Future Development of Mesoscale Modeling and Data Assimilation in JMA

Masaru Kunii

Meteorological Research Institute / JMA, Japan

mkunii@mri-jma.go.jp

Future Development of DA

- **Development of a cloud resolving 4 dimensional data assimilation system**
  - Assimilation of dense observation data to dynamically predict deep convection and associated local heavy rainfalls.

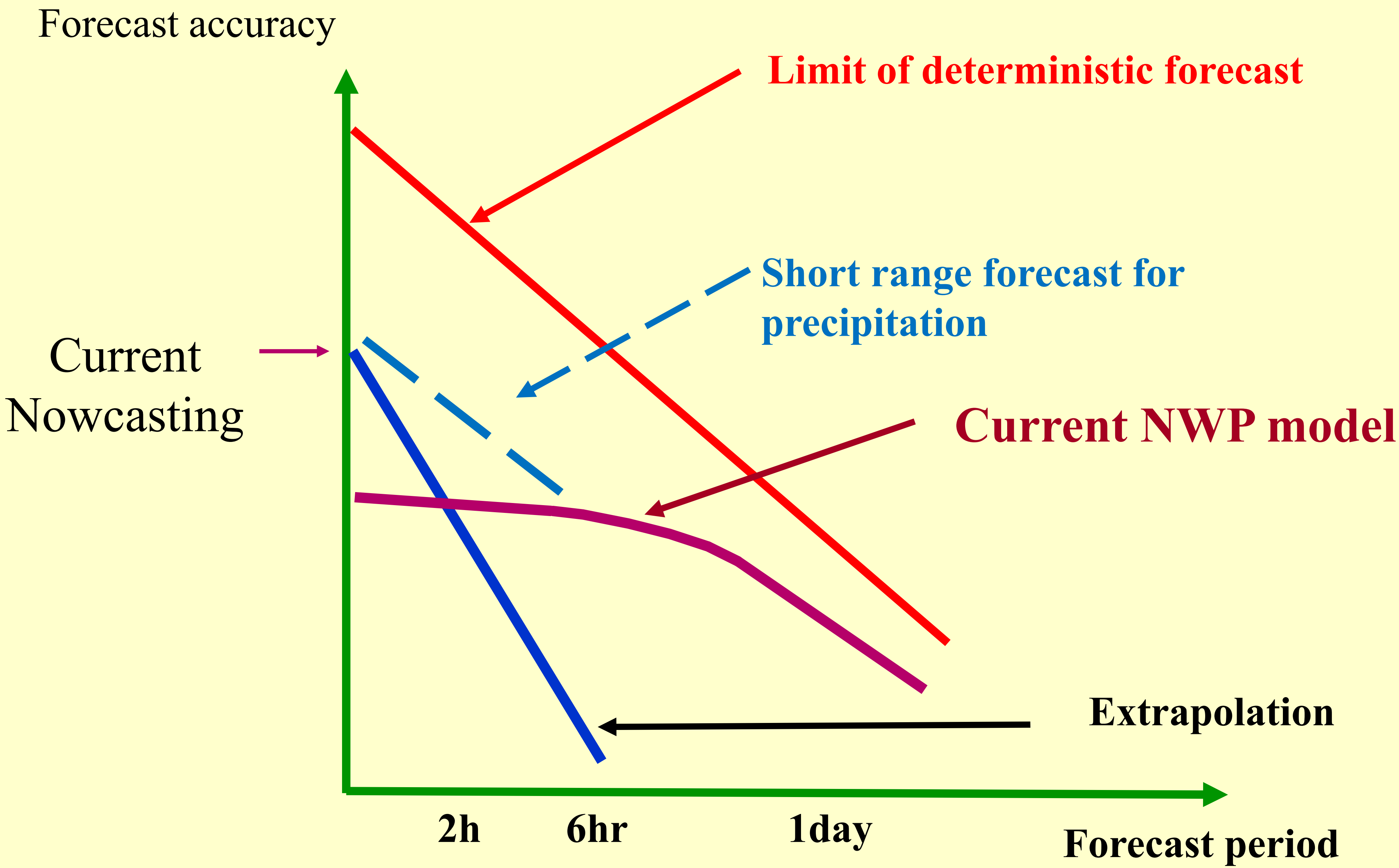
- **Development and validation of a cloud resolving ensemble analysis forecast system**
  - Probabilistic quantitative forecast for heavy rainfalls using ensemble data assimilation NWP.

