December 7, 2012, Training Workshop, Hong Kong Observatory

Research and Development of Mesoscale Data Assimilation at MRI

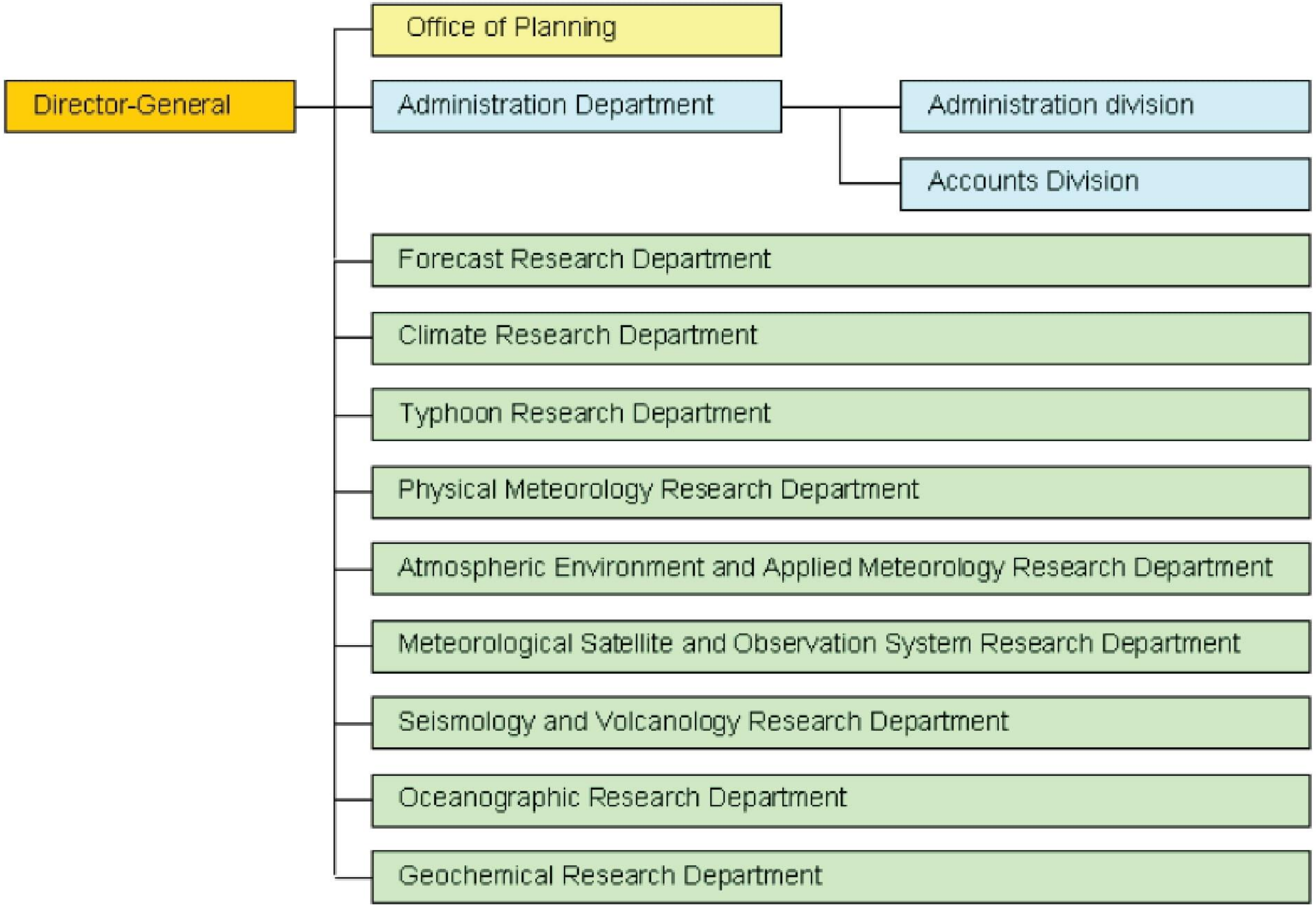
Masaru Kunii

Meteorological Research Institute / JMA, Japan

mkunii@mri-jma.go.jp


Sea of Japan
South Korea
Japan
Satellite
Traffic
Akita
Morioka
Sendai
Yamagata
Fukushima
Niigata
Toyama
Nagano
Utsunomiya
Kanazawa
Maebashi
Mito
Fukui
Kofu
Tokyo
Chiba
Gifu
Yokohama
Shizuoka
Nagoya
Tsu
Osaka
Matsue
Tottori
Okayama
Wakayama
Yamaguchi
Hiroshima
Tokushima
Matsuyama
Kochi
Fukuoka
Oita
Saga
Nagasaki
Kumamoto
Miyazaki
Kagoshima
Daegu
Ulsan
Busan
Tongyeong
100 mi
200 km
Map data ©2012 Google, SK M&C, ZENRIN -

Organization



Data assimilation at MRI

- **The 2nd Research Laboratory in Forecast Research Department**
  - Development of advanced mesoscale data assimilation methods
  - Development of utilization techniques of observation data
  - Development of mesoscale ensemble prediction methods

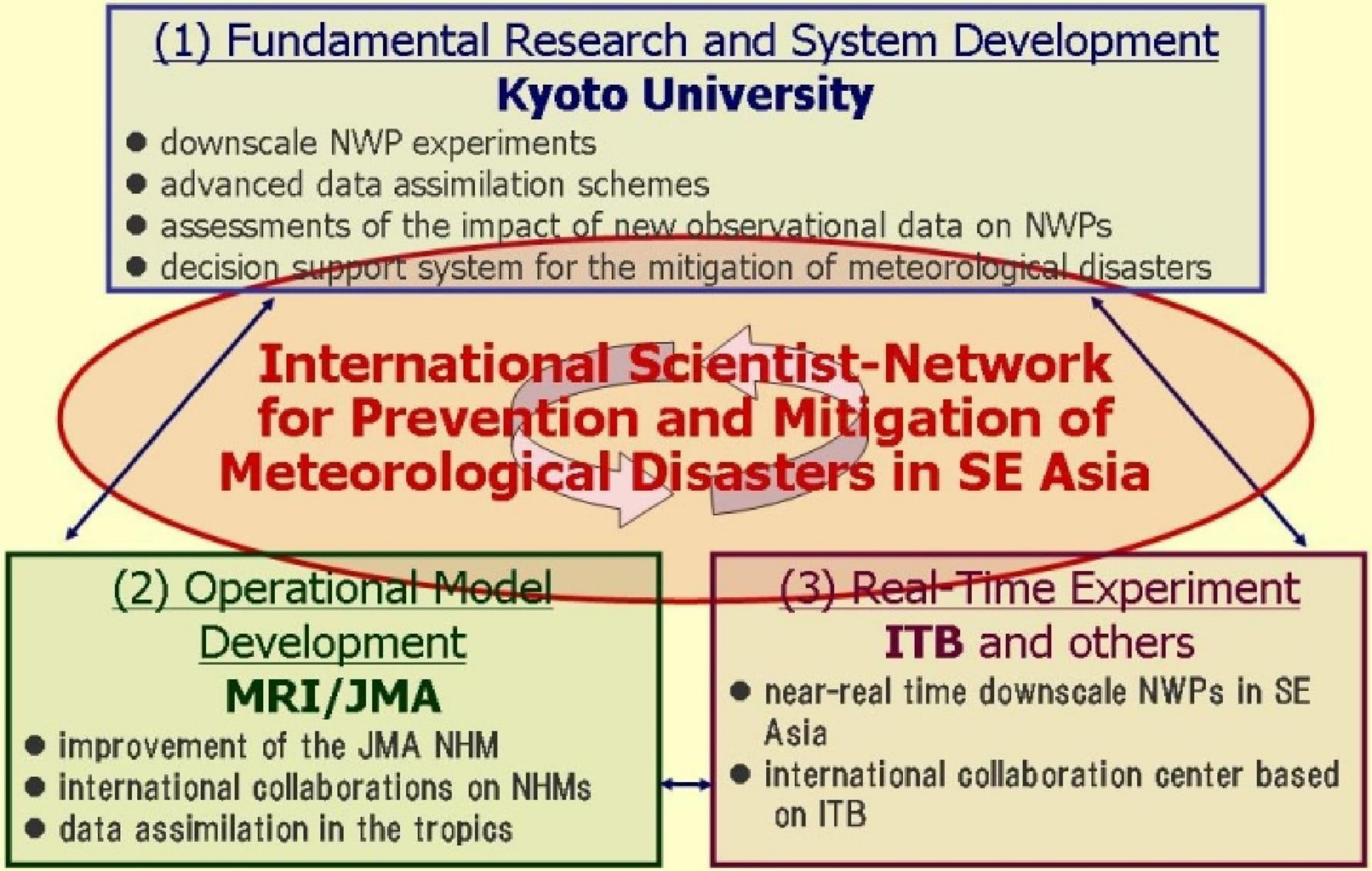
- **The first Research Laboratory in Typhoon Research Department**
  - Optimum observations for typhoons
  - Analysis of tropical thermal environment

Topic

- Mesoscale ensemble forecast
  - Ensemble forecast experiment for Nargis
- NHM-LETKF
  - Applied for local heavy rain cases.

International Research Project for Prevention and Mitigation of Meteorological Disasters in Southeast Asia

A Research Program for 2007.7-2010.3



Purpose

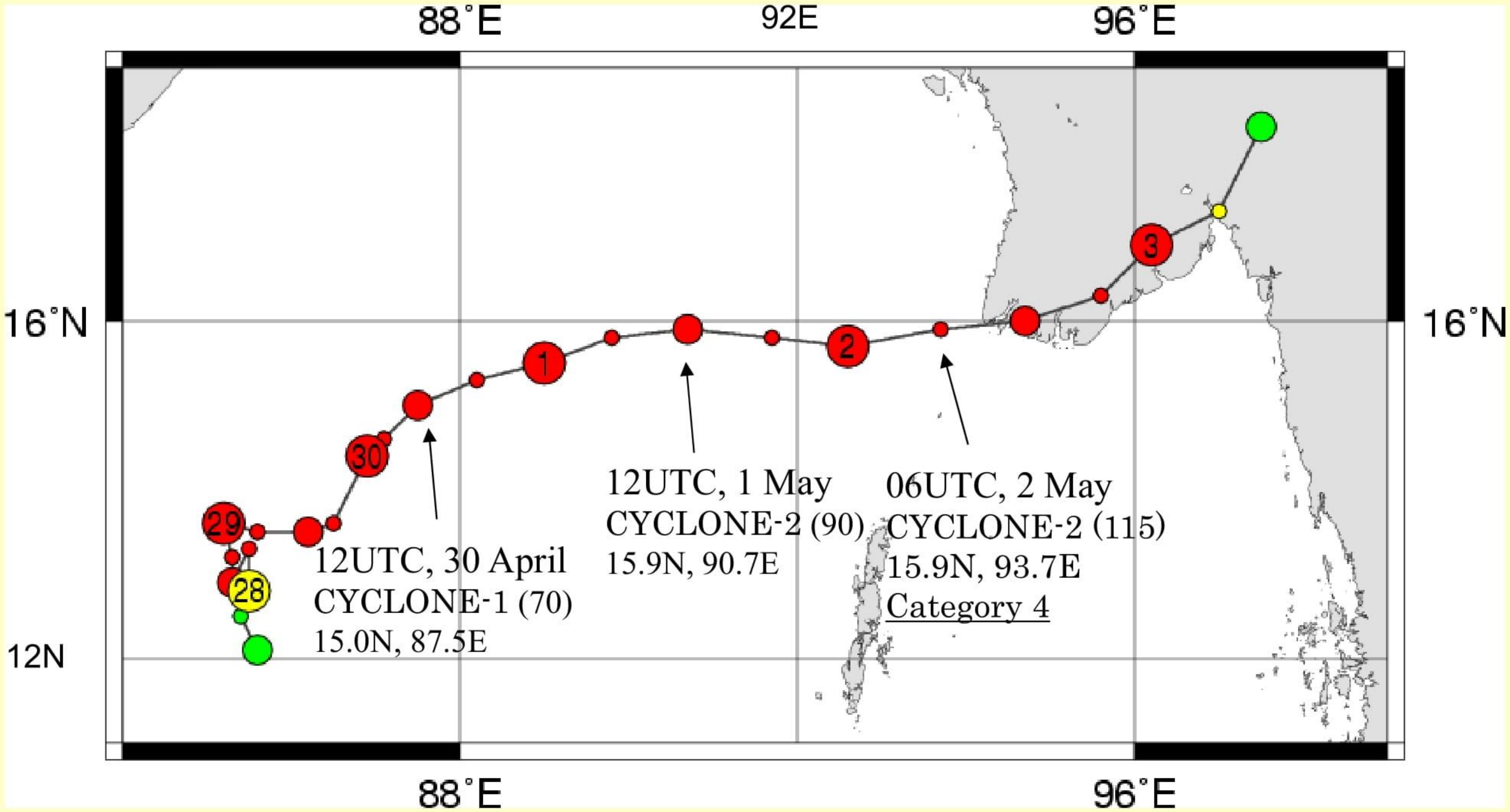
- Experimental downscale NWPs in SE Asia

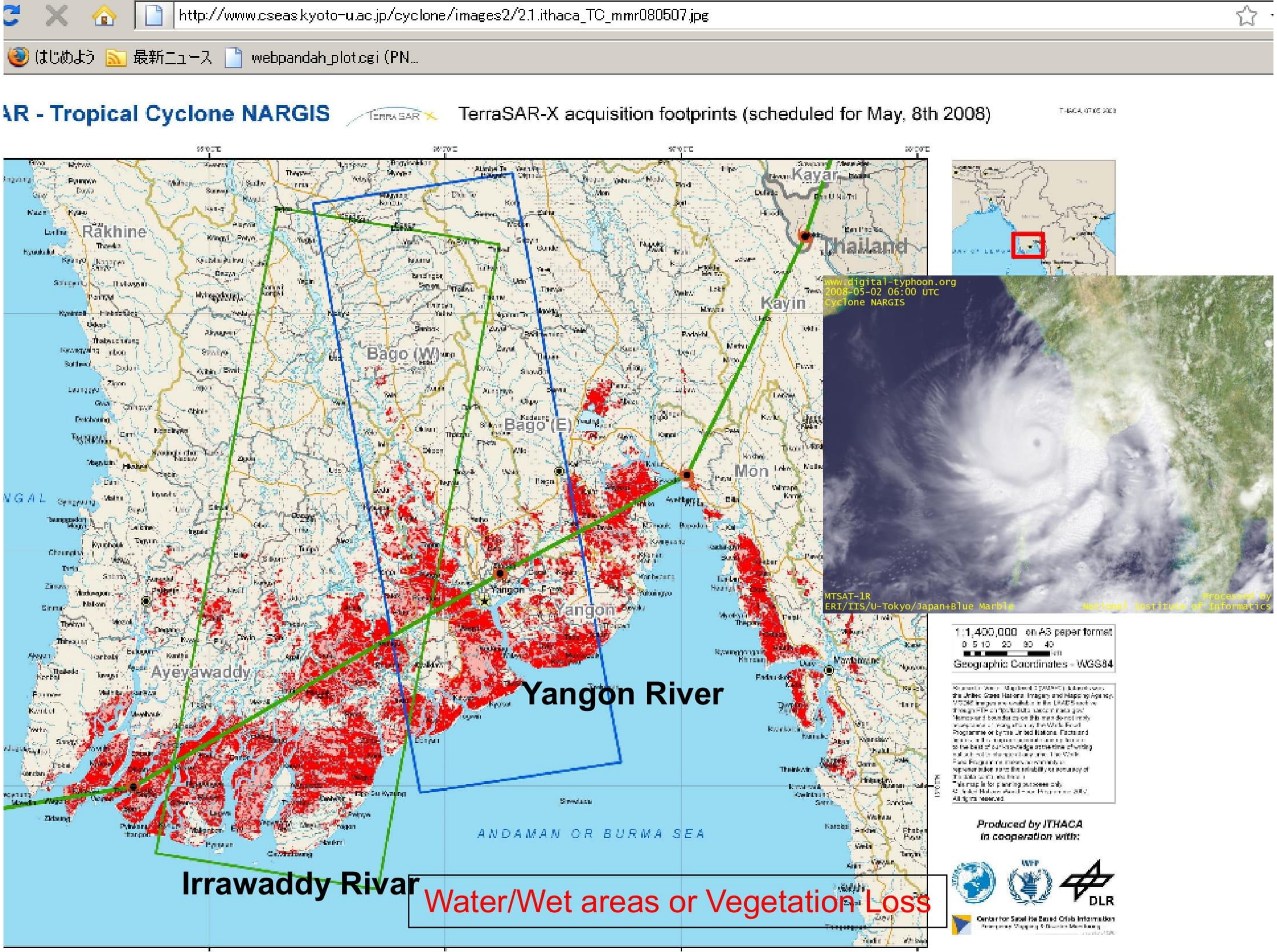
↓

- Research and development of
  "Decision support system for prevention and mitigation of meteorological disasters"

- Establishment of "International Scientist-Network for Prevention and Mitigation of Meteorological disasters in SE Asia"

Myanmar Cyclone Nargis in 2008




http://www.cseas.kyoto-u.ac.jp/cyclone/images2/2.1.ithaca_TC_mmr080507.jpg
はじめよう
最新ニュース
webpandah_plot.cgi (PN...
AR - Tropical Cyclone NARGIS
TerraSAR-X acquisition footprints (scheduled for May, 8th 2008)
Rakhine
Bago (W)
Bago (E)
Kayin
Kayar
Thailand
Mon
Yangon
Ayeyawaddy
ANDAMAN OR BURMA SEA
www.digital-typhoon.org
2008-05-02 06:00 UTC
Cyclone NARGIS
MTSAT-1R
ERI/IIS/U-Tokyo/Japan+Blue Marble
Processed by
National Institute of Informatics
1:1,400,000 on A3 paper format
Geographic Coordinates - WGS84
Produced by ITHACA
in cooperation with:
DLR
Yangon River
Irrawaddy Rivar
Water/Wet areas or Vegetation Loss

Forecast experiment of cyclone Nargis

- Initial condition: JMA's high resolution global analysis at 12UTC 20 April 2008 (0.1875 degrees 60 levels)

- Boundary condition: JMA's GSM (TL959L60) forecast
  (0.5 degrees, 17 pressure levels, 6 hourly)
- JMA's global land/SST analyses

- NHM with a horizontal resolution of 10 km is used with a domain of 341x341

※ Above data are archived at Kyoto University and are accessible for Southeast Asian Researchers.

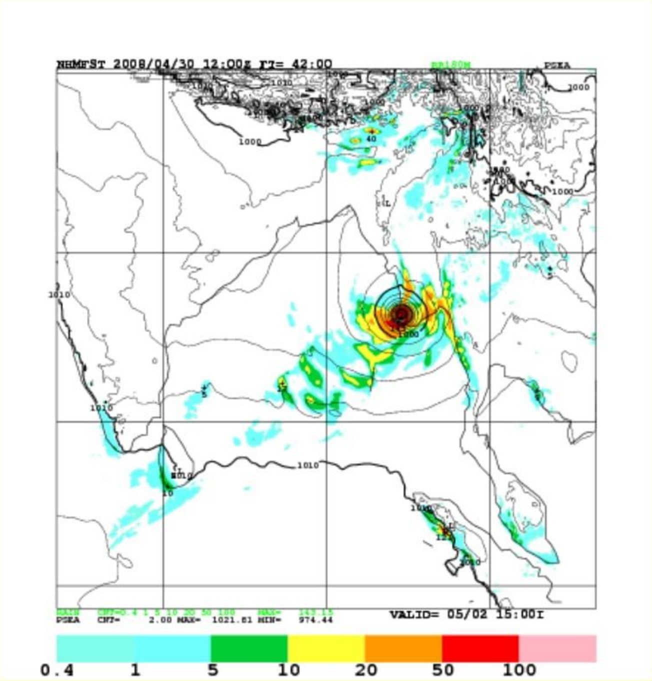
Nargis Forecast Experiment

- Input Data -

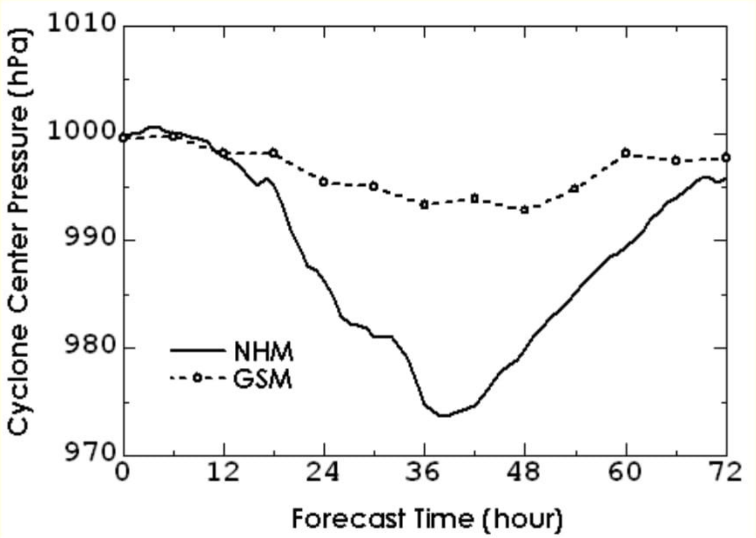
- Initial Value: **JMA GA**(2008.0430.12UTC)
- Boundary Value: **JMA 20km GSM Forecast**
- **JMA LAND** and **SST** analyses.

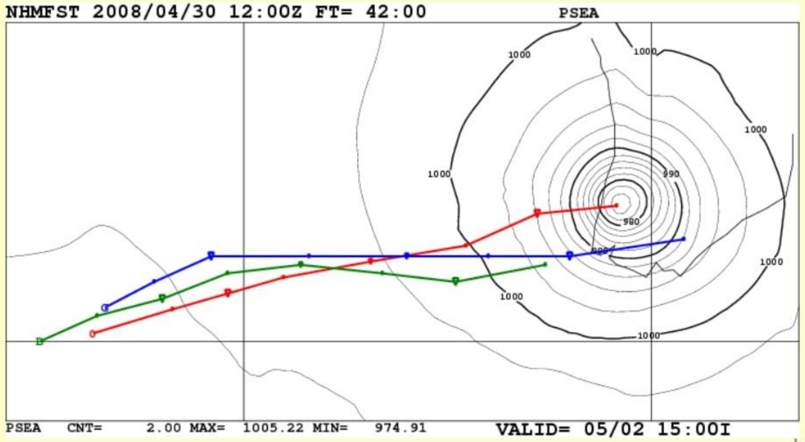
- NHM Forecast -

- Horizontal 10km grids (341x341), 40 levels. Δt=40sec.
- Results are compared to GSM and best tracks by the RSMC New Delhi and JTWC.

