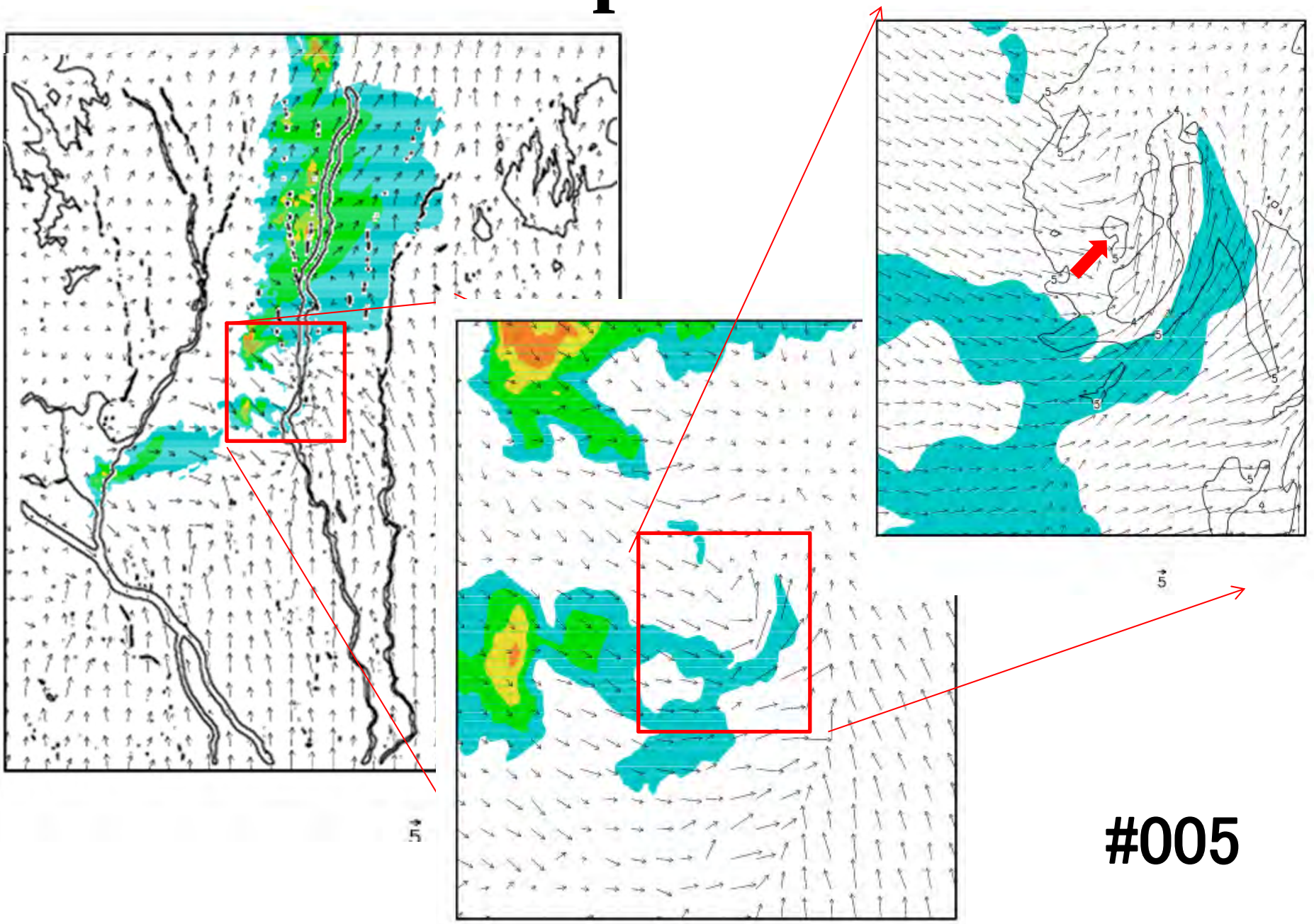
ΔP＝8P

#002

Downscale experiments Δx=50m



Downscale experiments Δx=50m



#005

Thank you for your attention

Acknowledgements

GPS data were provided from the GSI.