⇒ Participating **K-computer project**

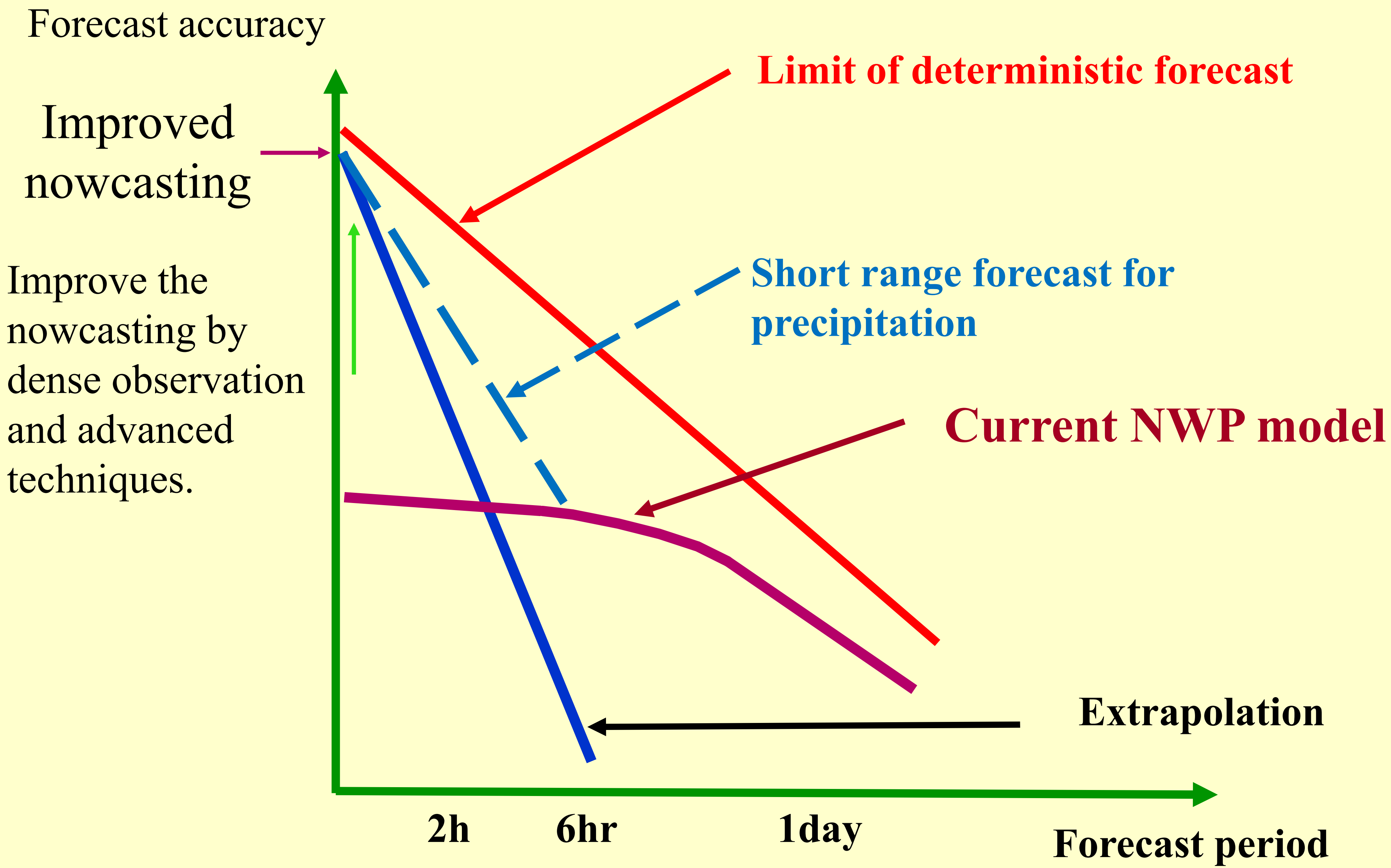
K-computer project

– development of cloud resolving 4DVAR –