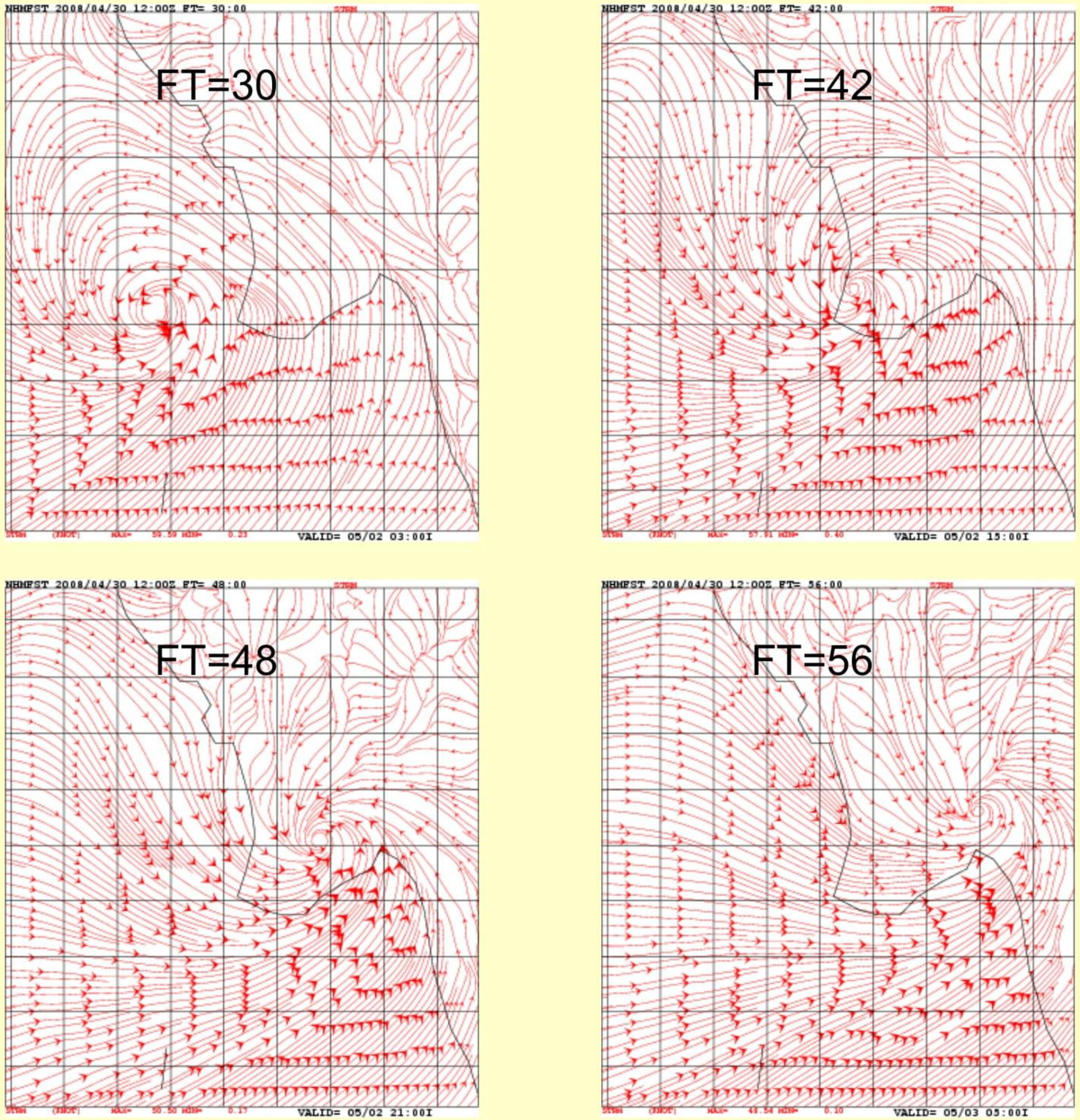


Kuroda et al. (2010, JMSJ)





Predicted surface wind by NHM



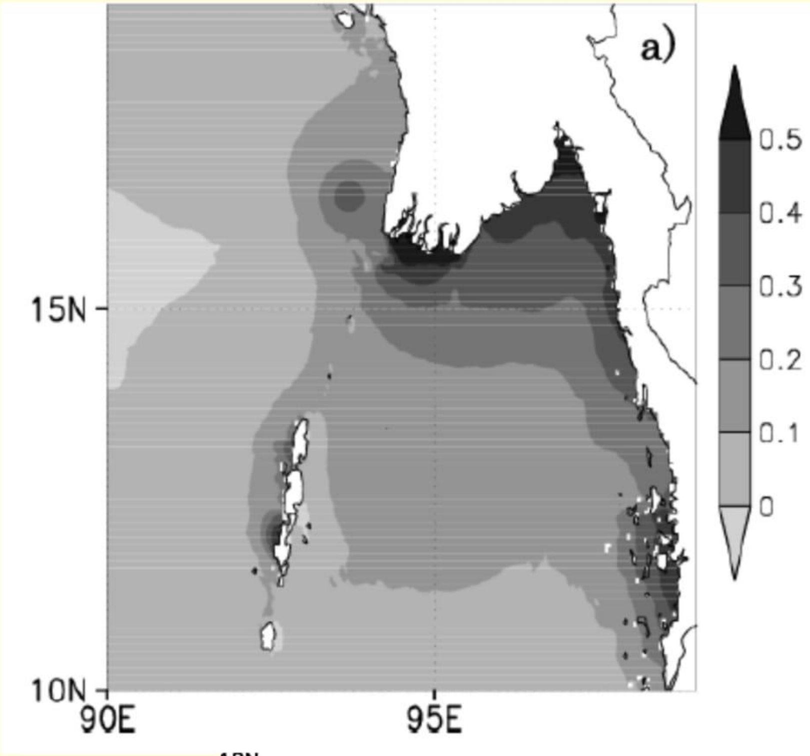
Storm surge simulation

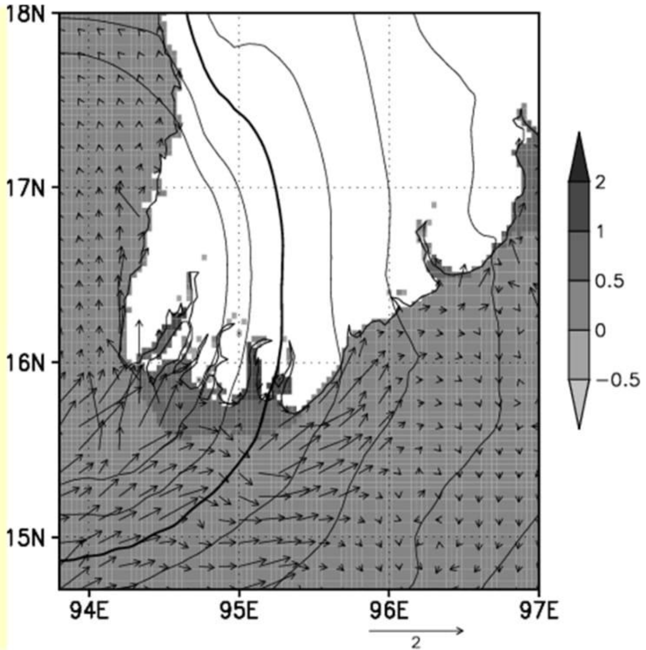
Princeton Ocean Model
(**POM**; Blumberg and Mellor, 1987)
Free Surface, 3D Noncompressible.
Implemented to this study by Kohno.

2008-4-30.1200UTC Init.
- Initial State: Static
- Input: **surface wind** and **pressure**,

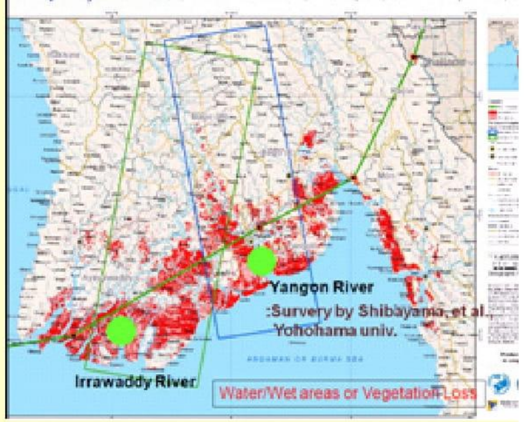
Resolution：2 minutes mesh(≈ **3.5km**),
3D（12 layers: σ Coord.）
Domain: 84E-99E, 10N-23N (451 × 391 grids).
Time step: 2 sec.(explicit mode), 60 sec.(implicit mode).

Ext.Bnd：flow in/out due to balance on surface pressure.
Sea/Land Bnd.：flood and drying-up are not considered.
Calculate on surge deviation (not on astronomical tide).

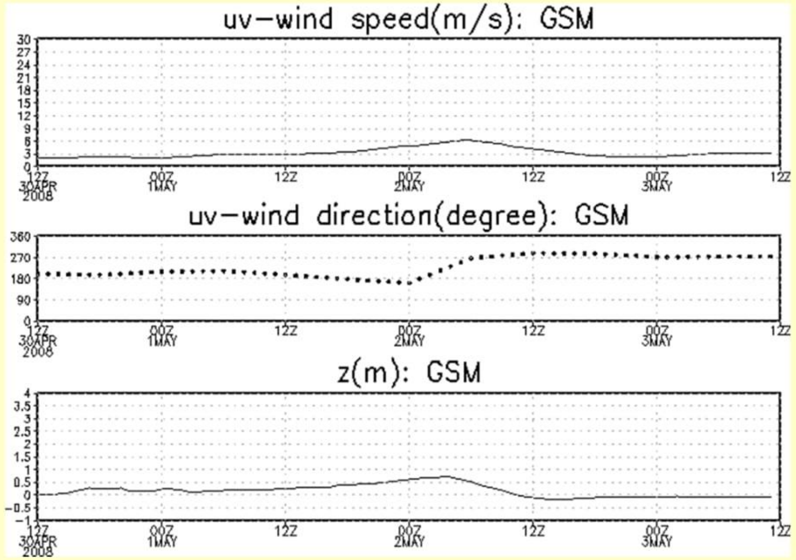




Simulated storm surge

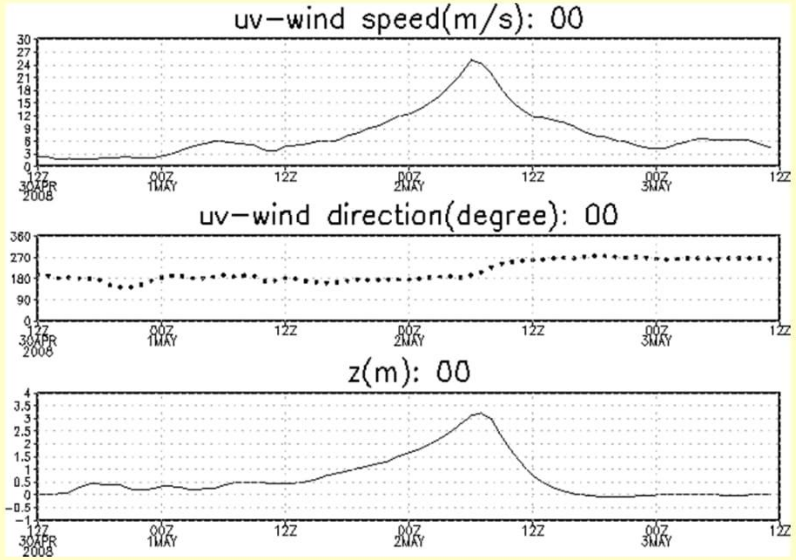


at Irrawaddy river point
(16.10N, 95.07E)



Maximum water level 0.7m

20km GSM Forecast Used



Maximum water level 3.2m

10 km NHM Forecast Used

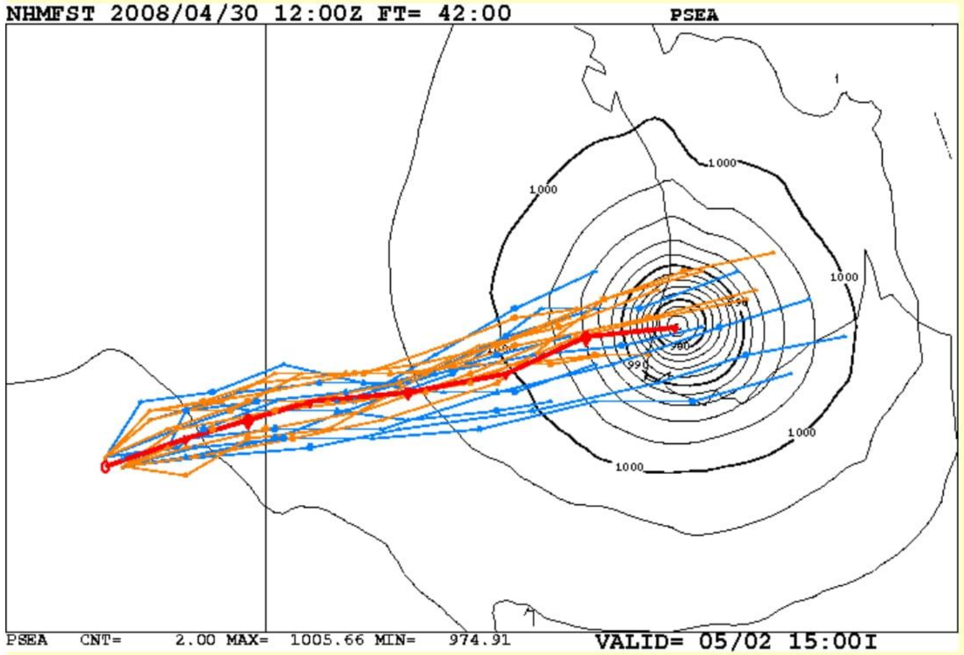
Kuroda et al. (2010, JMSJ)

Mesoscale ensemble prediction of Nargis

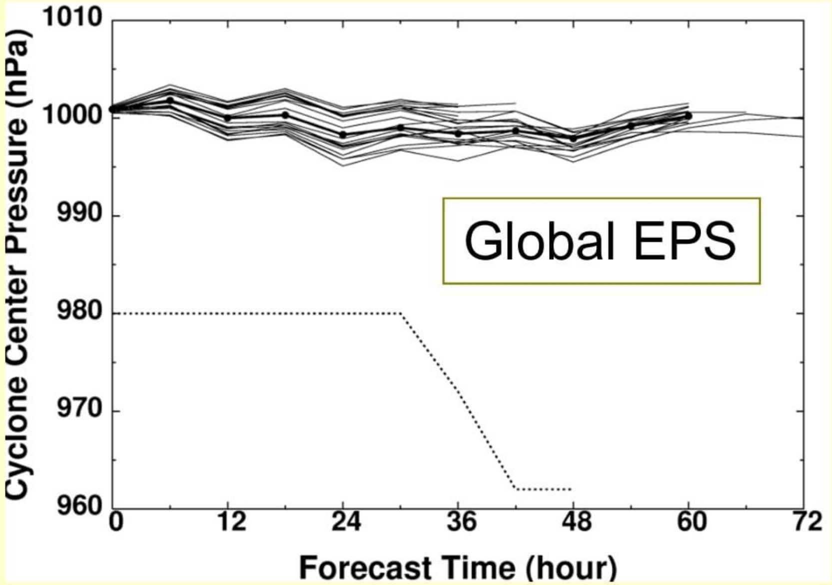
Dataset	Horizontal Resolution	Lev -els	Time	Format	Ens. mem.
NCEP GFS Forecast	1.0x1.0 deg.	27	Init. : Every 6hr Valid: Every 3hr	GRIB	
NCEP GFS Analysis	1.0x1.0 deg.	27	Every 6hr	GRIB	
JRA25 (55)	1.25x1.25 deg.	24	Every 6hr	GRIB	
JMA GSM Forecast (JMBSC)	0.5x0.5 deg. 1.25x1.25 before 2007.11.21	18	Init. : Every 6hr Valid: Every 6hr	GRIB2 GRIB before 2007.11.21	
JMA GA	0.1875 deg. ≈ 20km	60 (η)	Every 6hr	NuSDaS	
JMA One-week EPS	1.25x1.25 deg.	11	Init.: 1200UTC daily Valid: every 12hr	NuSDaS	51

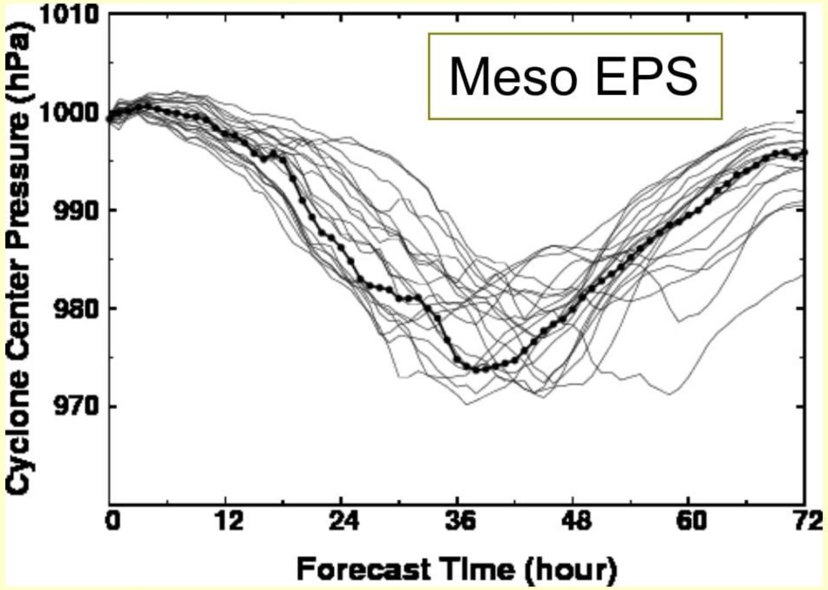
Ensemble prediction of Nargis with 10 km NHM

Perturbations by JMA One-week EPS 21 members



Predicted tracks until FT=42 (valid time 06 UTC 2 May 2008) by the control run (red line) and the ensemble prediction by NHM.





Evolution of center pressures

Saito et al. (2010, JMSJ)

Accuracy of the ensemble mean

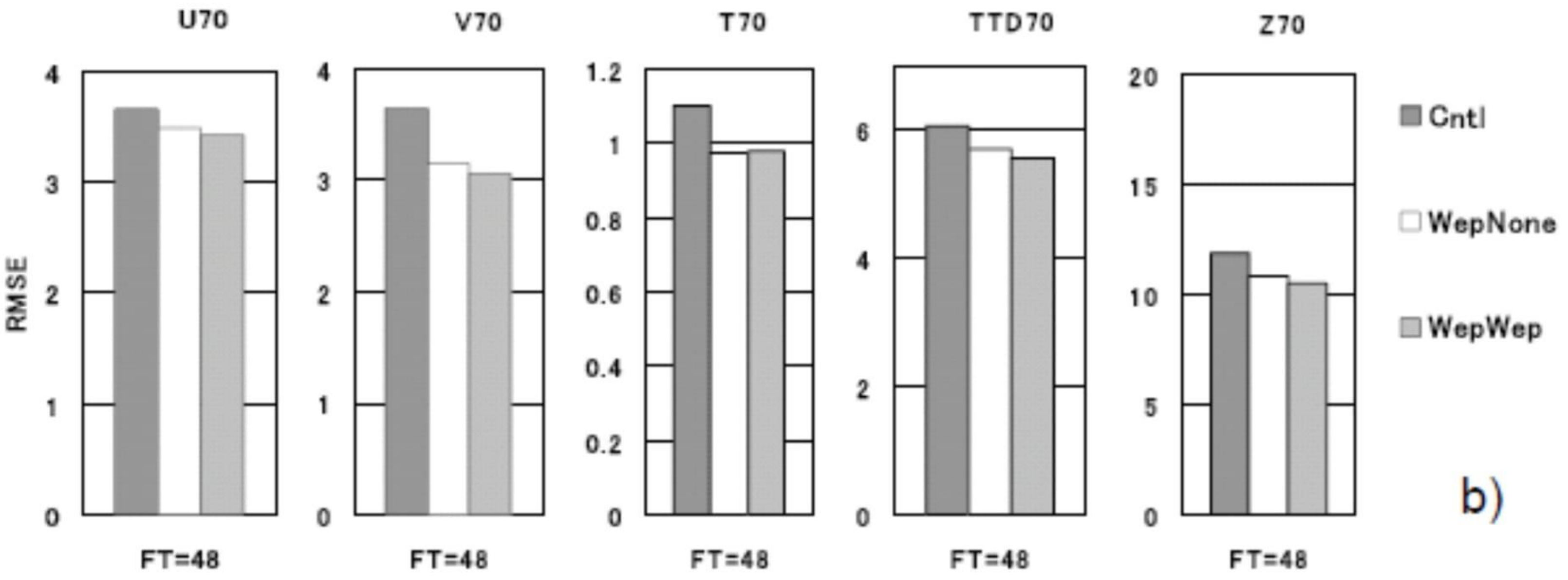
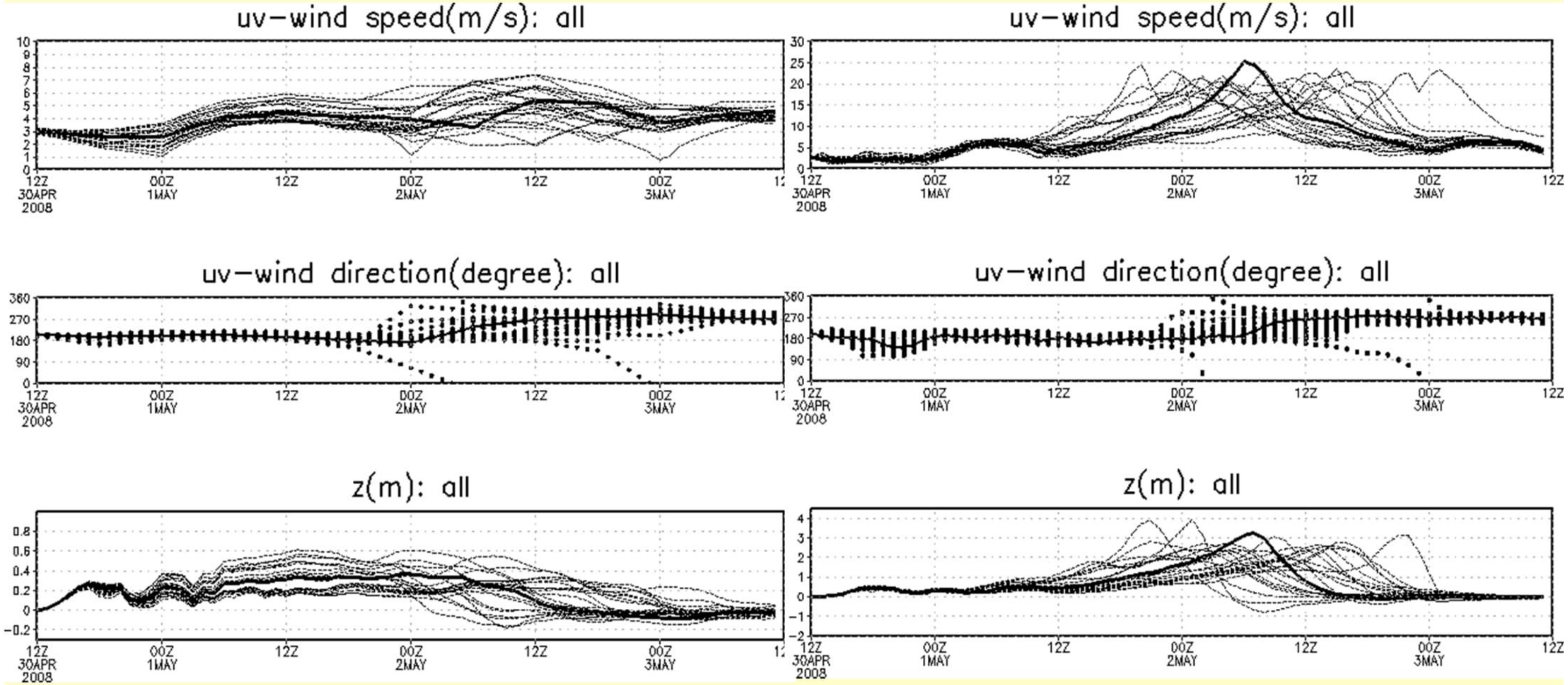


Fig. 13. a) Root mean square errors of U, V, T, T-TD and Z at 700 hPa level at FT=24 against the analysis of 12 UTC 1 May 2008. From left to right, control run (dark shaded bar), ensemble mean without the lateral boundary perturbation (WepNone; white bar) and ensemble mean without the lateral boundary perturbation (WepWep; light shaded bar). **b)** Same as in a) but at FT=48 against the analysis of 12 UTC 2 May 2008.