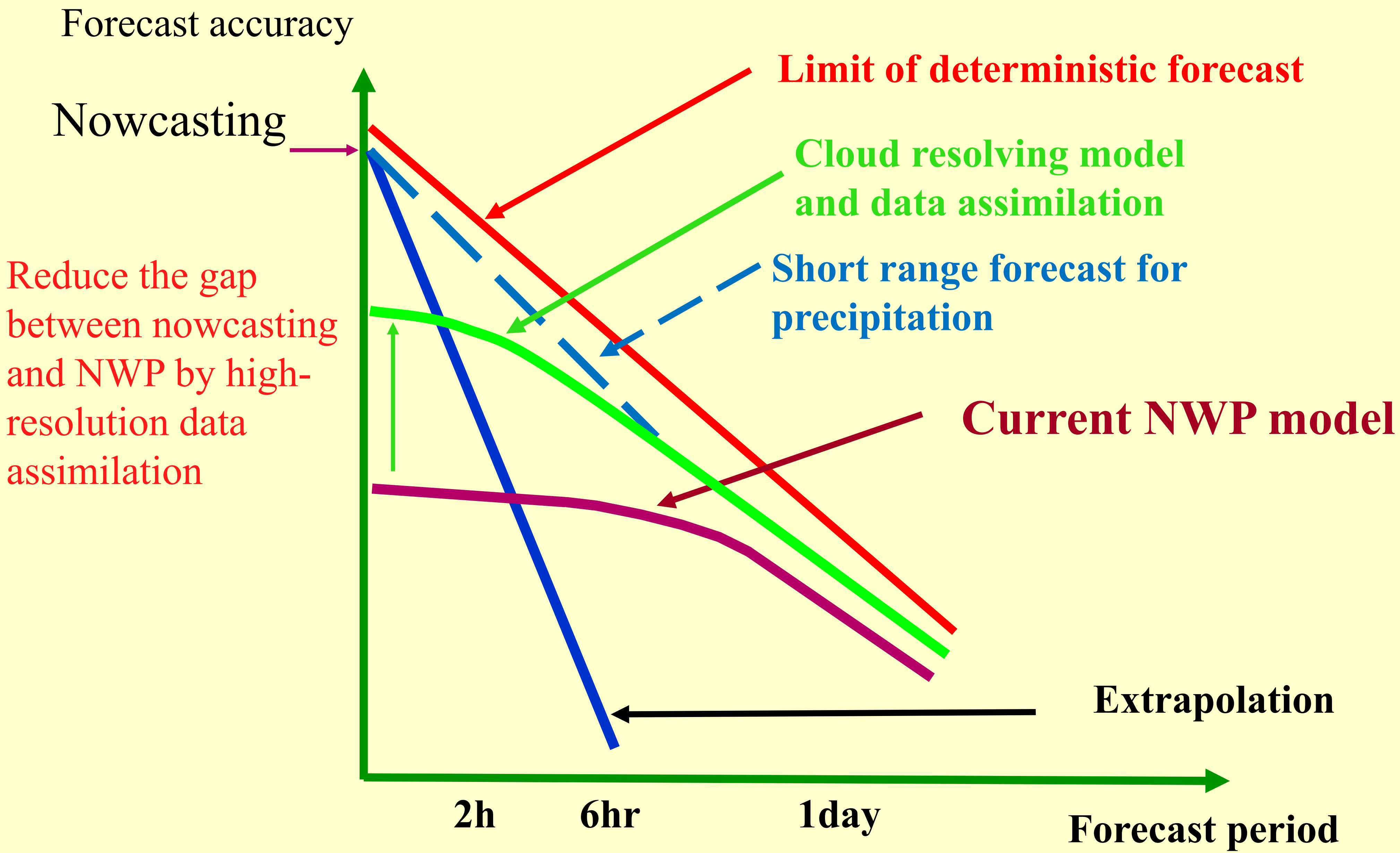
Approaches to predict local heavy rain



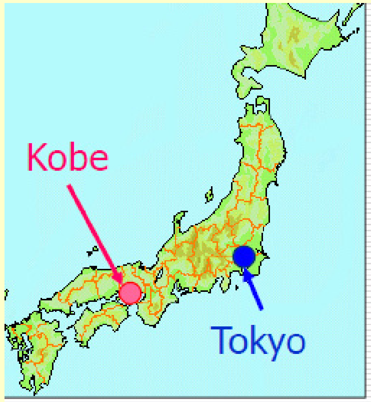
Approaches to predict local heavy rain (1)



Approaches to predict local heavy rain (2)

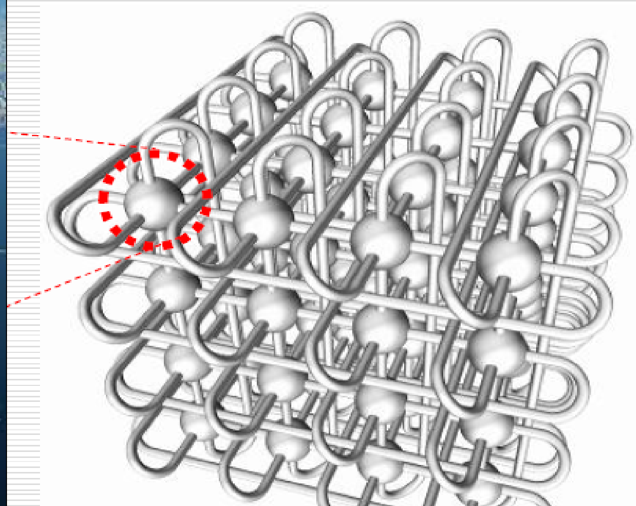


K-computer project

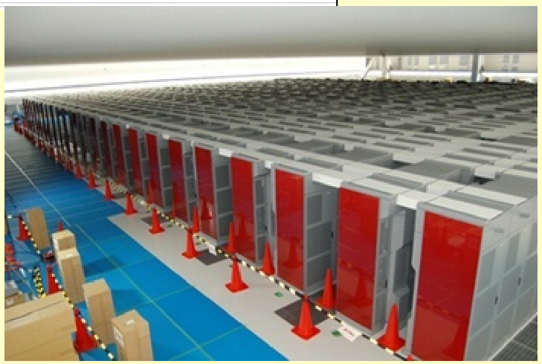


450km (280miles)
west from Tokyo

- Logical 3-dimensional torus network
- Peak bandwidth: 5GB/s x 2 for each direction of logical 3-dimensional torus network
- bi-section bandwidth: > 30TB/s



3-dimensional torus



TOP500 CERTIFICATE

K computer, a Fujitsu System at the RIKEN Advanced Institute for Computational Science (AICS), Kobe, Japan

is ranked

No. 1

among the World's TOP500 Supercomputers
with 8.162 PFlop/s Linpack Performance
on the TOP500 List published at the ISC'11 Conference, June 20, 2011

Congratulations from the TOP500 Editors

Hans Meuer, University of Mannheim — Erich Strohmaier, NERSC/Berkeley Lab — Jack Dongarra, University of Tennessee — Horst Simon, NERSC/Berkeley Lab

The K-computer has been constructed in Kobe. Whole system is complete in 2012.

http://www.nsc.riken.jp/index-eng.html

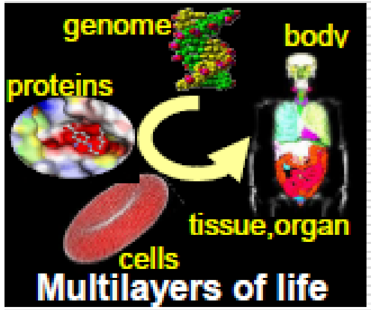
Fujitsu SPARC64™ VIIIfx, 8 cores, 128 Gflops x 80,000

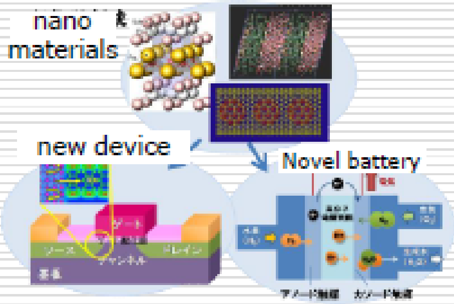
8.162 Pflops in the LIMPACK benchmark in June 2011 with a computing efficiency ratio of 93.0%.