Saito et al. (2010, JMSJ)

Simulated storm surge

at Irrawaddy river point (16.10N, 95.07E)



Maximum water level 0.6 m

Maximum water level 4.0 m

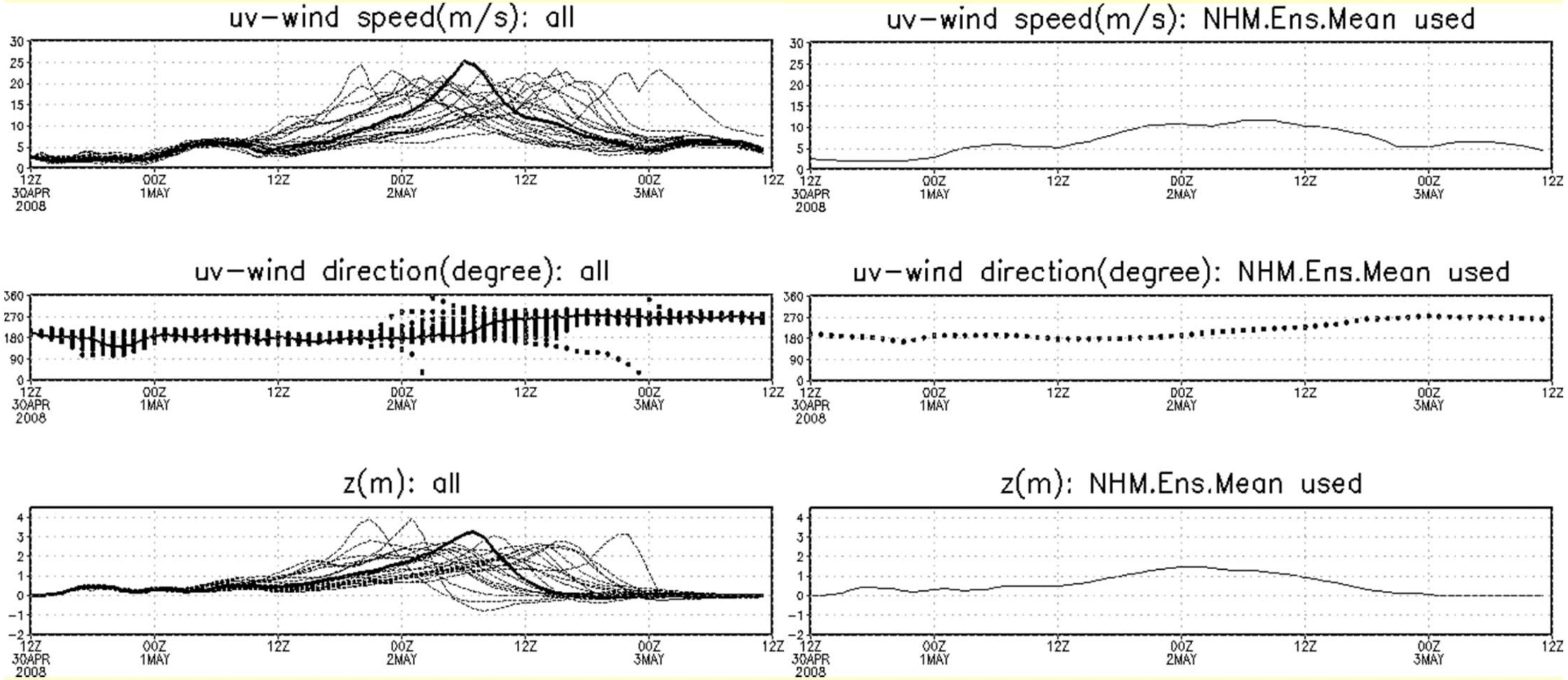
Global EPS Used

NHM EPS Used

Saito et al. (2010, JMSJ)

Simulated storm surge

at Irrawaddy river point (16.10N, 95.07E)



Maximum water level 4.0m

Maximum water level 1.5m

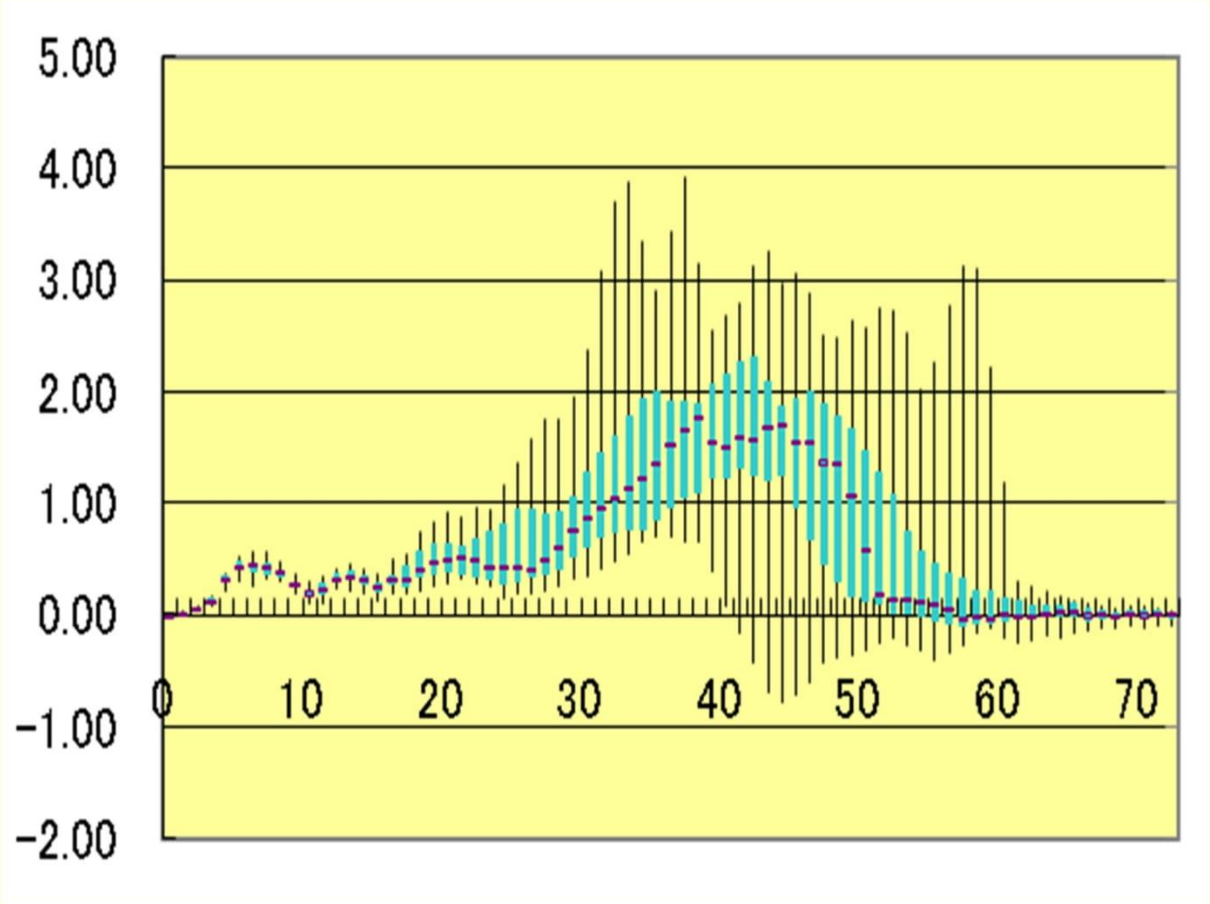
NHMEPS Used

NHM EPS Ens. Mean Used

each scenario is more important than the ensemble mean in the disaster prevention

Saito et al. (2010, JMSJ)

Probabilistic prediction of storm surge



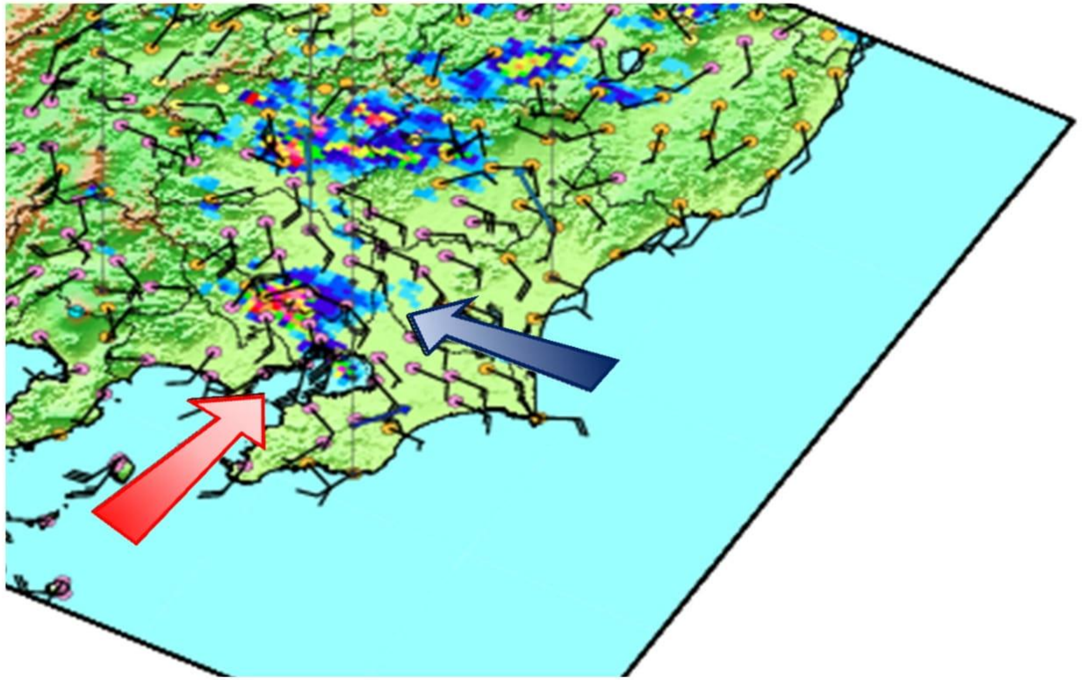
Time sequence of the maximum, minimum and center magnitudes of tide levels at the Irrawaddy point. Widths between 25 % and 75 % probability values are depicted with solid rectangles, whose upper and lower sides correspond to 25 % and 75 %, respectively.

LETKF nested system for the cloud resolving model

Hiromu Seko, Tadashi Tsuyuki, Kazuo Saito (MRI/JMA)
Tohru Kuroda (JAMSTEC)
Tadashi Fujita (JMA)
Takemasa Miyoshi (Univ. of Maryland)

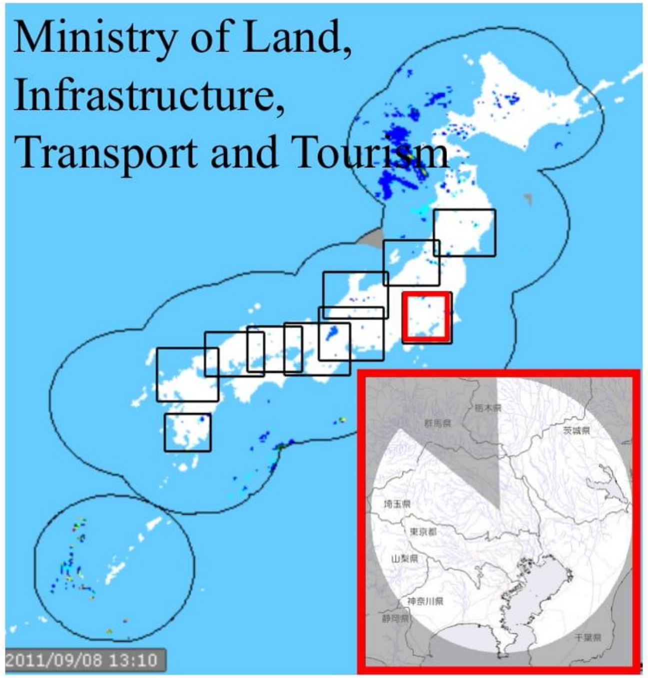
Necessity of a nested assimilation system

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



Necessity of a nested assimilation system

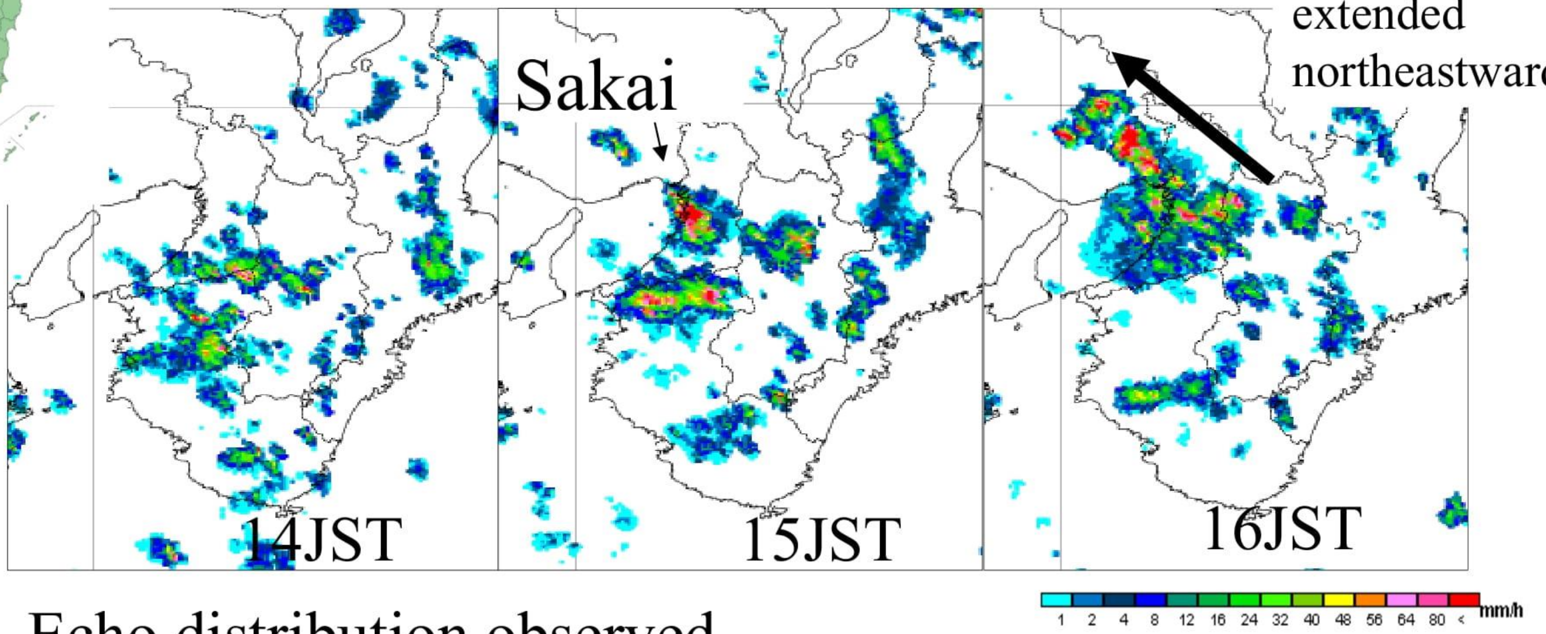
- <u>Local heavy rainfalls cause urban flash floods</u>.
- To reproduce local heavy rainfalls, mesoscale convergence and convection cells should be reproduced simultaneously by the numerical models with large and small grid intervals.
- **An X-band radar network and a GPS network have been established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



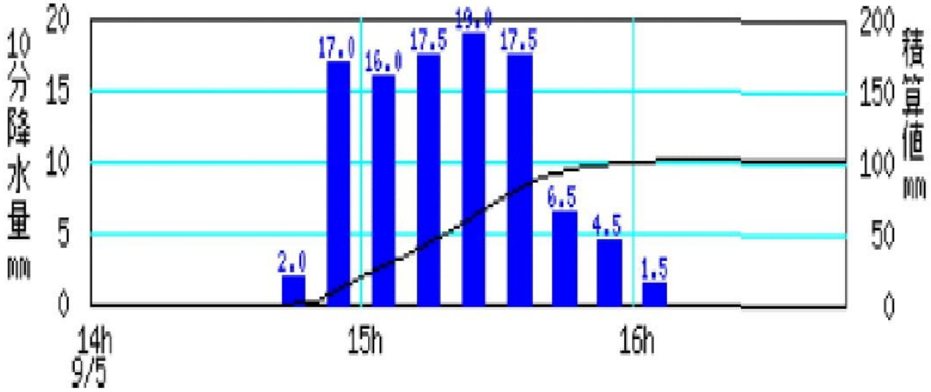
Necessity of a nested assimilation system

- Local heavy rainfalls cause urban flash floods.
- To reproduce local heavy rainfalls, mesoscale convergence 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.**

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

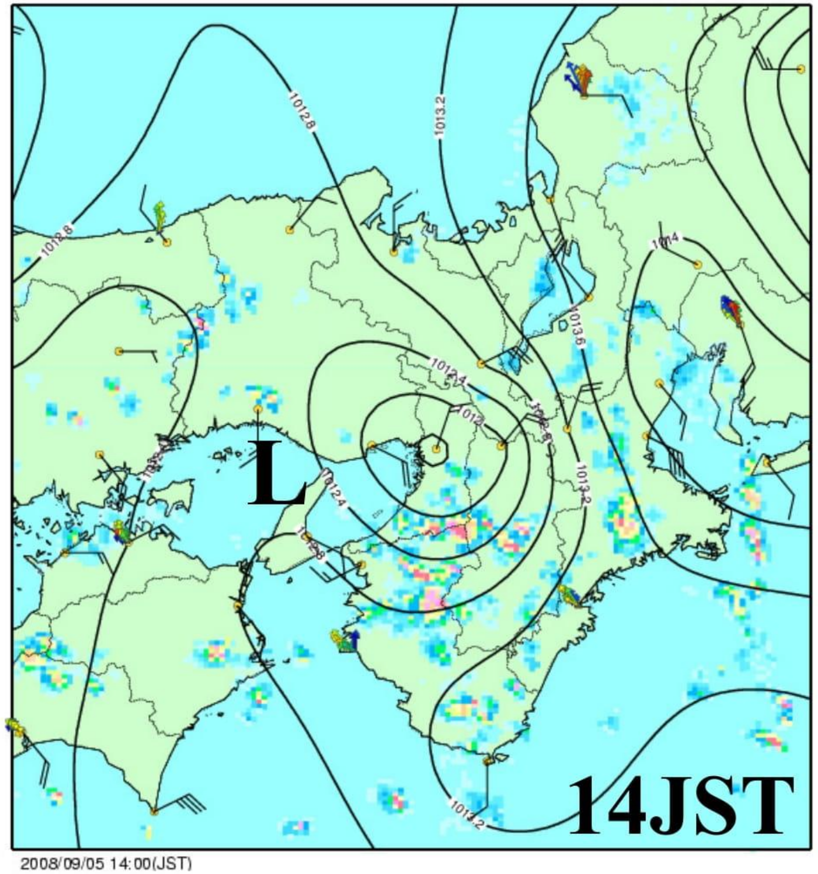


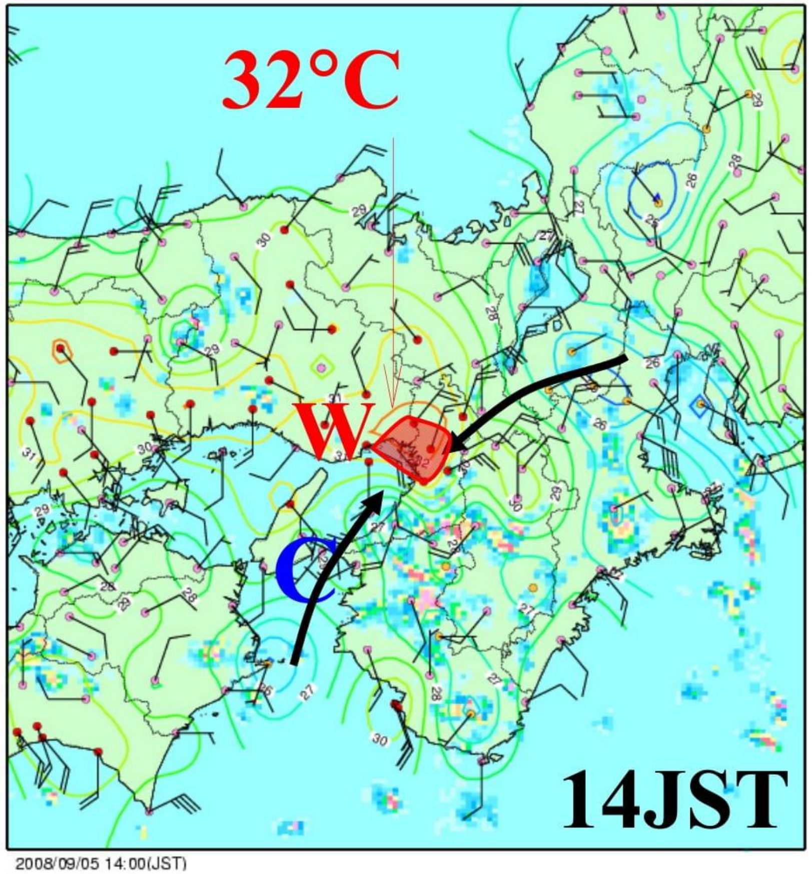
Echo distribution observed by conventional radars (5th Sep. 2008)



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

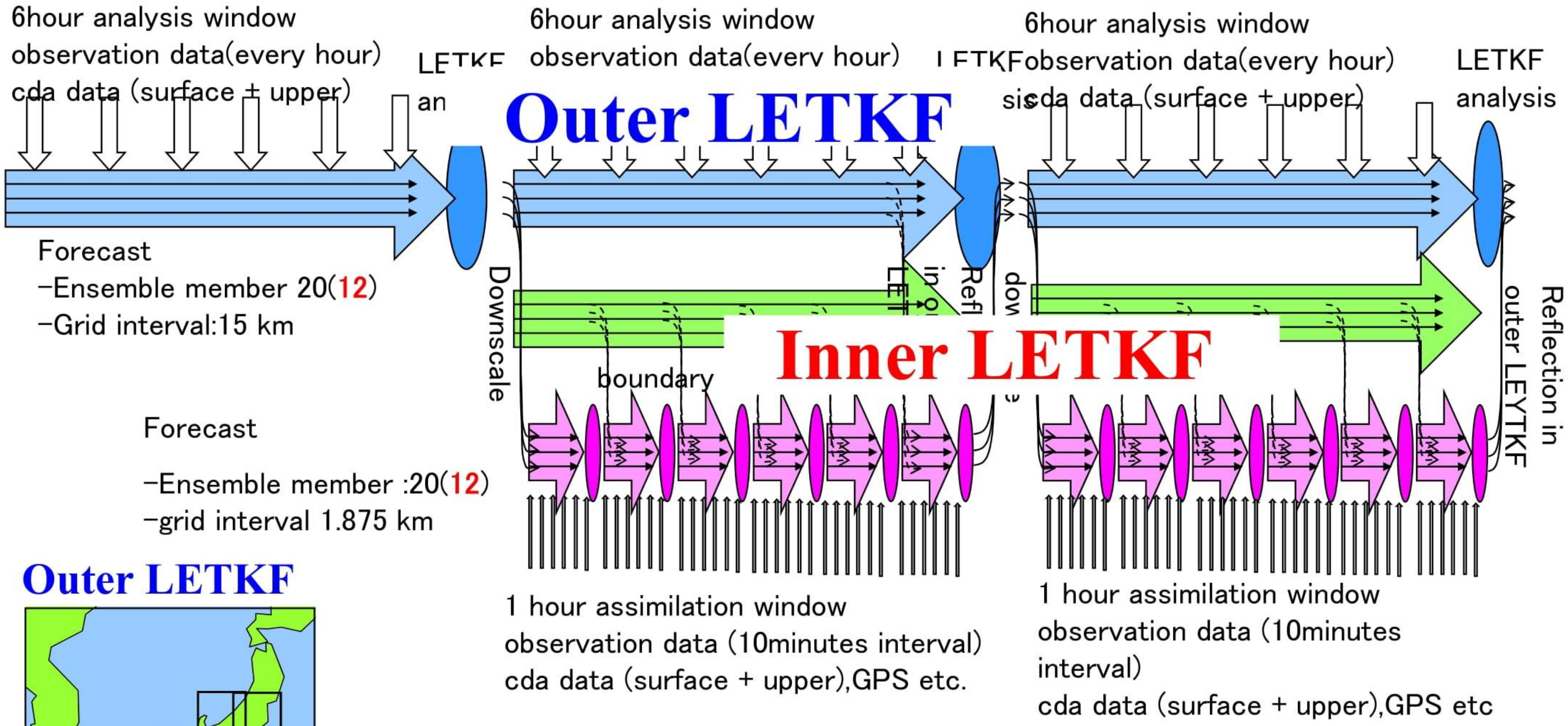
Sakai-city intense rainfall event

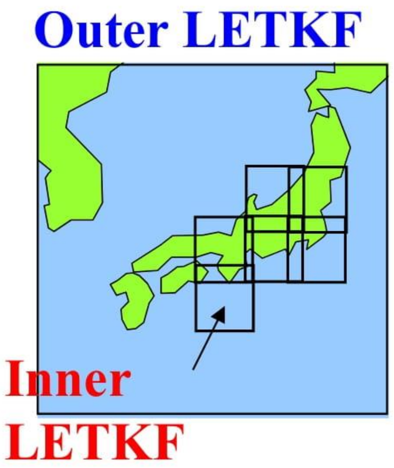




- There was a high temperature area at Osaka and a thermodynamic low system was generated here.
- **A northeasterly flow and a southerly flow were converged at the Osaka Plain.**