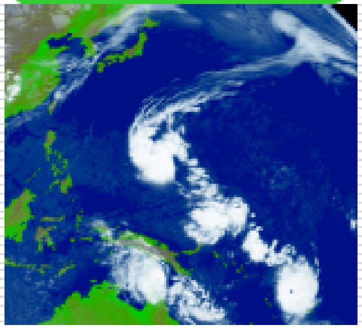
Five strategic fields (2011-2015)

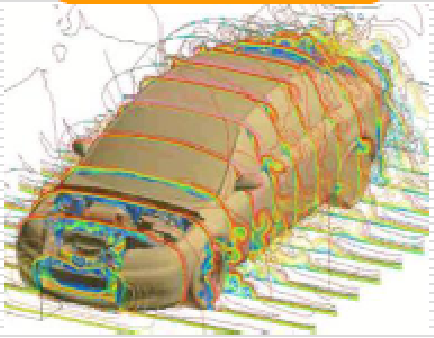
Field 3

Life Science & Medicine	New materials & Energy	**Earth Sciences**	Next generation Engineering	Matter & Universe







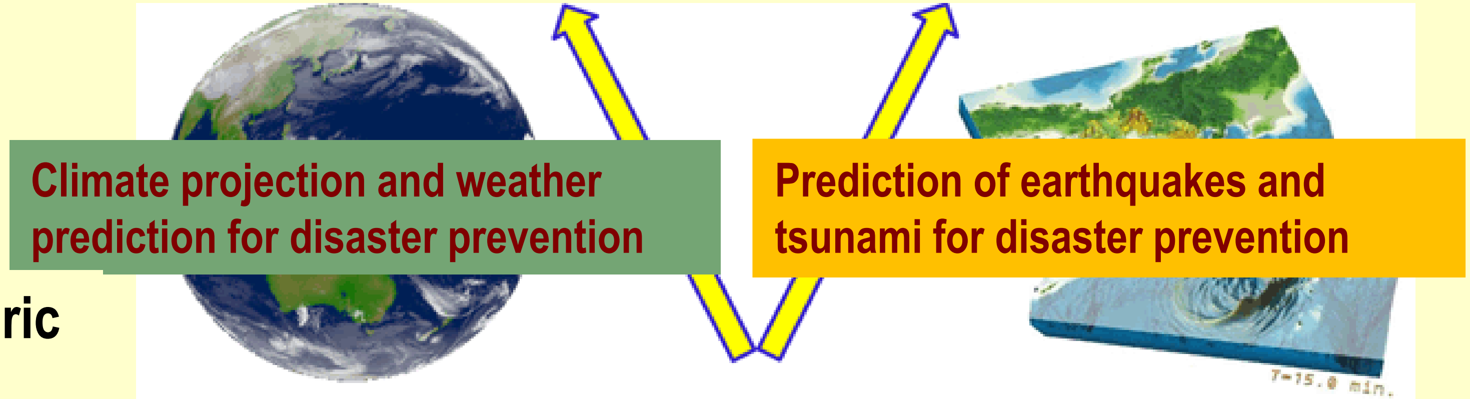


core institute

RIKEN	Institute for Solid State Physics U. Tokyo	**JAMSTEC**	Institute for Industrial Science U. Tokyo	Center for Comp. Science U. Tsukuba
Life science Community	materials science Community	Earth science Community	Engineering Community Insdutry	Basic science Community
Supercomputer resources	Supercomputer resources	Supercomputer resources	Supercomputer resources	Supercomputer resources

Ukawa (2010)

Field 3: Global Change Prediction for Disaster Prevention

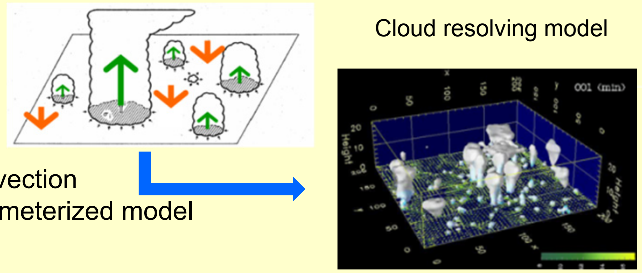


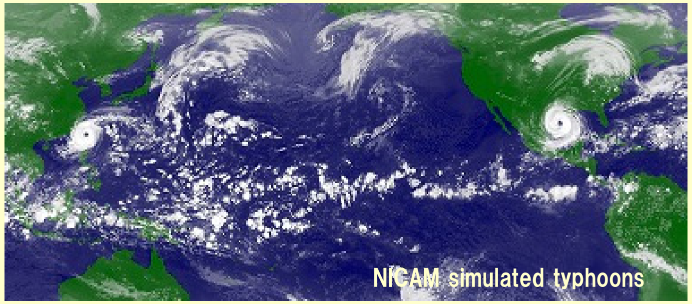
Atmospheric Sciences

Solid Earth Sciences

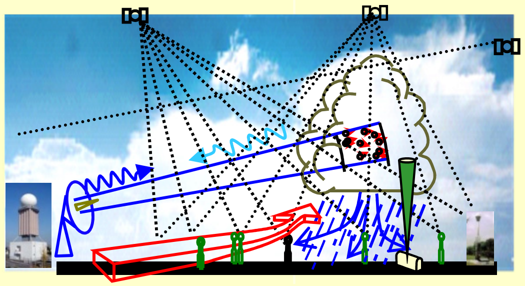
Subject 1: Projection of tropical cyclones in climate change by a cloud resolving global model (NICAM)