Schematic of nested LETKF system

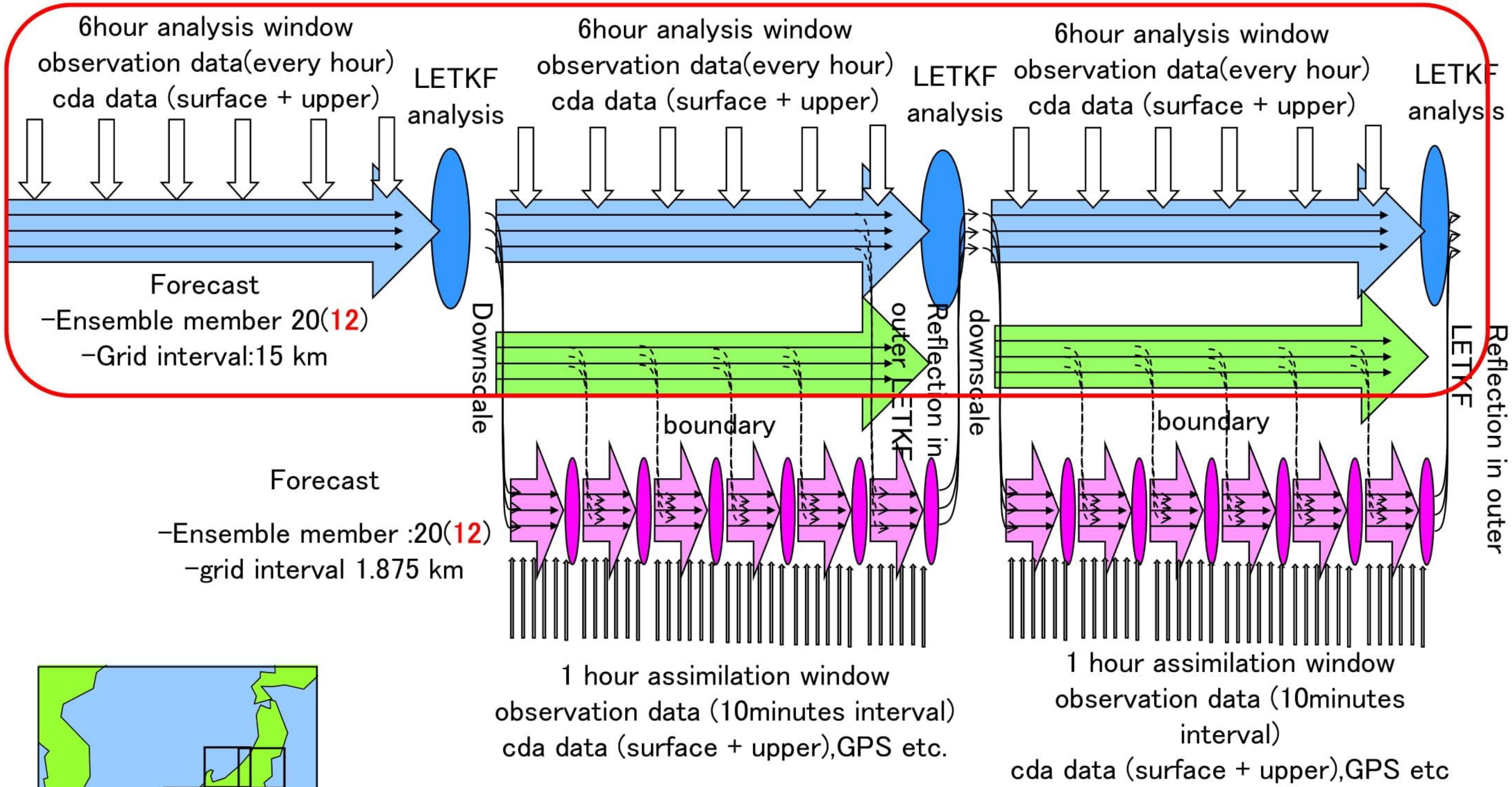


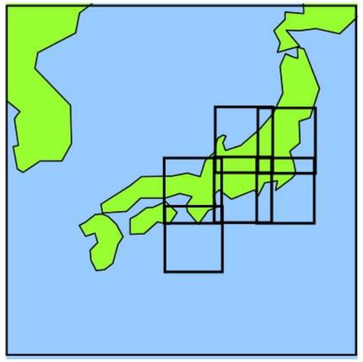


- **To reproduce local heavy rainfalls, mesoscale convergence and convection cells should be reproduced simultaneously.**

=> *Nested assimilation system was used.*

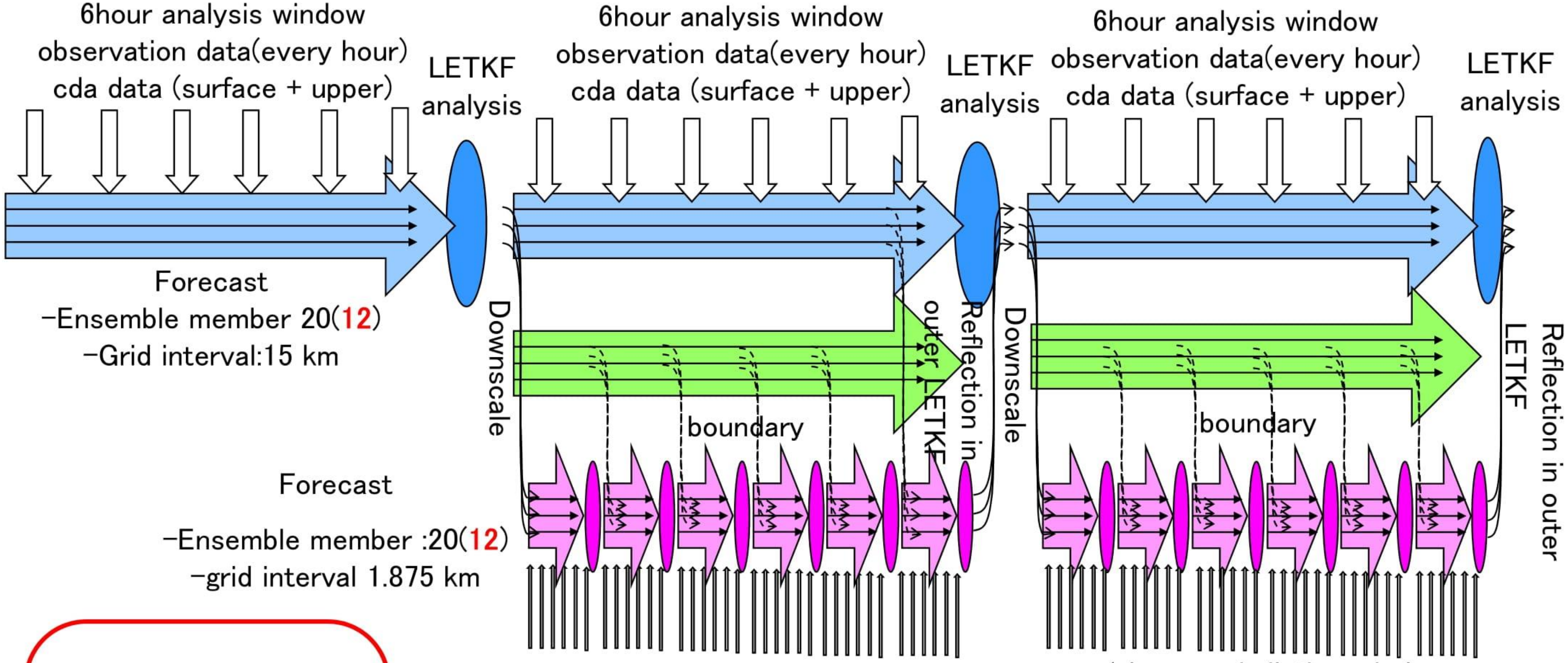
Schematic of nested LETKF system

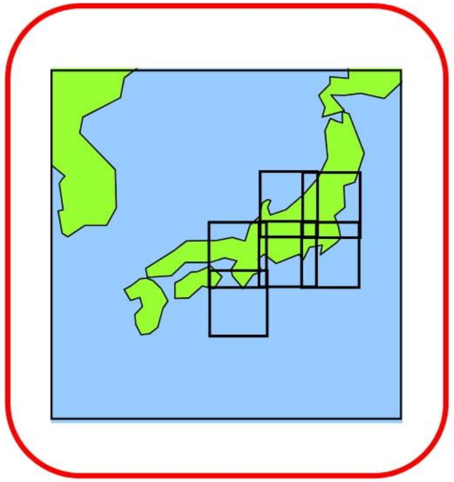




- **The outer LETKF with a grid interval of 15 km assimilates the conventional data of Japan Meteorological Agency. Assimilation window was 6 hours.**

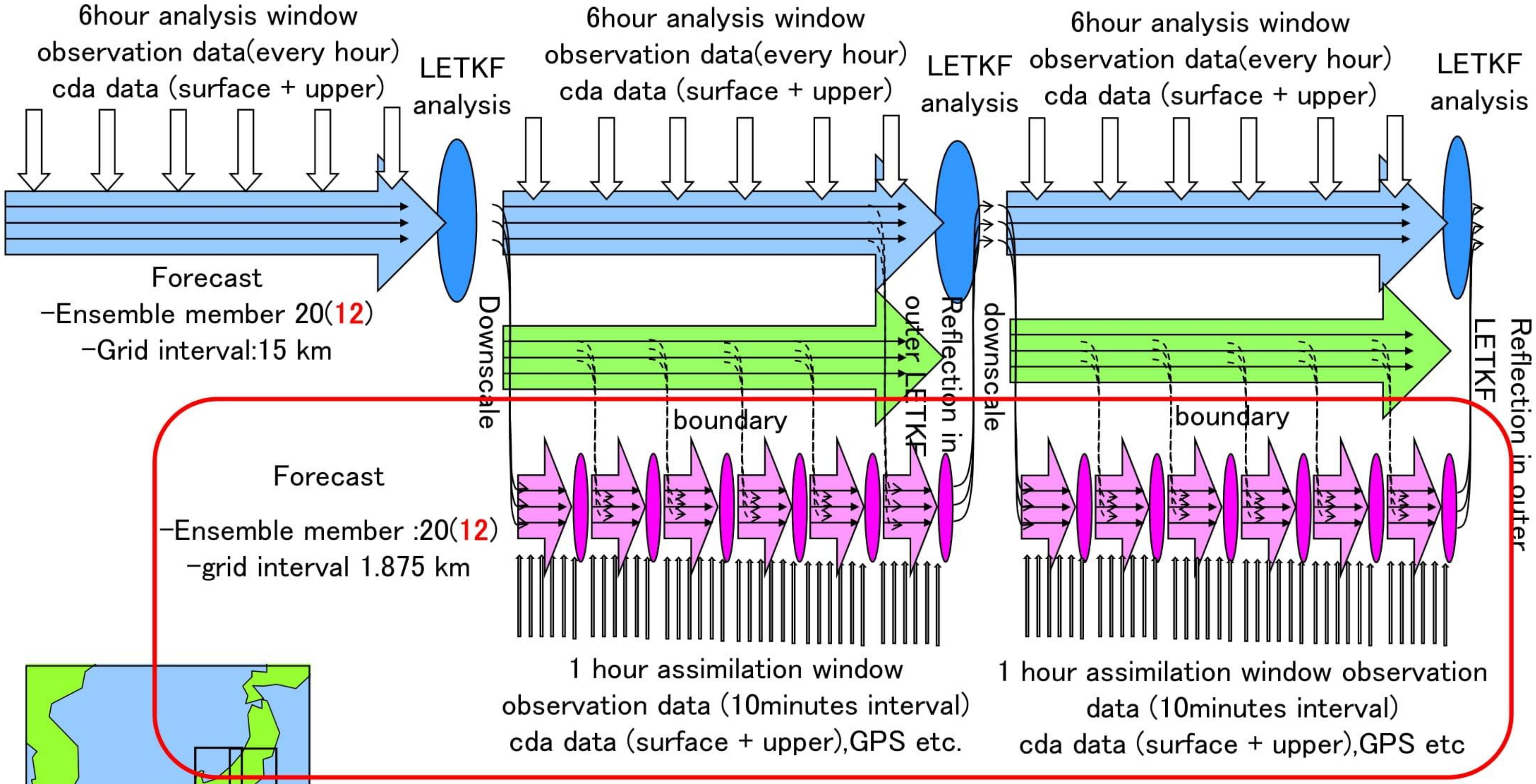
Schematic of nested LETKF system

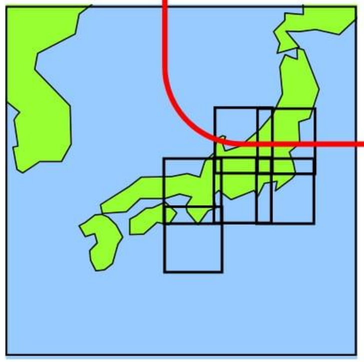




- **Inner LETKFs were deployed in the outer LETKF.**
- **Boundaries of the inner LETKFs were overlapped to reduce the regions that were determined by the outer LETKF.**

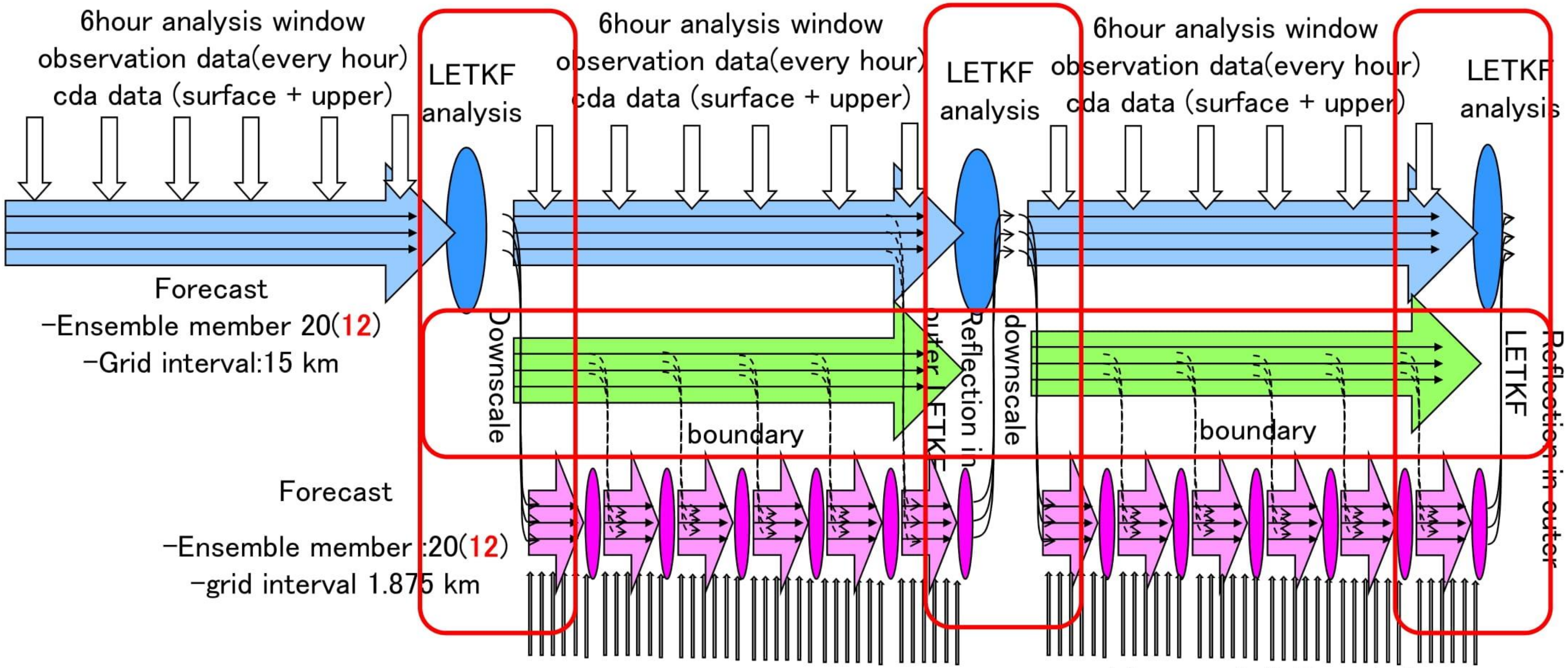
Schematic of nested LETKF system

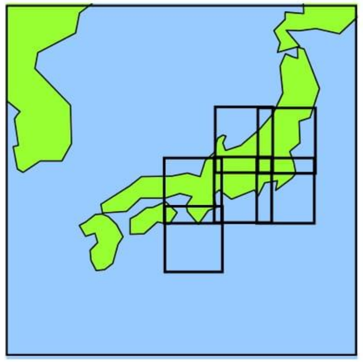




- **The grid interval of the inner LETKF is about 2 km. The inner LETKF assimilated the conventional data and high resolution data. Assimilation window was 1 hour.**

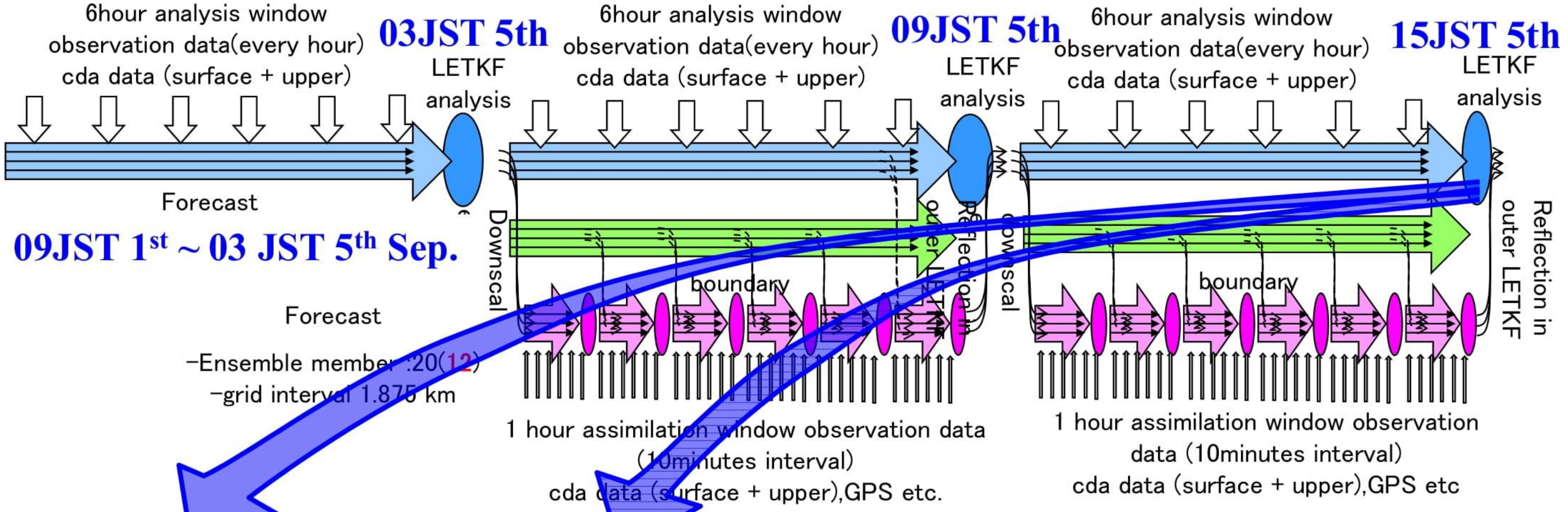
Schematic of nested LETKF system



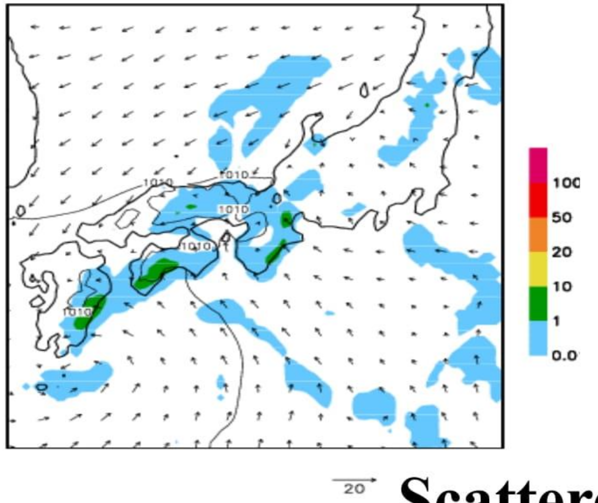


- **Results of the inner LETKFs were reflected in the outer LETKF every 6 hours.**
- **Initial and boundaries of the inner LETKFs were produced from forecasts of the outer LETKF.**

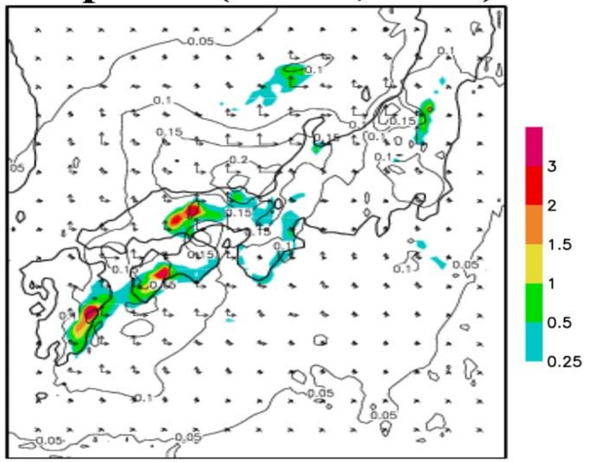
Results of nested LETKF system



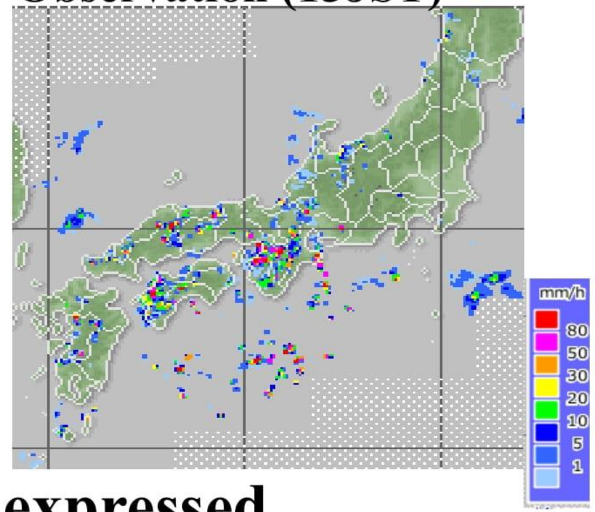
Ensemble mean (15JST,15km)



Spread (15JST,15km)

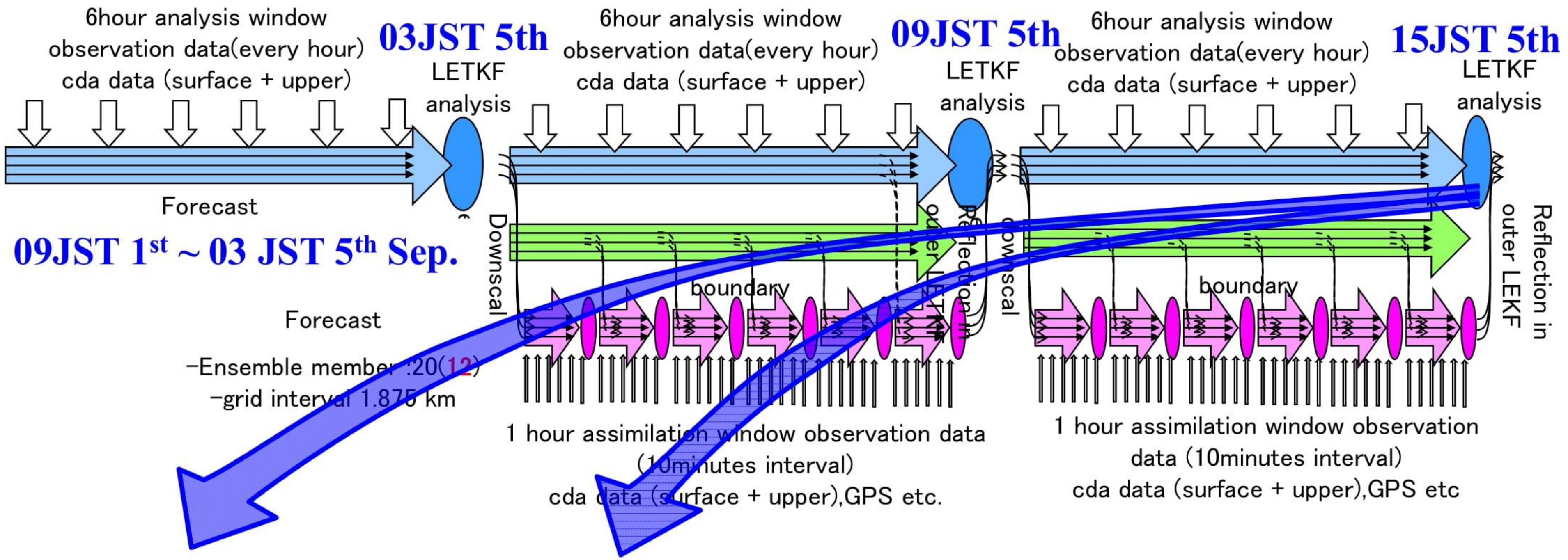


Observation (15JST)

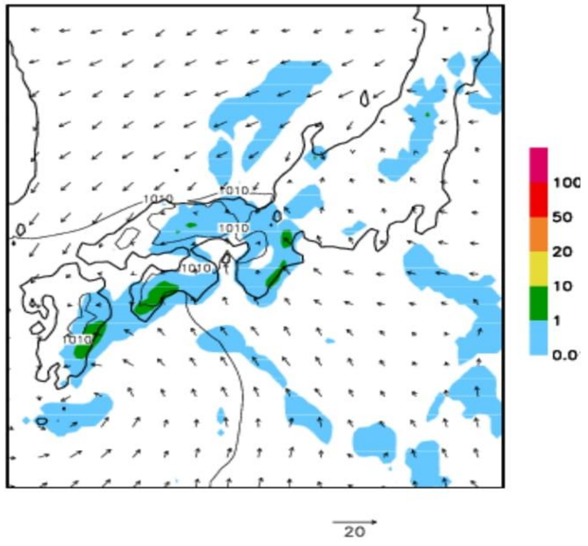


Scattered rainfall regions were expressed as weak rainfall by outer LETKF.

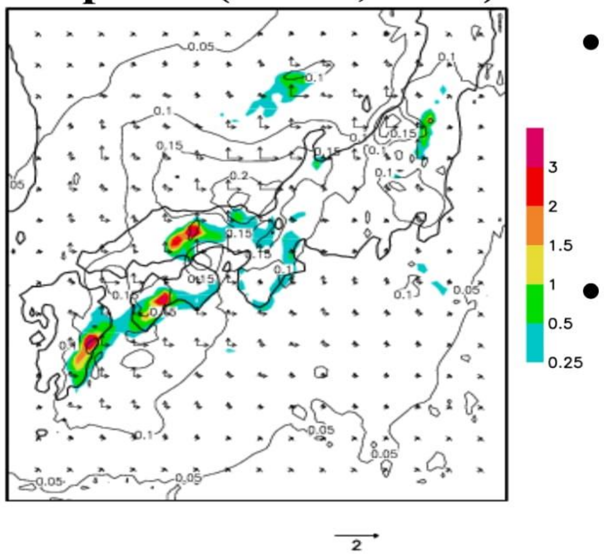
Results of nested LETKF system



Ensemble mean (15JST,15km)

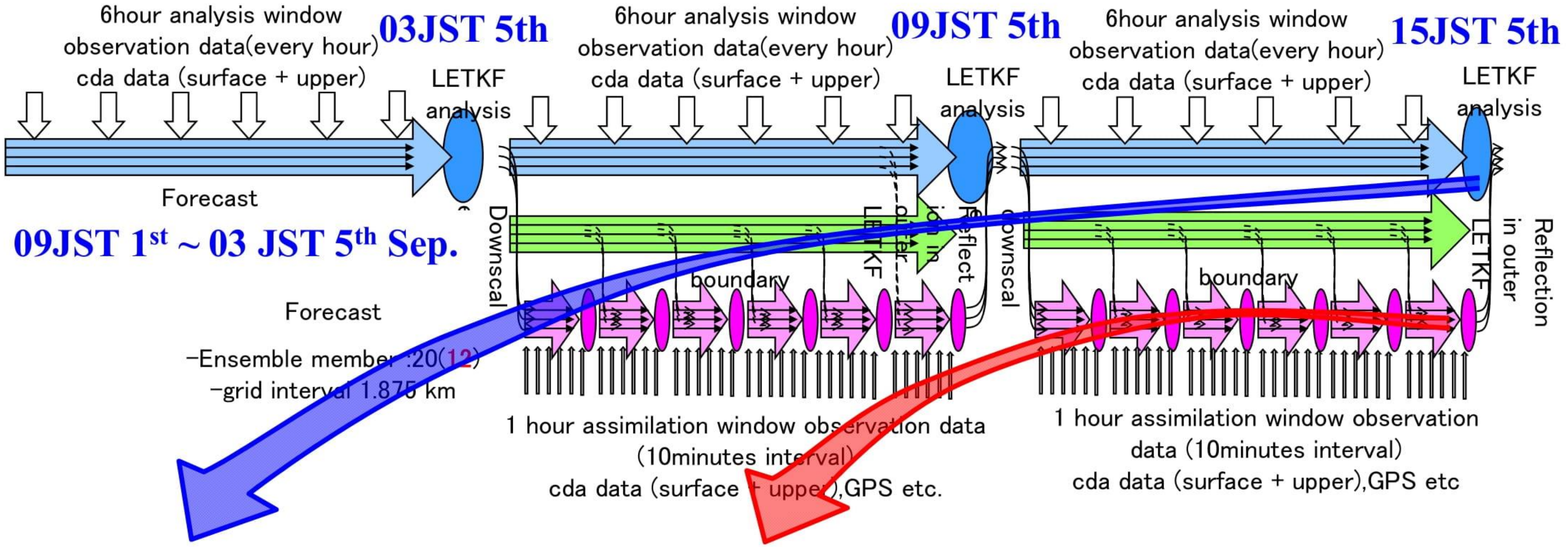


Spread (15JST,15km)

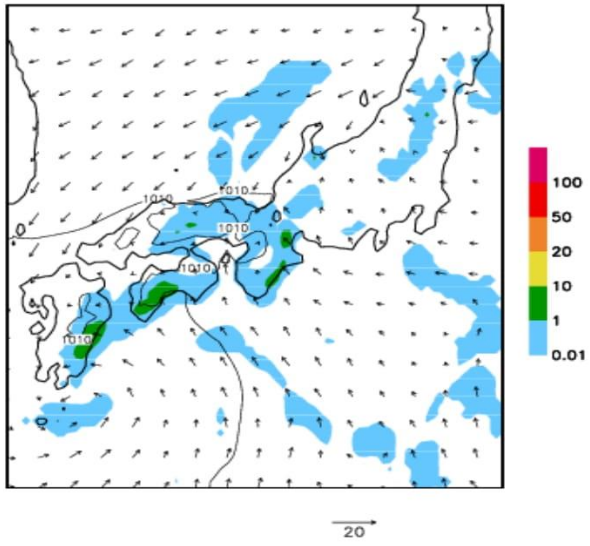


- **Spread at the center of the domain was relatively large.**
- **So we deployed the inner LETKF at the center of the domain.**

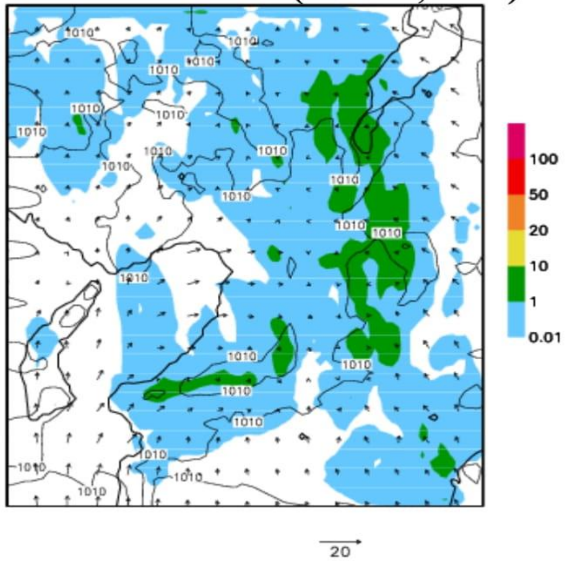
Results of nested LETKF system



Ensemble mean (15JST,15km)

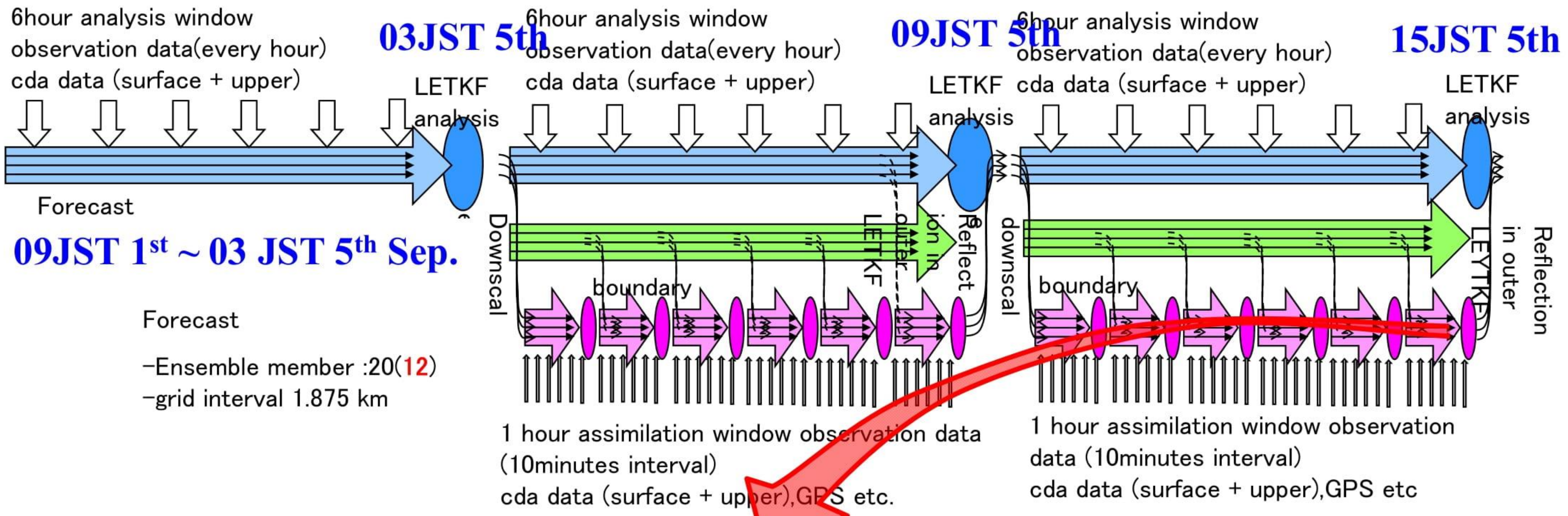


Ensemble mean (15JST,2km)



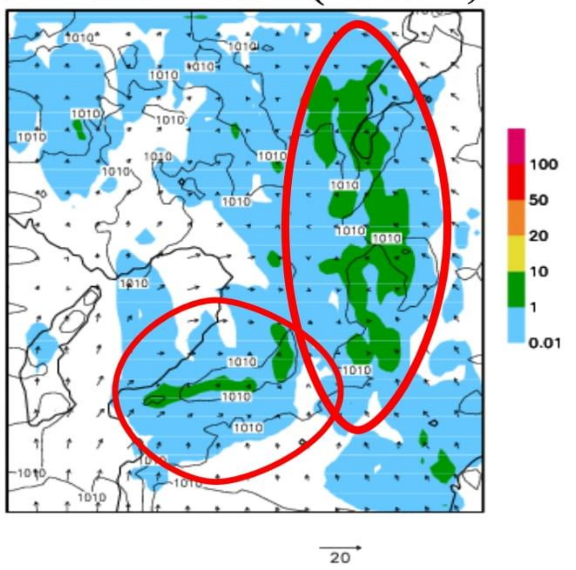
- **Detailed structures were produced by the inner LETKF with a grid interval of 2 km.**

Assimilation of conventional data

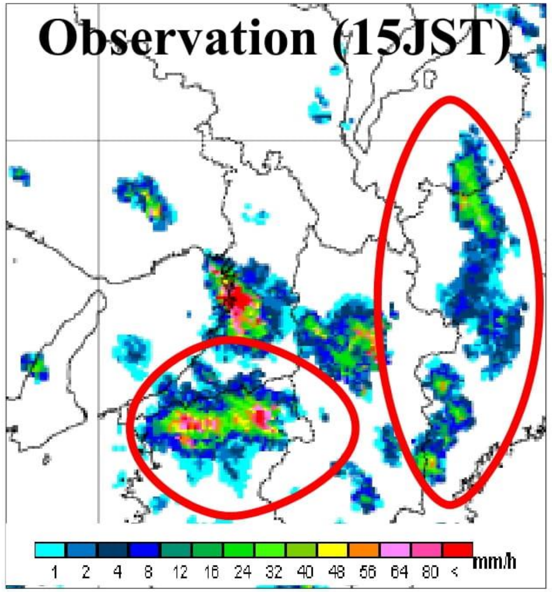


- **Rainfall regions were similar to the observed ones.**
  (Rainfall regions were produced over the mountain areas)

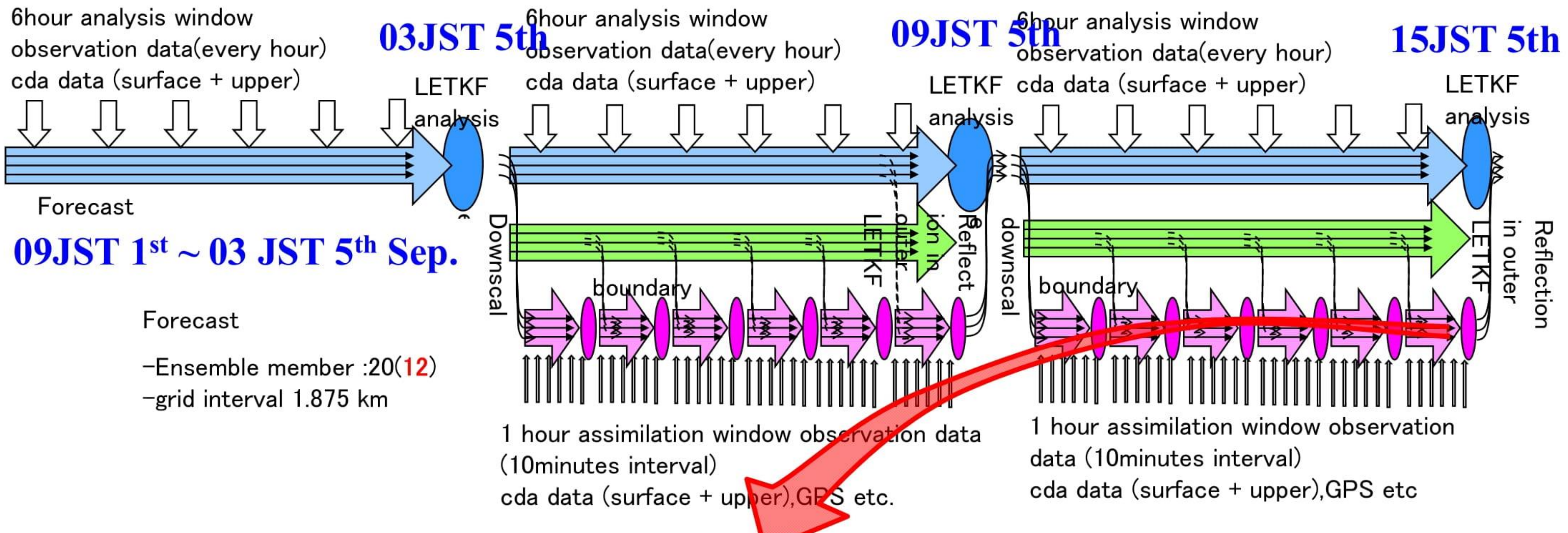
Ensemble mean (15JST,2km)



Observation (15JST)

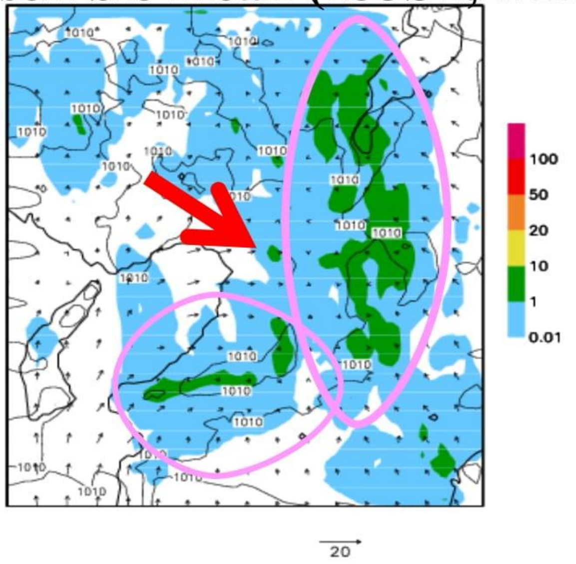


Assimilation of conventional data

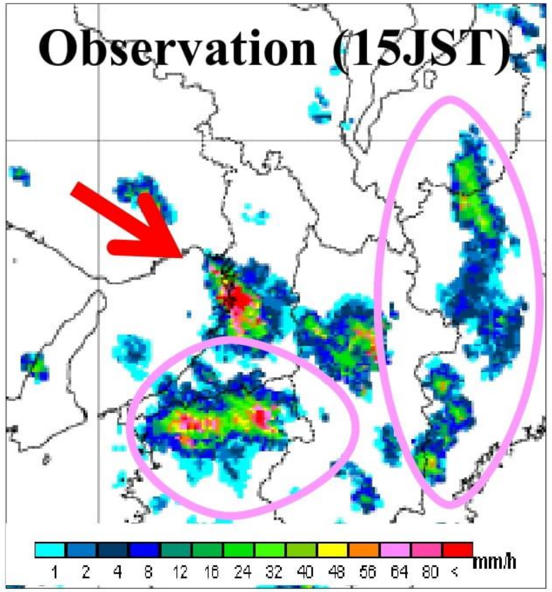


- **However, the rainfall that developed into the Sakai intense rainfall was too small.**

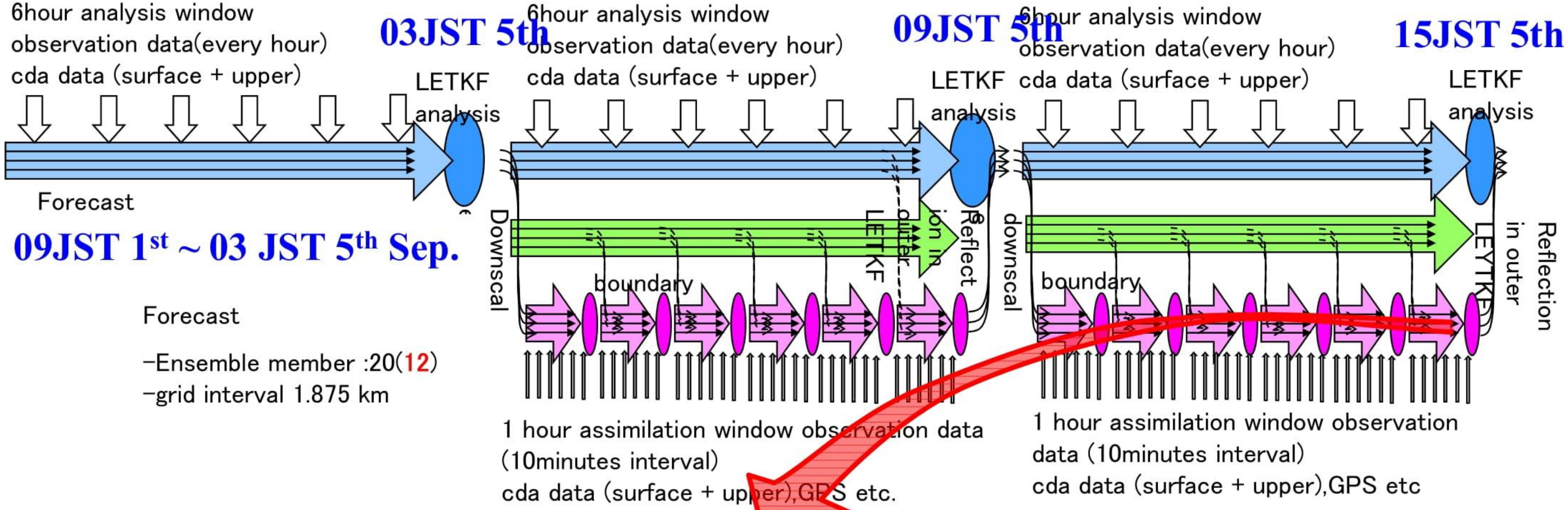
Ensemble mean (15JST,2km)



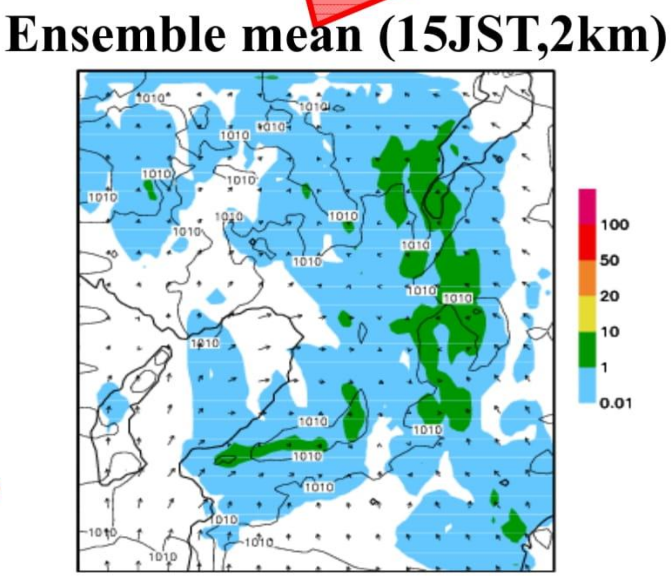
Observation (15JST)