JAMSTEC and AORI, University of Tokyo

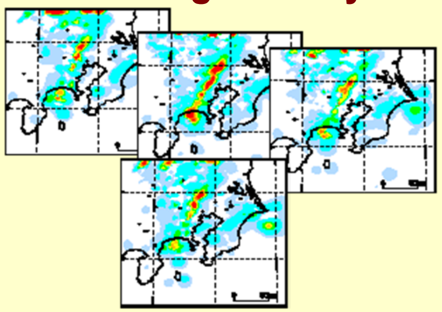




Subject 2: Prediction of heavy rainfalls by a cloud resolving NWP system



Assimilation of cloud scale dense observation data

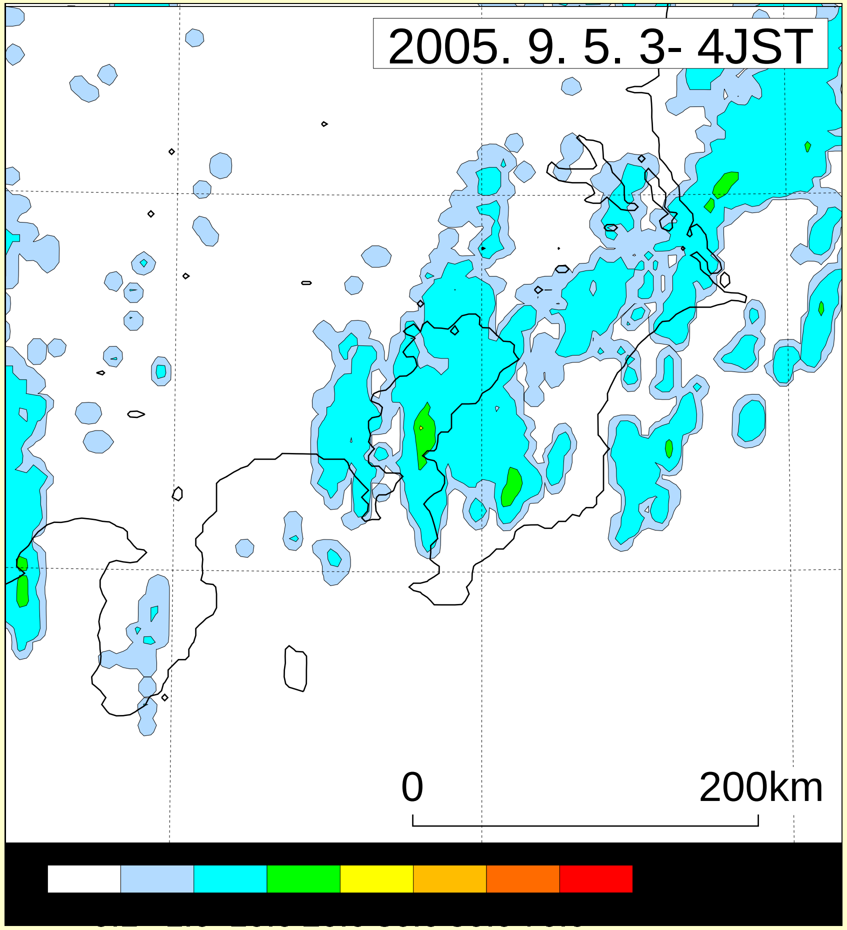


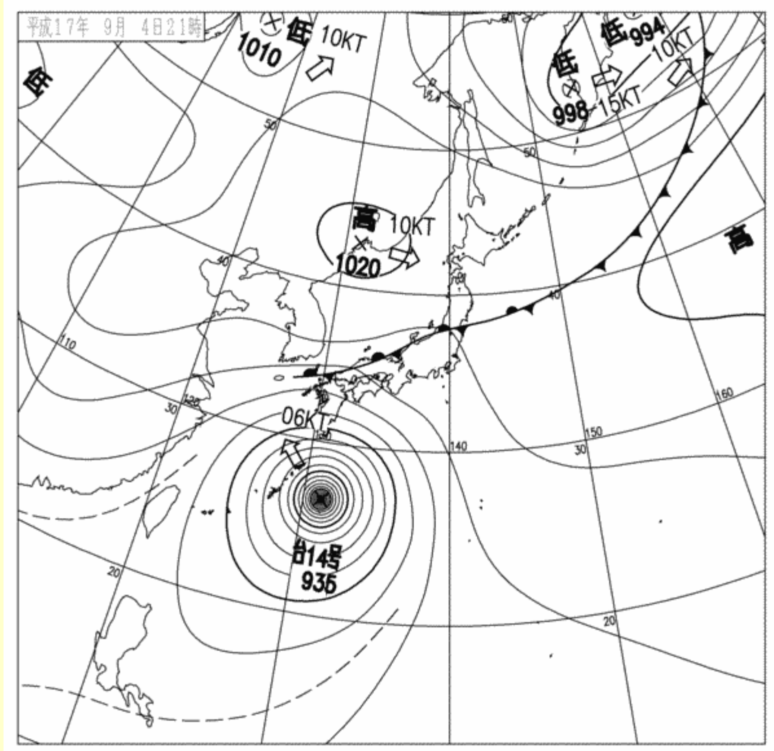
Estimation of the forecast error covariance form the cloud resolving ensemble prediction

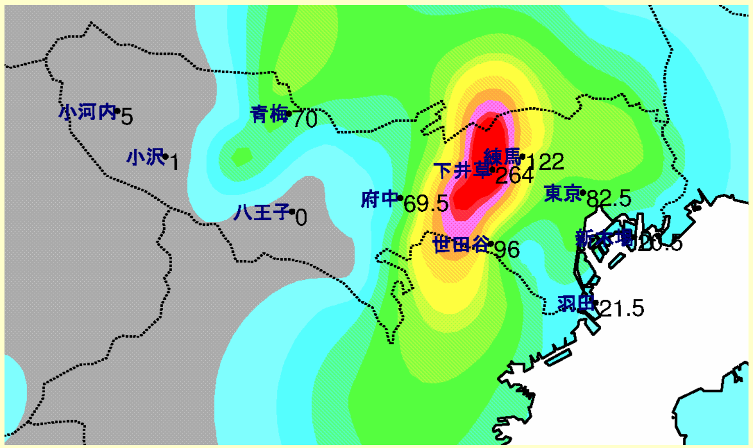
MRI and JMASTEC

To show a feasibility of the dynamical and probabilistic prediction of local heavy rainfalls in the scale of local municipalities by a cloud resolving ensemble NWP system (hourly, 1-2 km, 50-100 members)