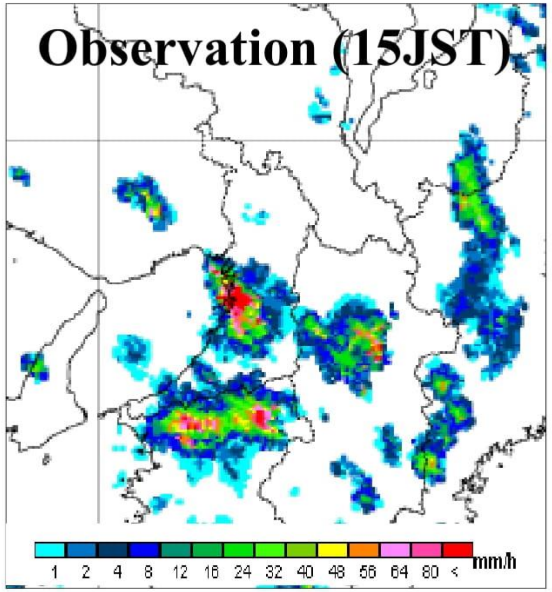


Assimilation of conventional data



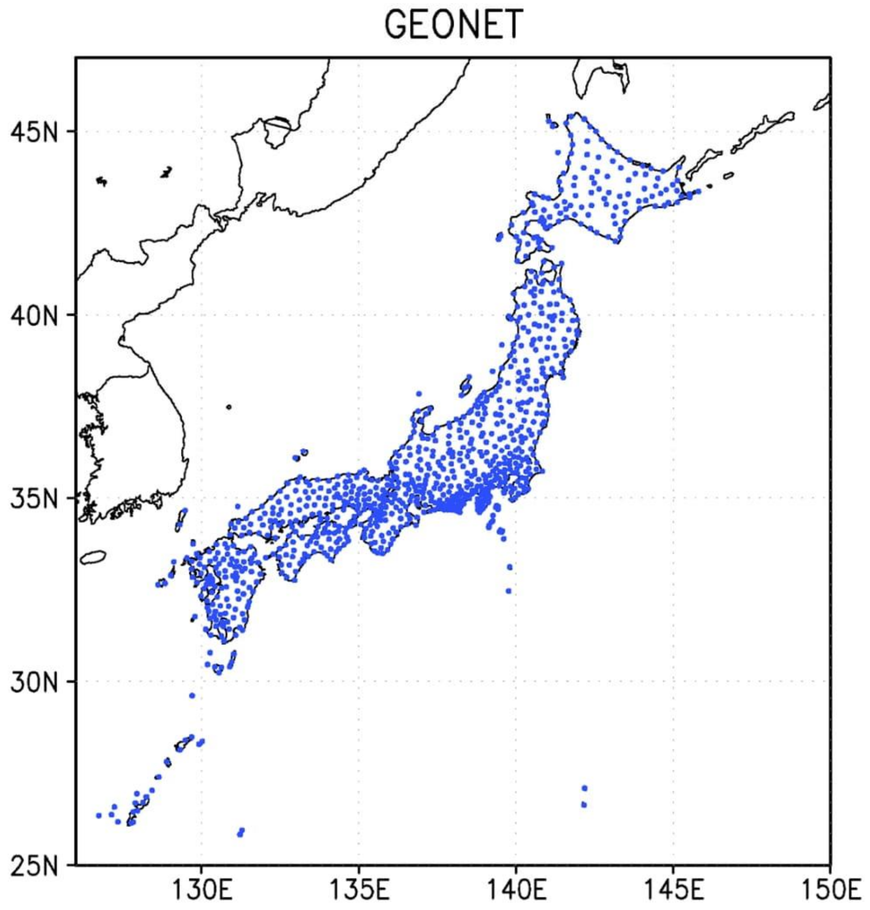
- **To be similar to the observed distribution, higher resolution data, such as GNSS PWV data, is needed.**



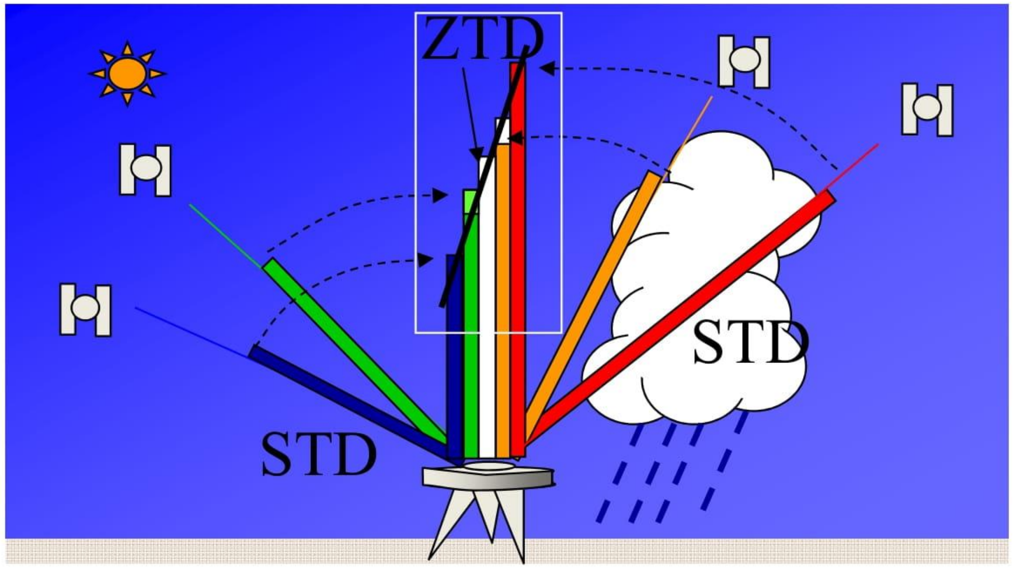


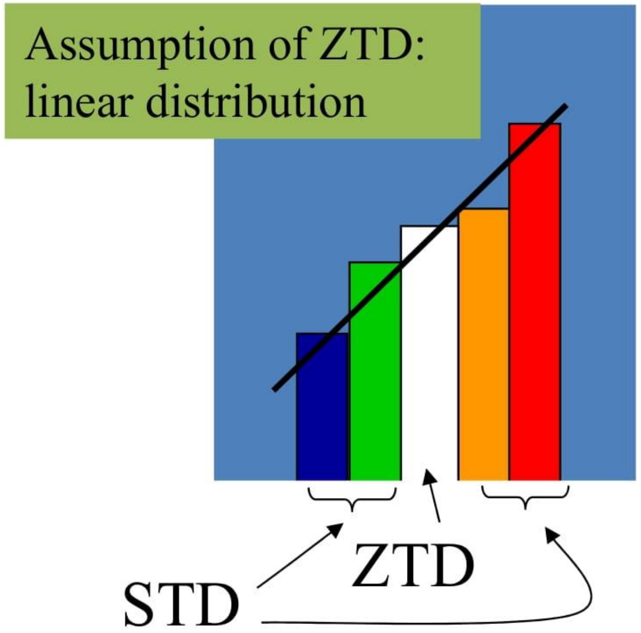
How to estimate PWV data

- **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.**



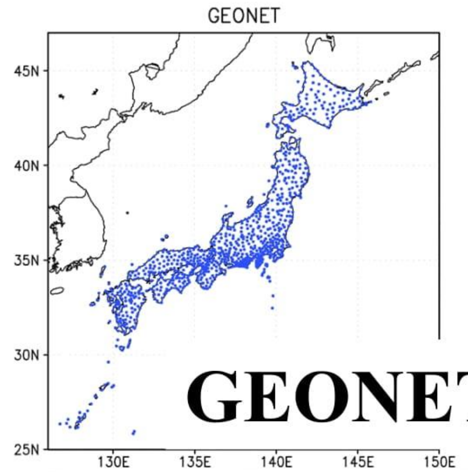
How to estimate PWV data





- 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

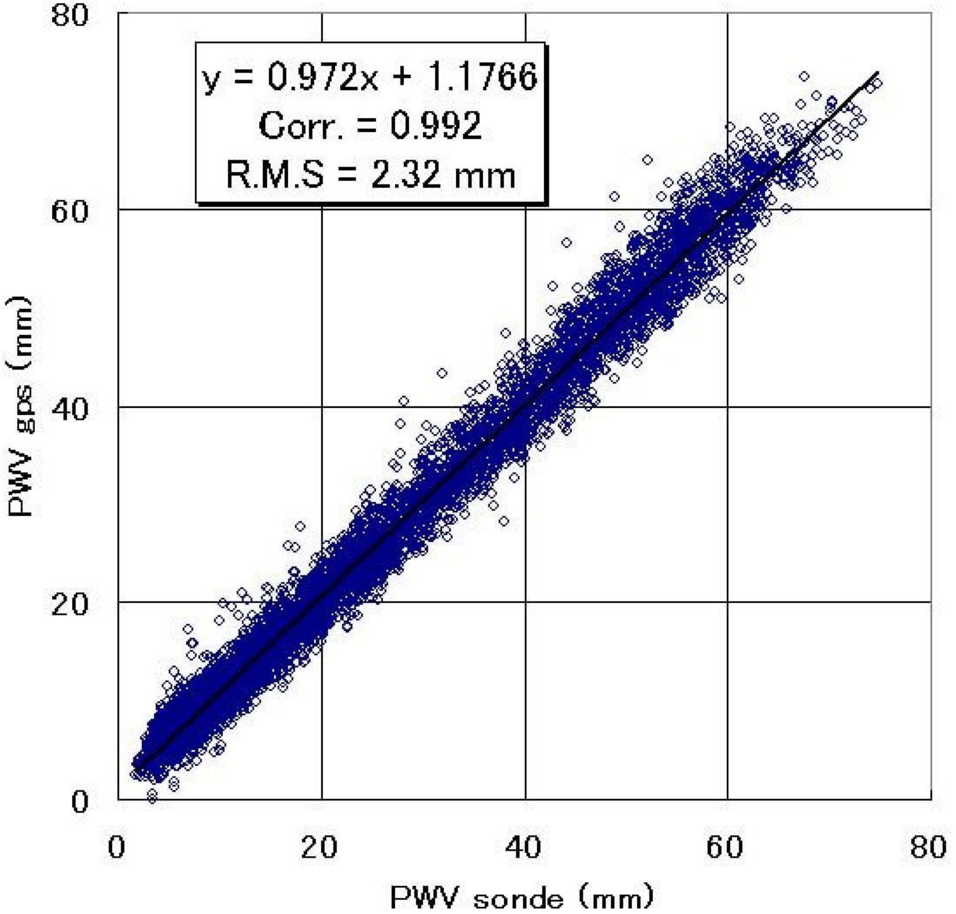
Comparison with GPS-PWV and sonde-PWV（Period Jun. 1999 ～ May 2000）. Distances between GPS-PWV and sonde-PWV were less than 10km horizontally and 20m vertically.

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

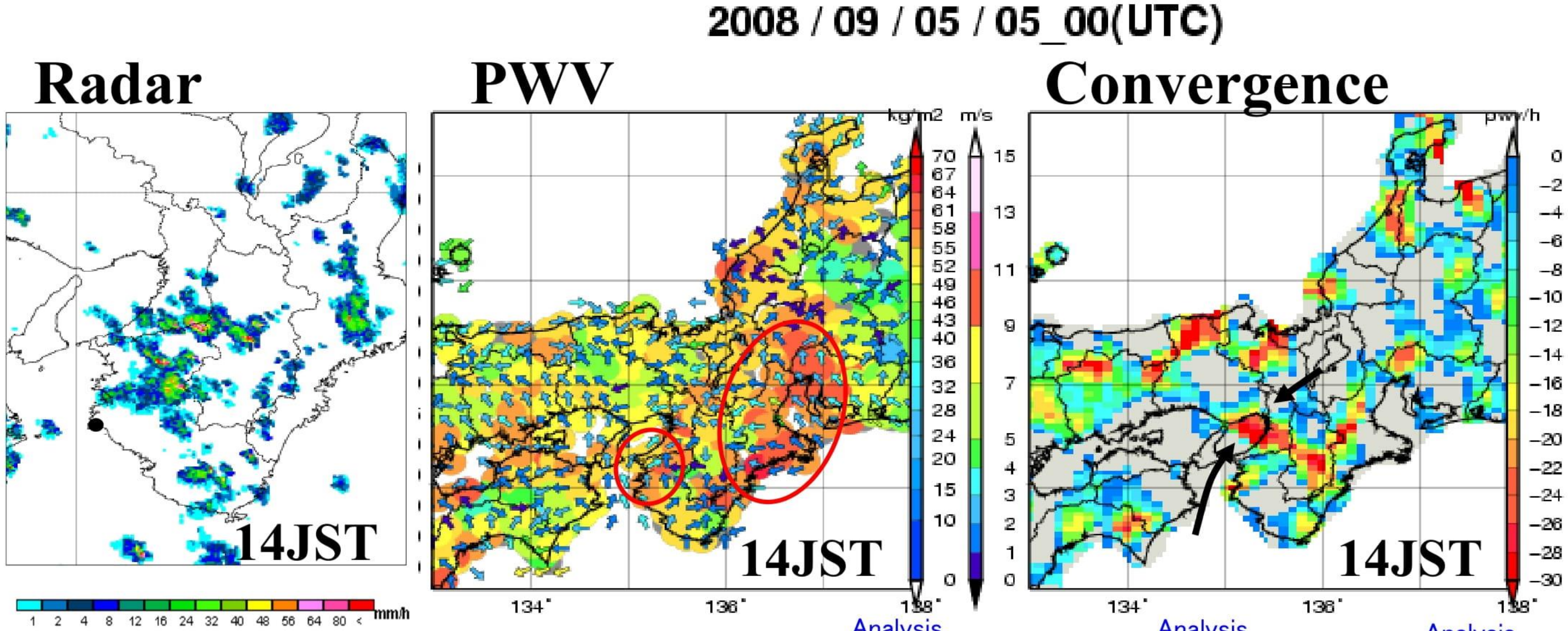
*高度差＝GPS点標高－高層観測点標高

RMS = 2.3mm

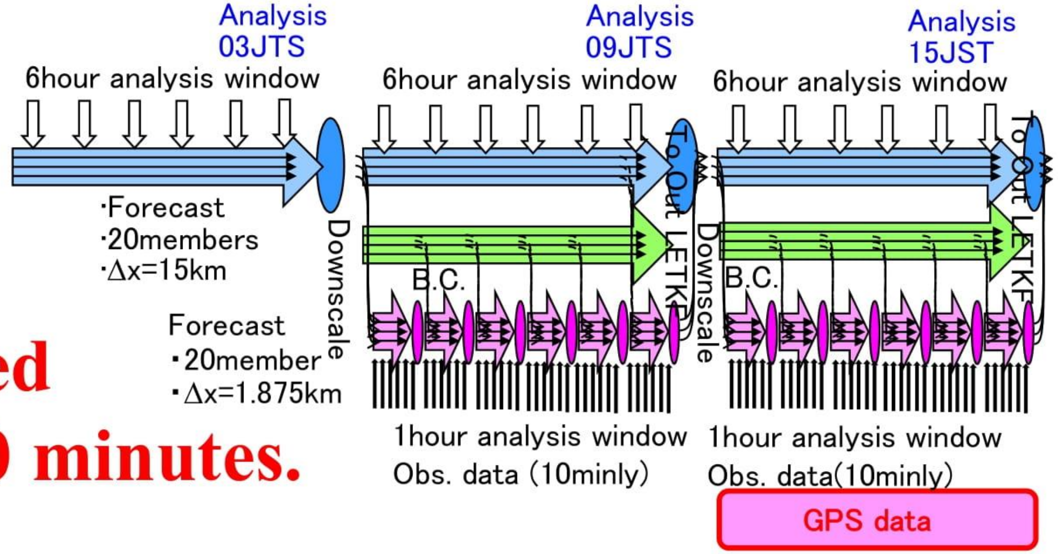
（Precise orbit was used in the estimation of GPS-PWV.)



Observed GPS-PWV data



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



GPS-PWV was assimilated from 9 to 15 JST every 10 minutes.

Assimilation method GPS-PWV

Observation data :GPS-derived PWV

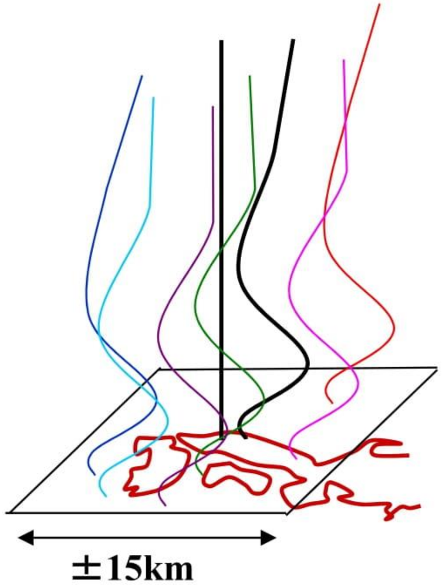
Difference between the GPS receivers' altitude and model topography <50 m.

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.

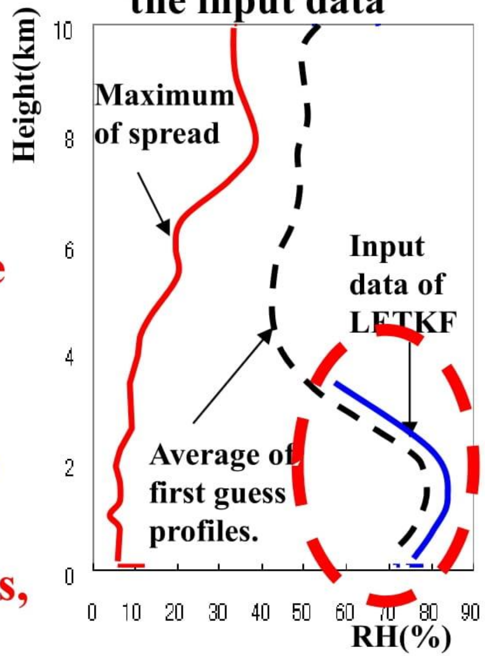


Assumption: the difference between analysis and first guess is larger at the layer with a wider spread of RH.

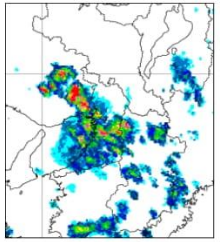
Water vapor was should be modifies only at the layer of which the correlation with PWV was large.

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.

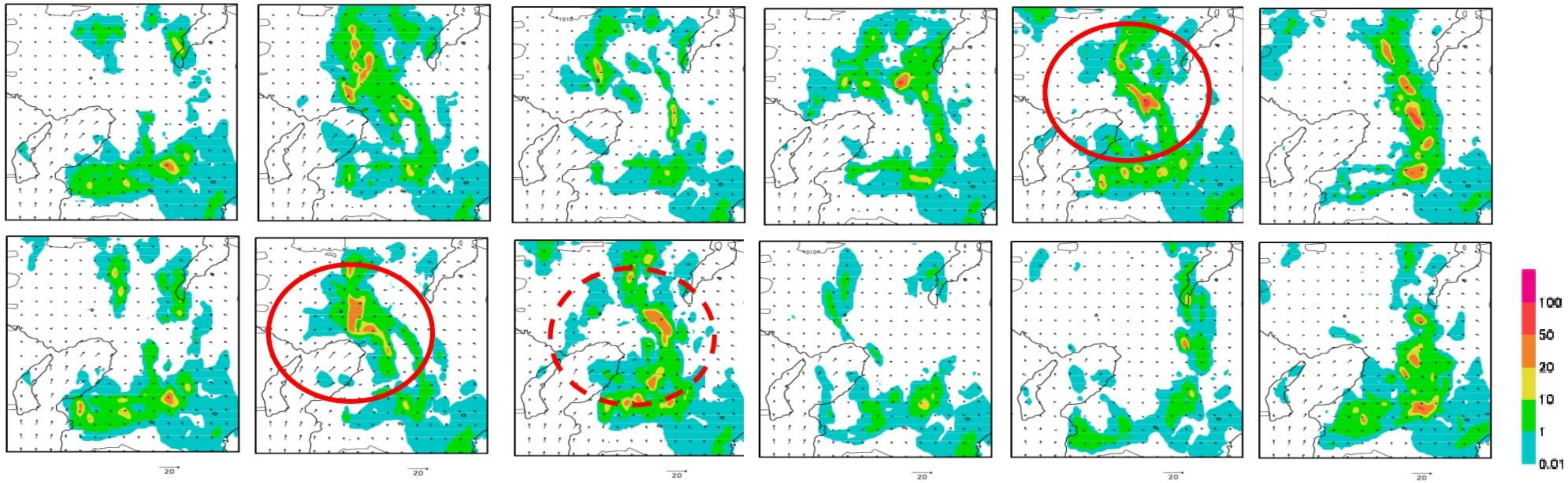
Example of the input data



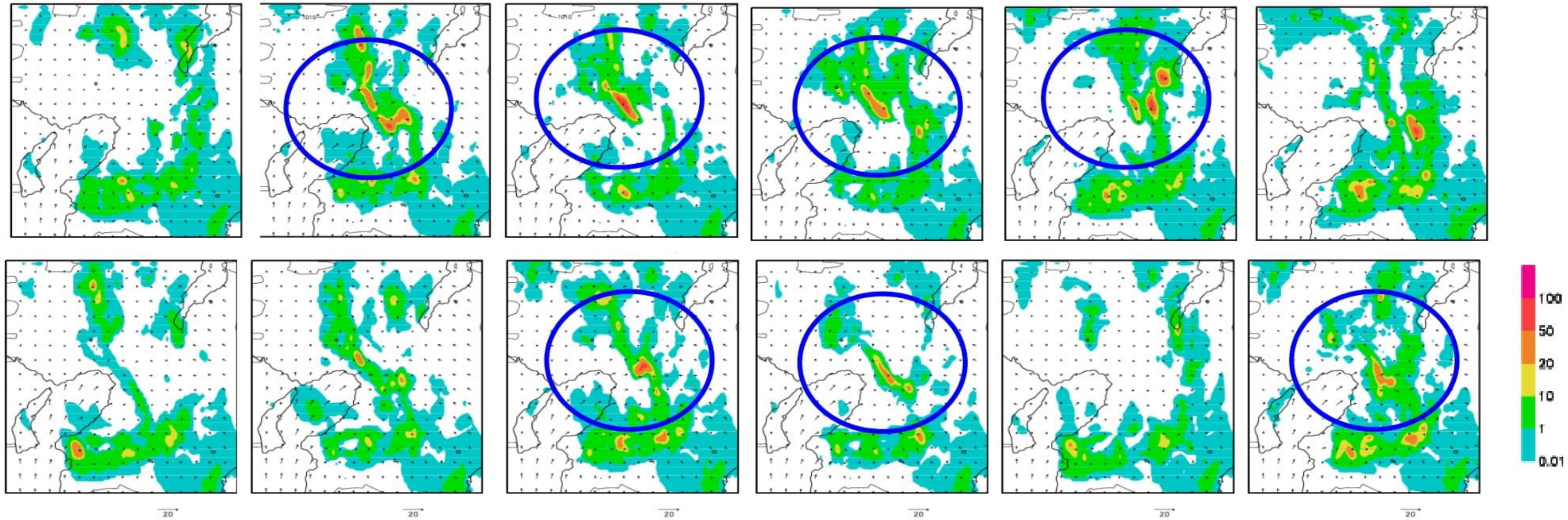
Assimilation of GPS-PWV data



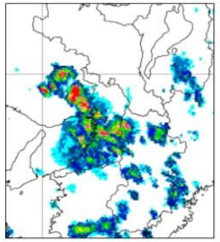
CNTL 17JST

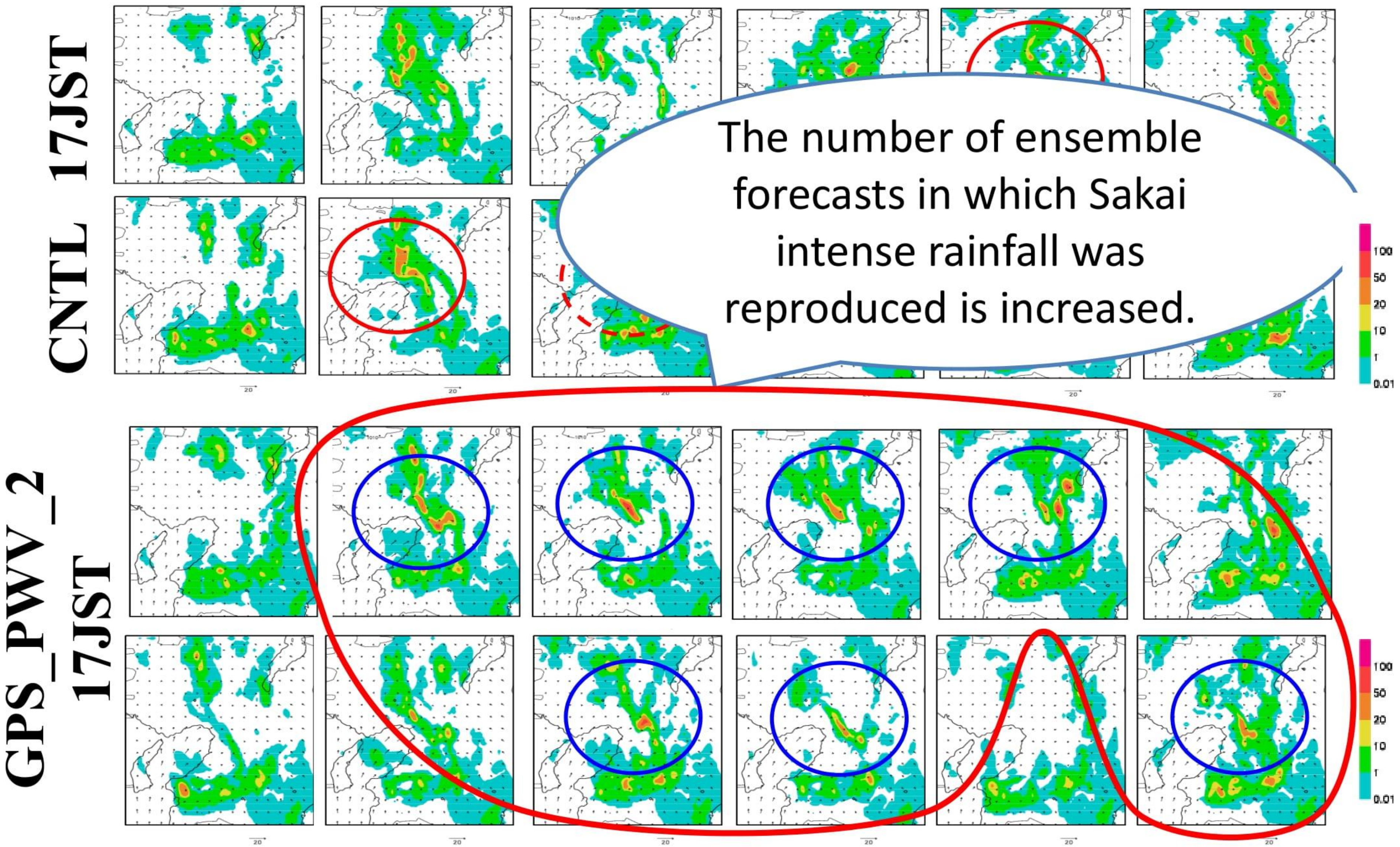


GPS_PWV_2_
17JST



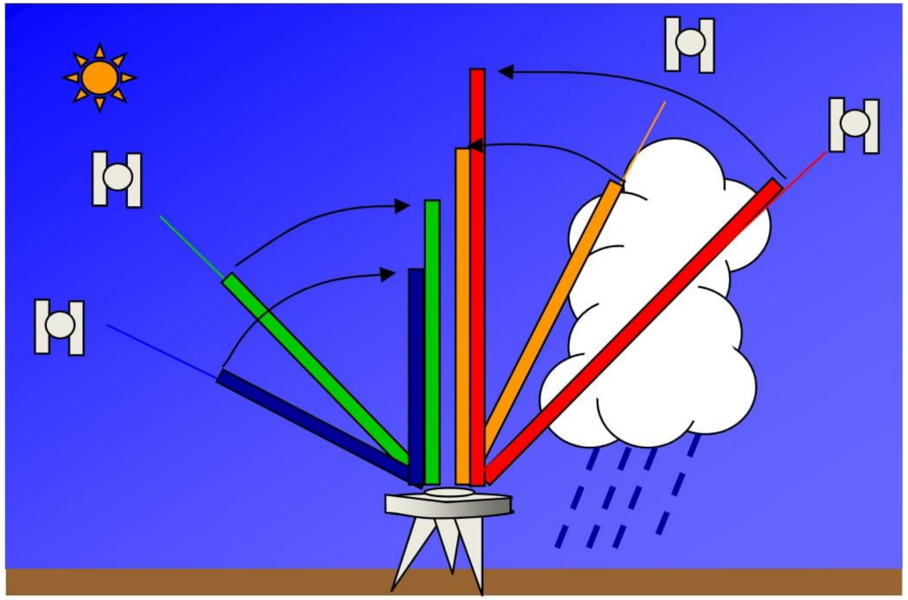
Assimilation of GPS-PWV data

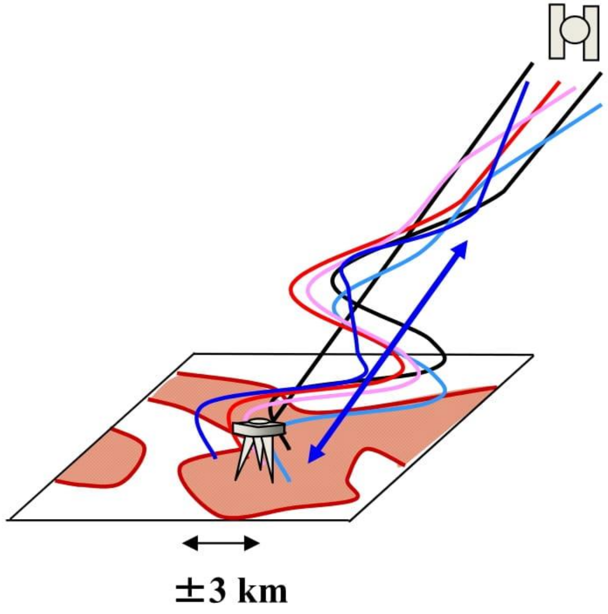




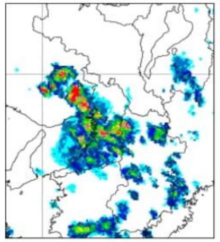
GPS-slant water vapor (SWV) data

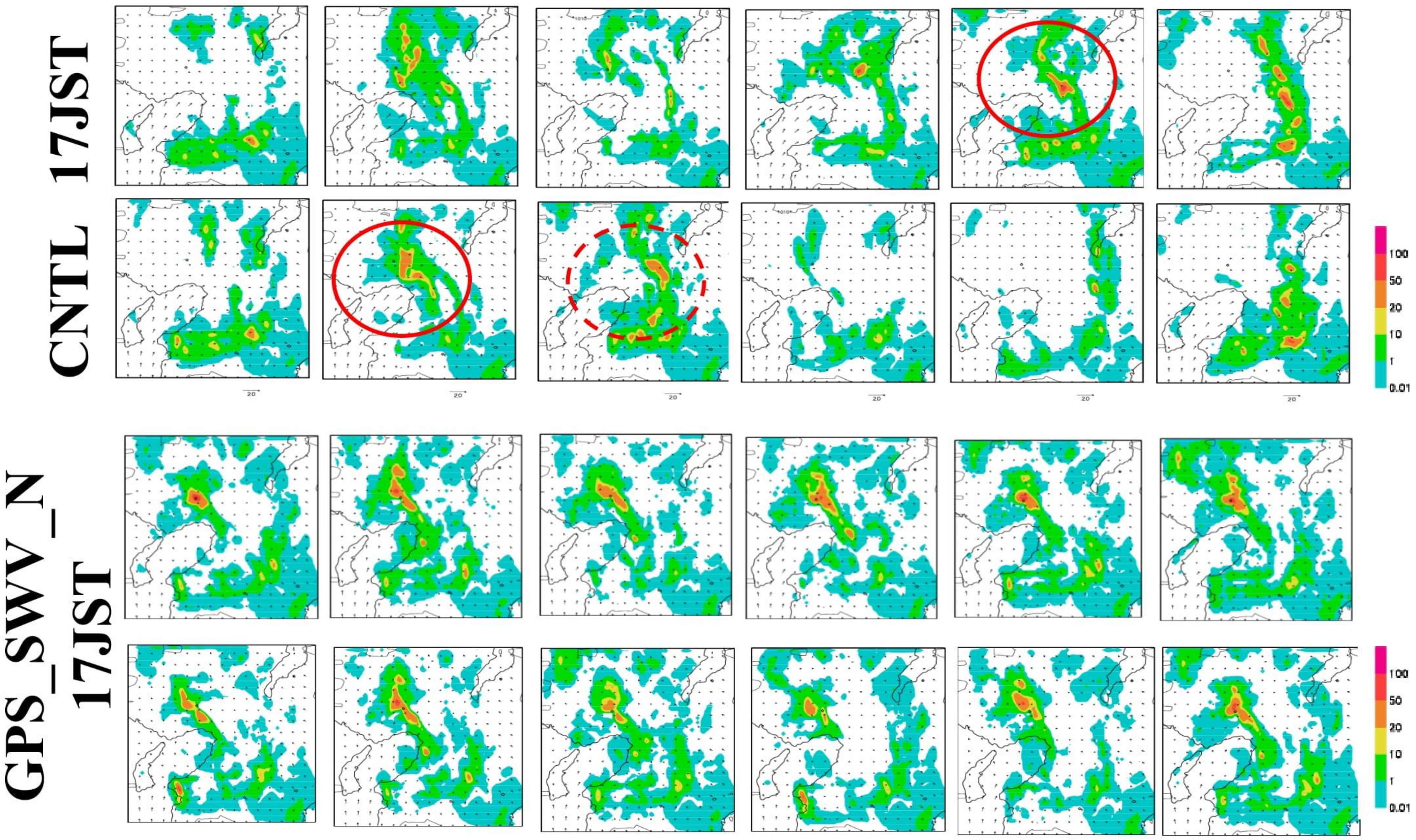
- Slant water vapor (SWV) was the water vapor amount along the path from GPS satellite and GPS receivers
- SWV was retrieved from PWV, gradient and residual, and surface meteorological data, such as T and P.
- **SWV was assimilated by using the same method of PWV, except the paths were slanted.**



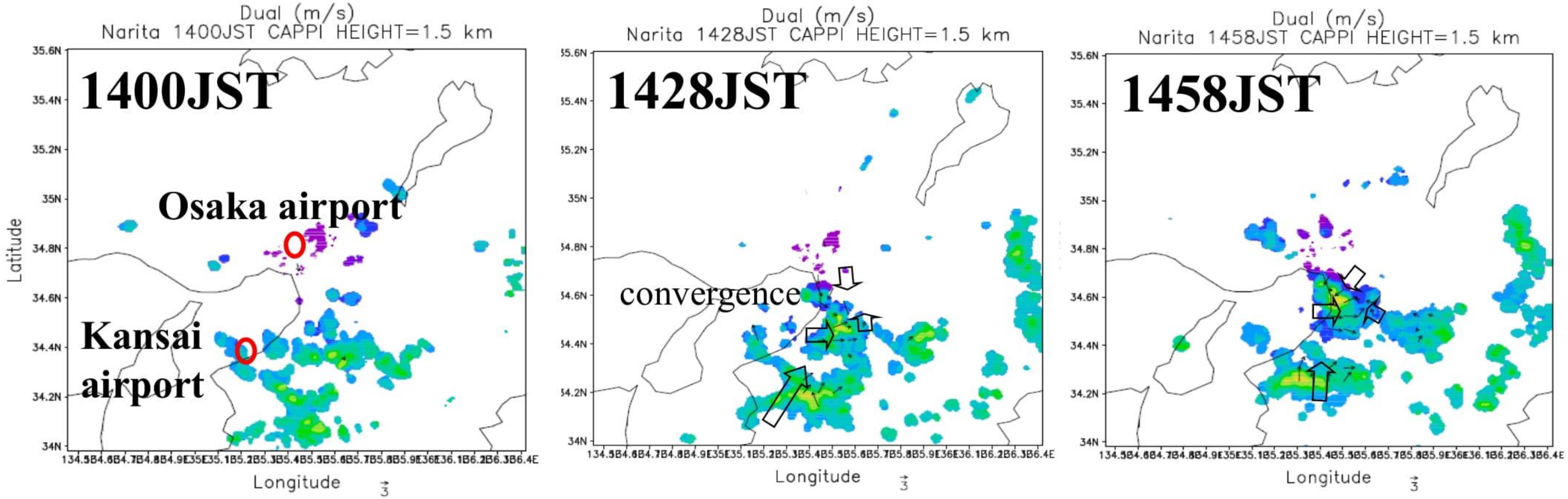


Assimilation of GPS-SWV data



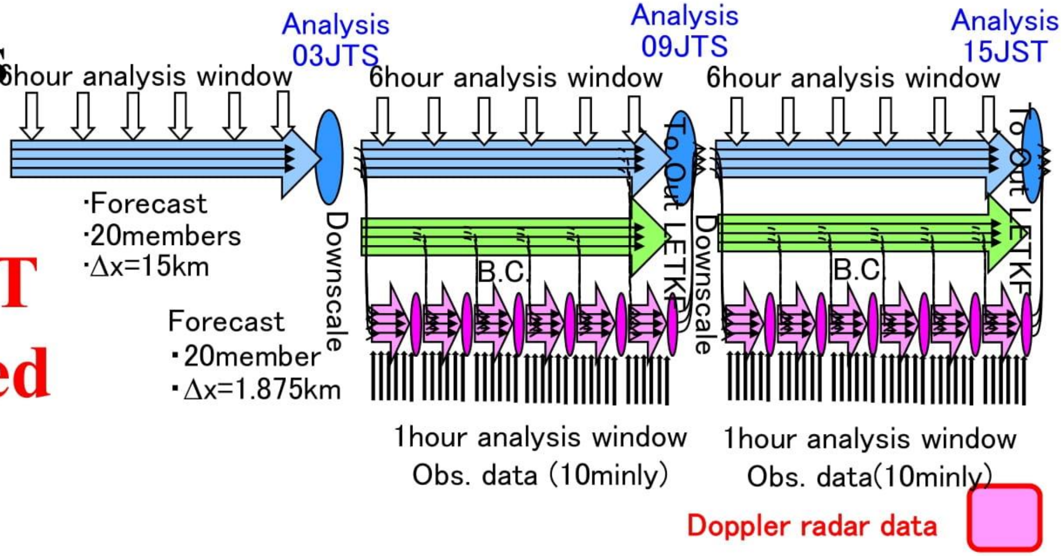


Horizontal wind obtained from Doppler radars

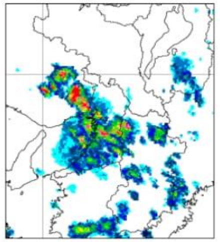


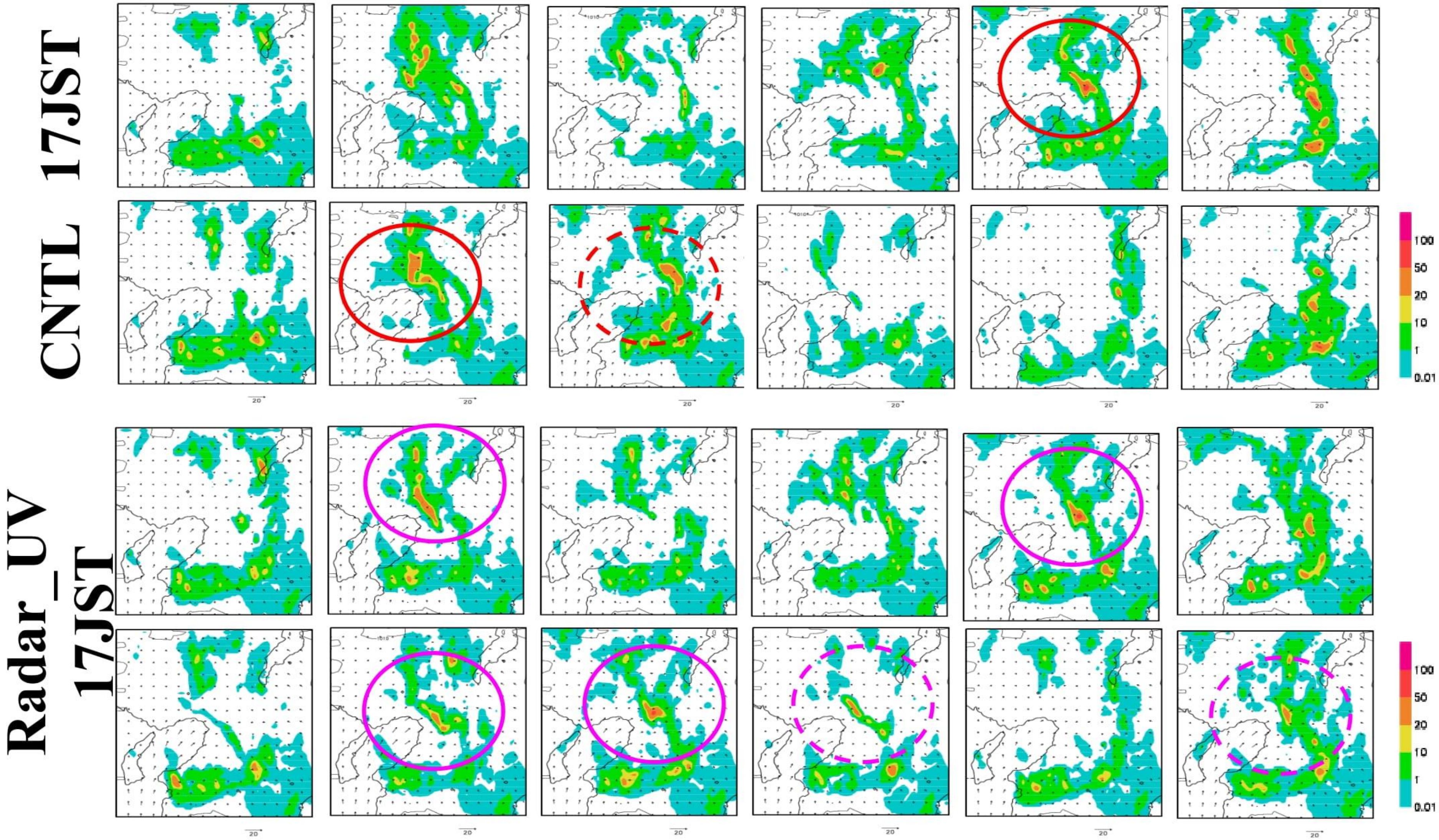
Horizontal winds were estimated from the radial winds of Kansai and Osaka airports using dual analysis.

Radial wind from 14JST to 15JST was assimilated every 10 minutes.

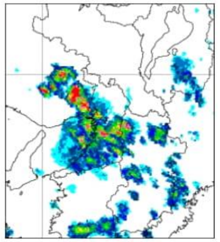


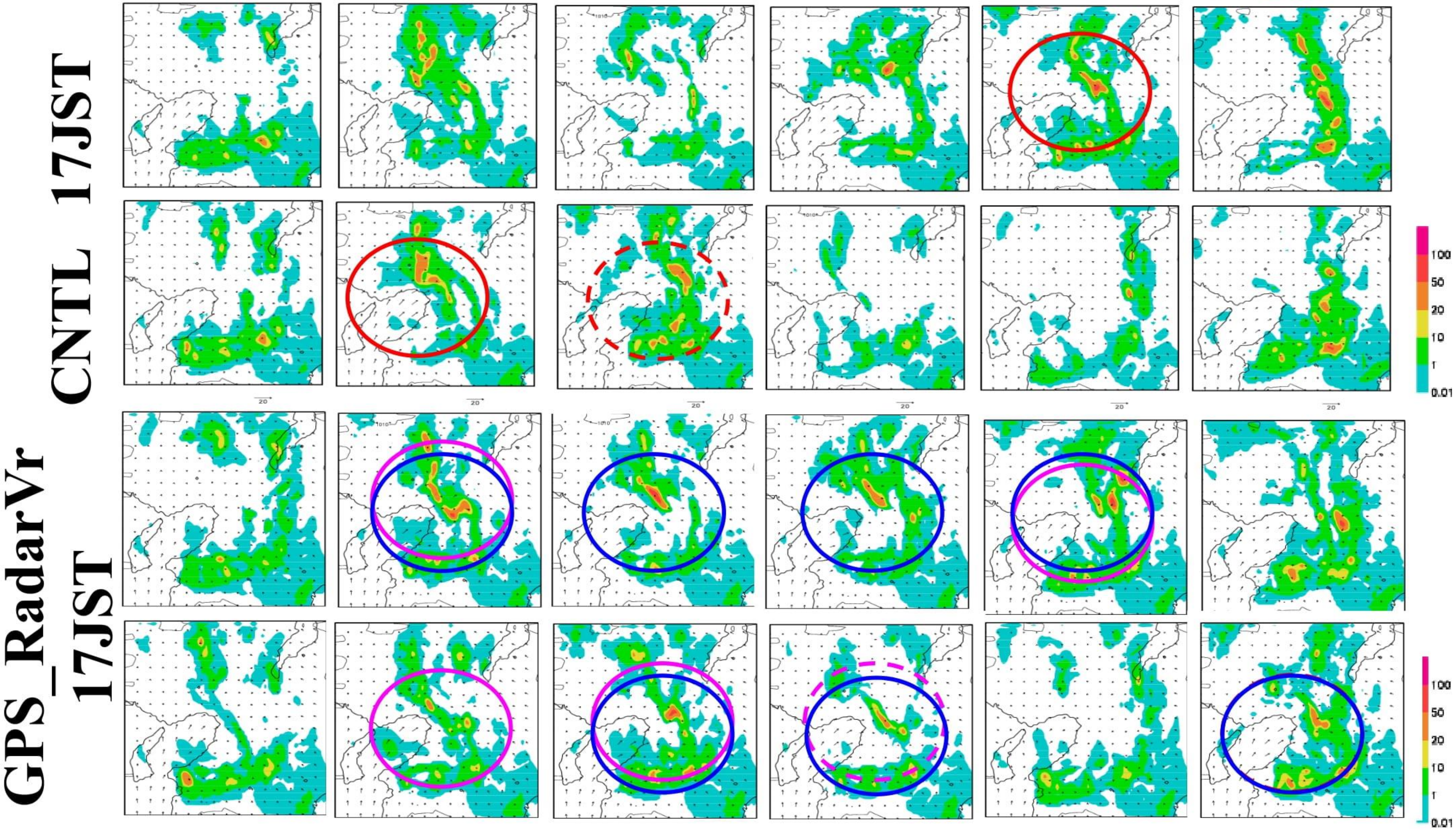
Horizontal wind improves the rainfall forecasts,
although the impact was weaker than GPS-PWV.





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

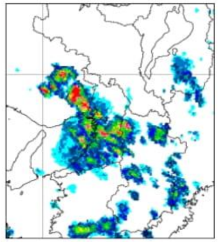


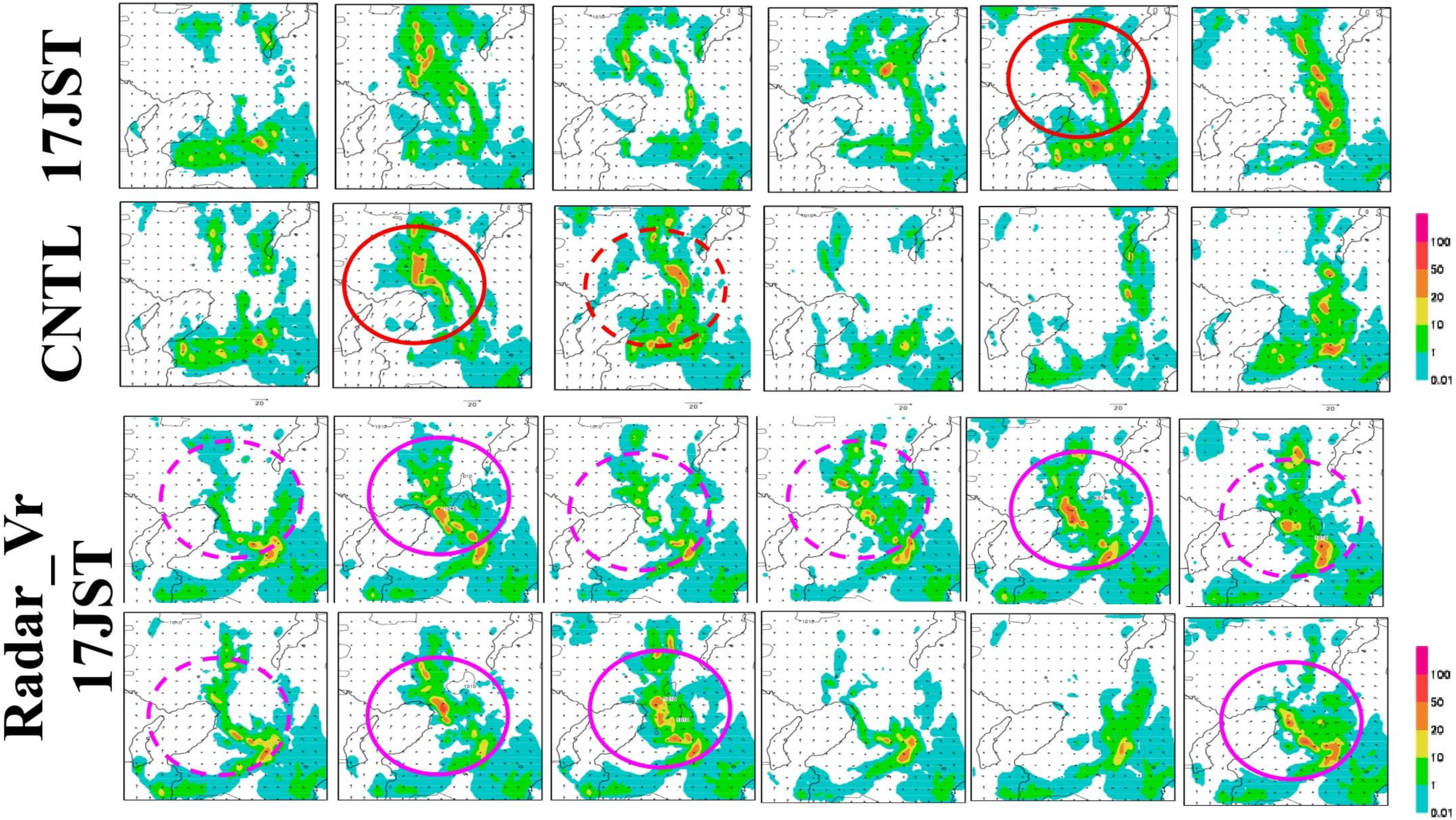


Blue and pink circles indicate the rainfalls improved by GPS and radar data

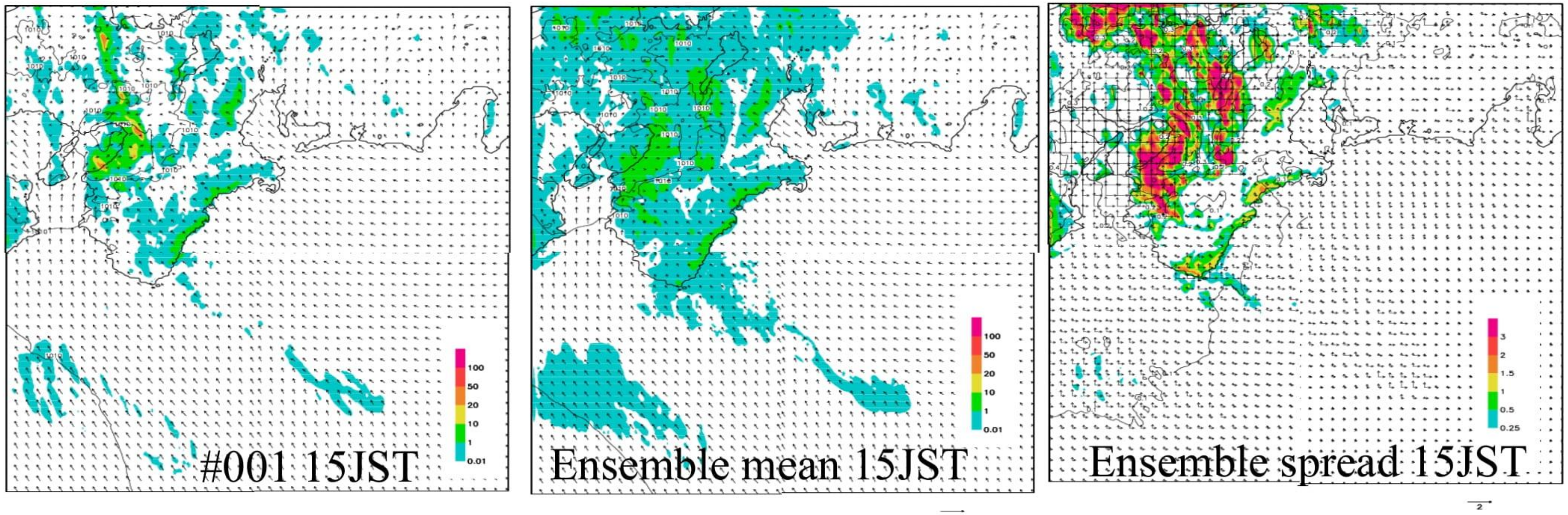
Radial winds also improve the rainfall forecasts.

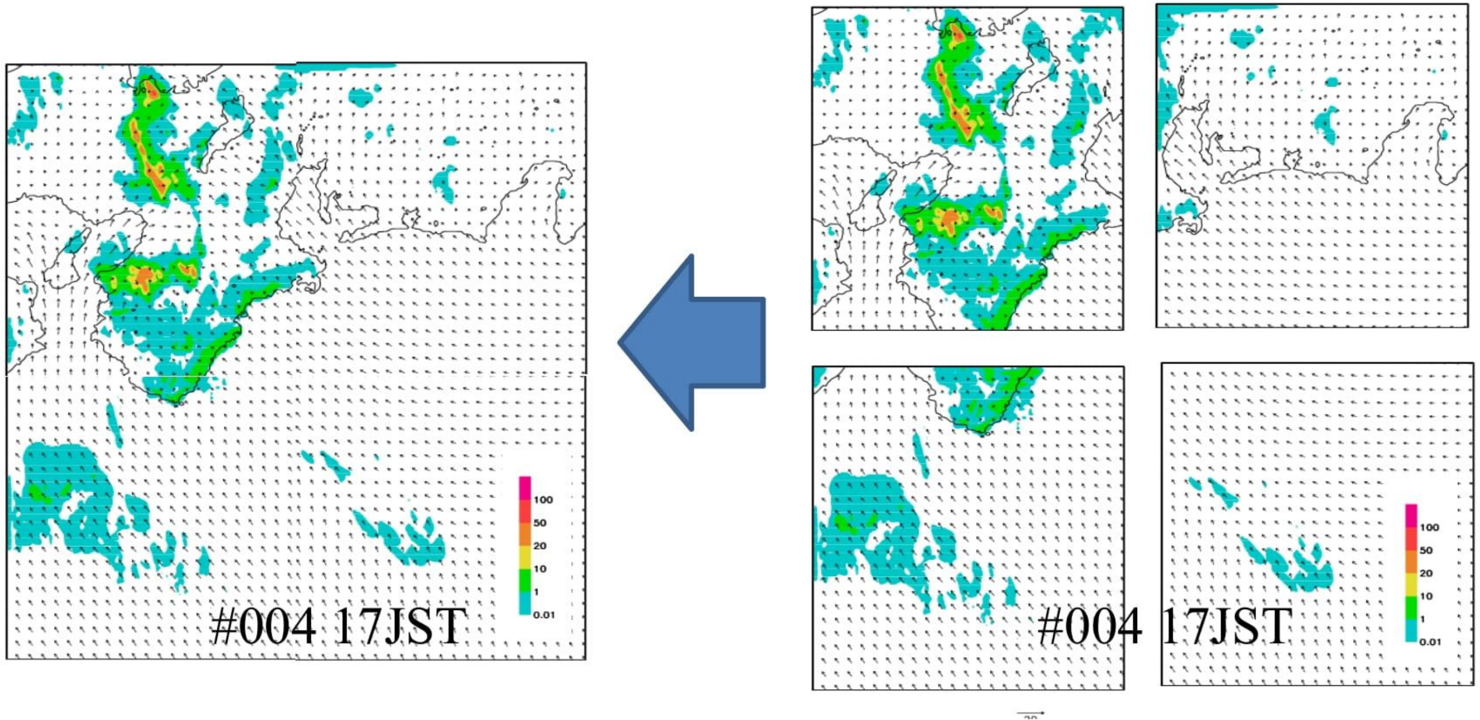
Impact was larger than that of horizontal wind.



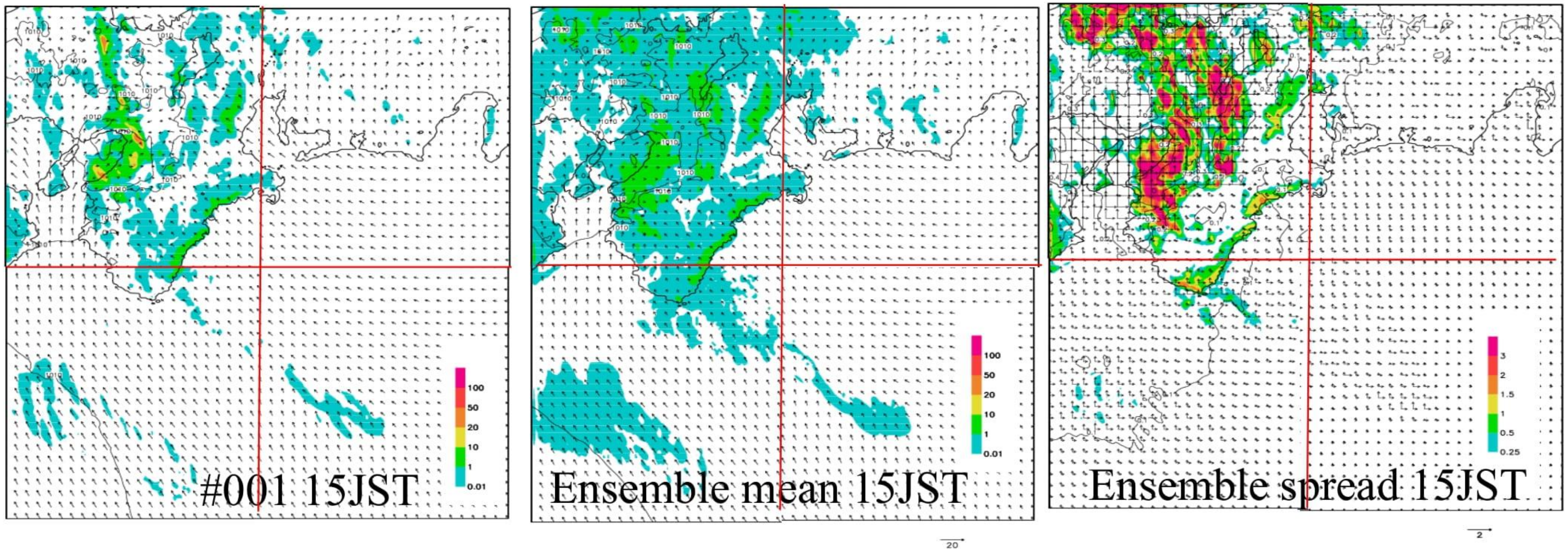


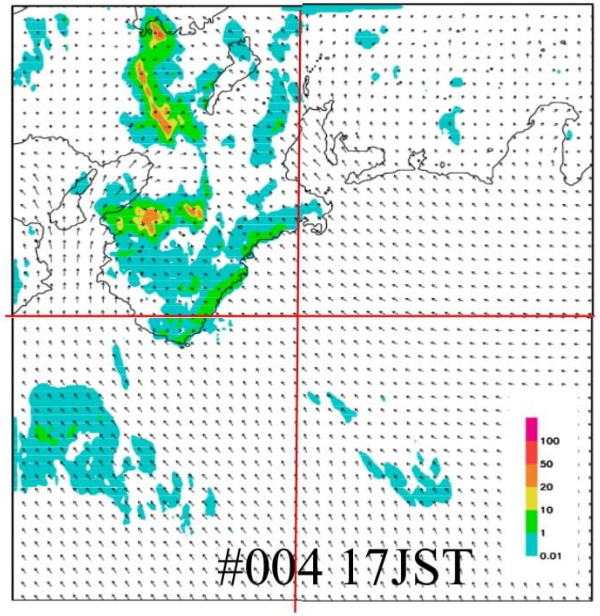
Overlap regions of patches (Boundary Problem)





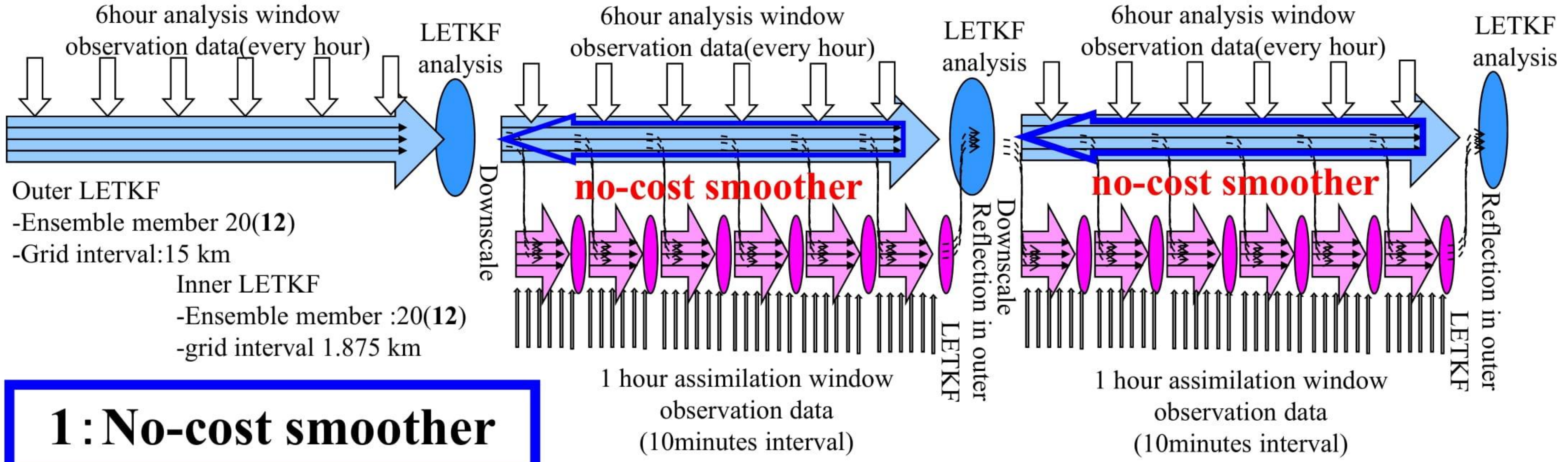
Overlap regions of patches (Boundary Problem)



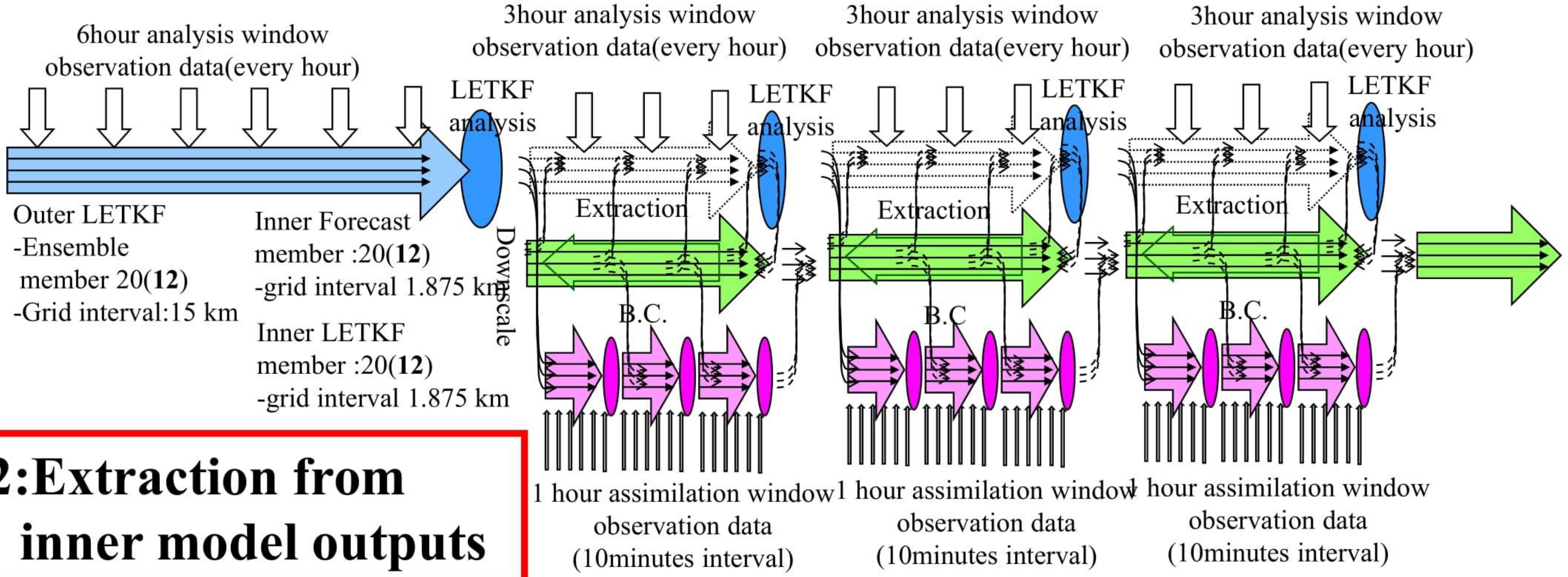


- Four inner LETKFs were deployed in the outer LETKF.
- **Unrealistic convection cells were not generated on the boundary.**

Further improvements

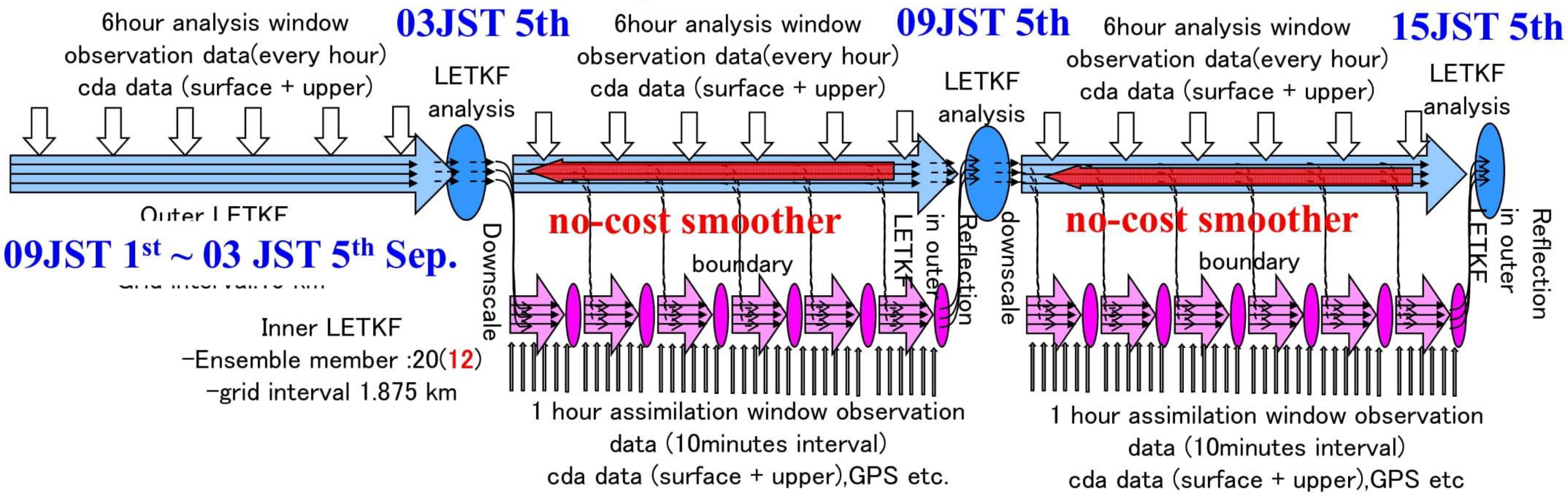


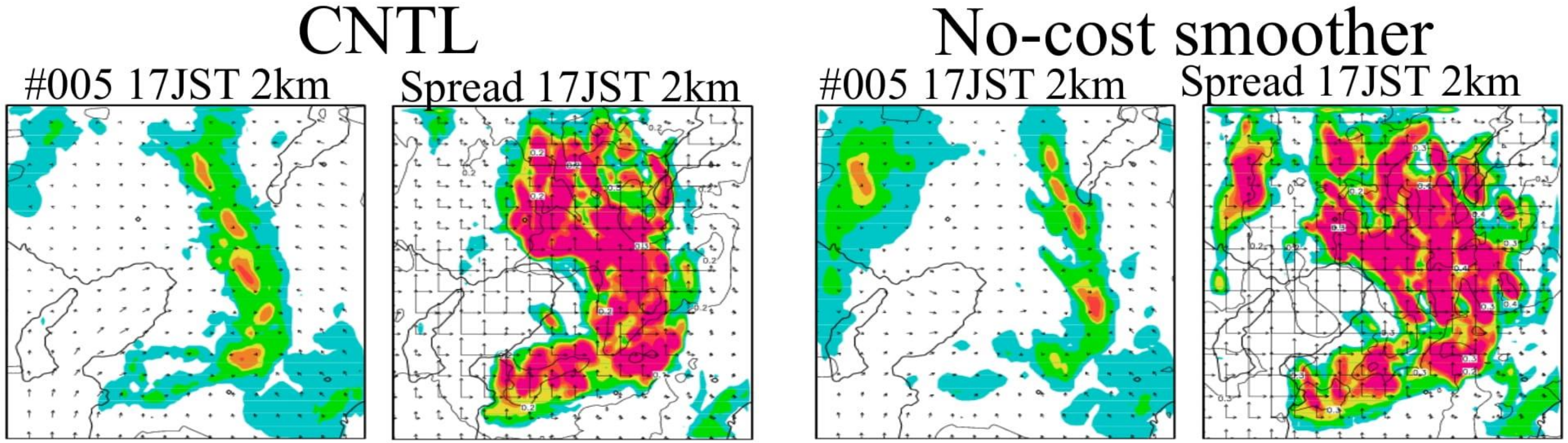
1：No-cost smoother



2:Extraction from inner model outputs

Utilization of no-cost smoother





No-cost smoother enlarged the large spread region.

Summary and future plans

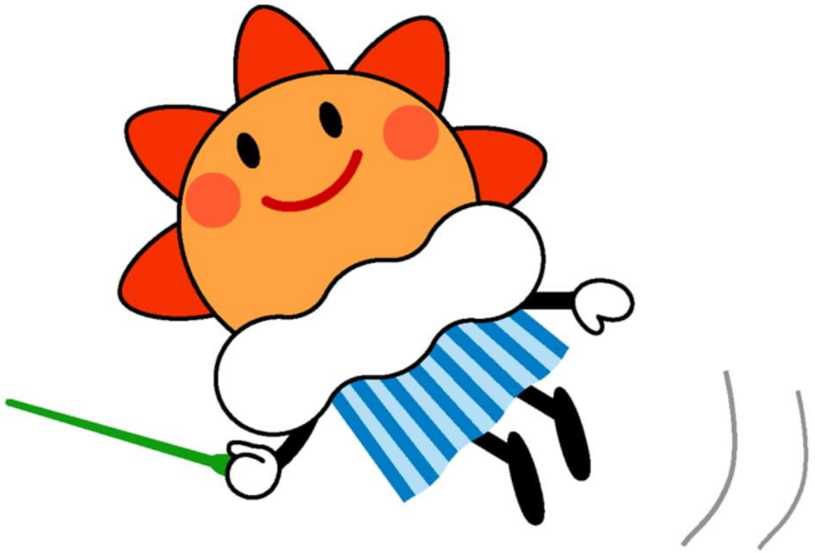
1. The nested LETKF system is under development to reproduce the environments and convection cells.

2. The Sakai intense rainfall on 5th Sep. 2008 was reproduced by the nested LETKF system.

3. GPS-water vapor data and the horizontal winds of radar data increased the number of forecasts in which the intense rainfall was reproduced.

4. The number of kinds of assimilation data will be increased. Other improvements on the nested system will be implemented.

Thank you for your attention



Acknowledgements

GPS data were provided from the GSI.