Local Heavy rainfall on September 2005 in Tokyo





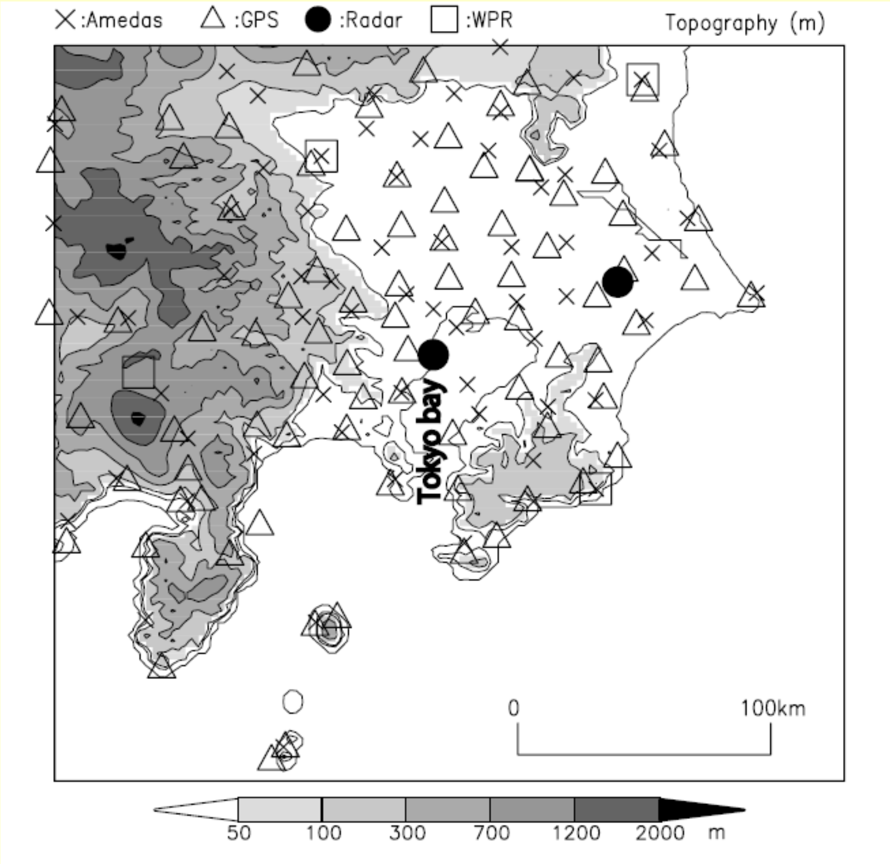


Local heavy rainfall on 4 September 2005

100mm precipitation in 1 hour was observed in Tokyo. No significant disturbances over Tokyo metropolitan area.

Cloud resolving 4DVAR with cloud microphysics

(Kawabata et al., 2011; *Mon. Wea. Rev.)*



Kessler warm rain process was implemented in LT/ADJ models.

4DVAR assimilation of

- Doppler Radar's Radial Winds
- Radar Reflectivity
- GPS precipitable water vapor
- Surface observations (wind, temperature)

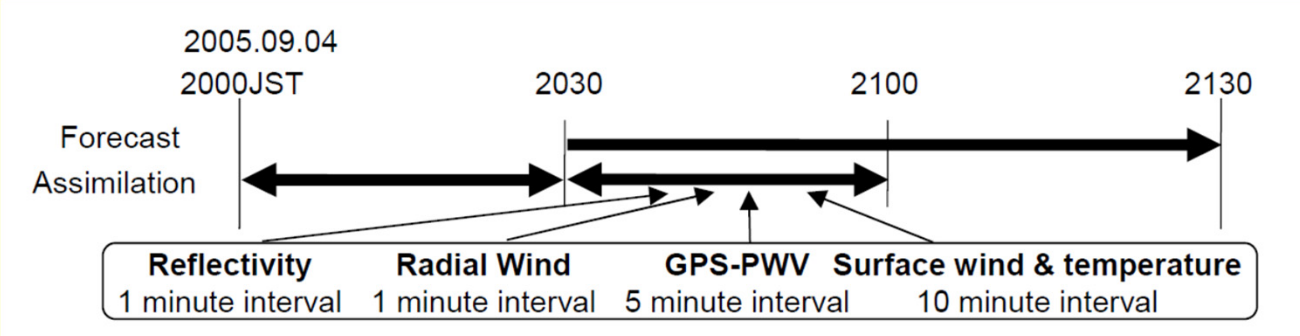
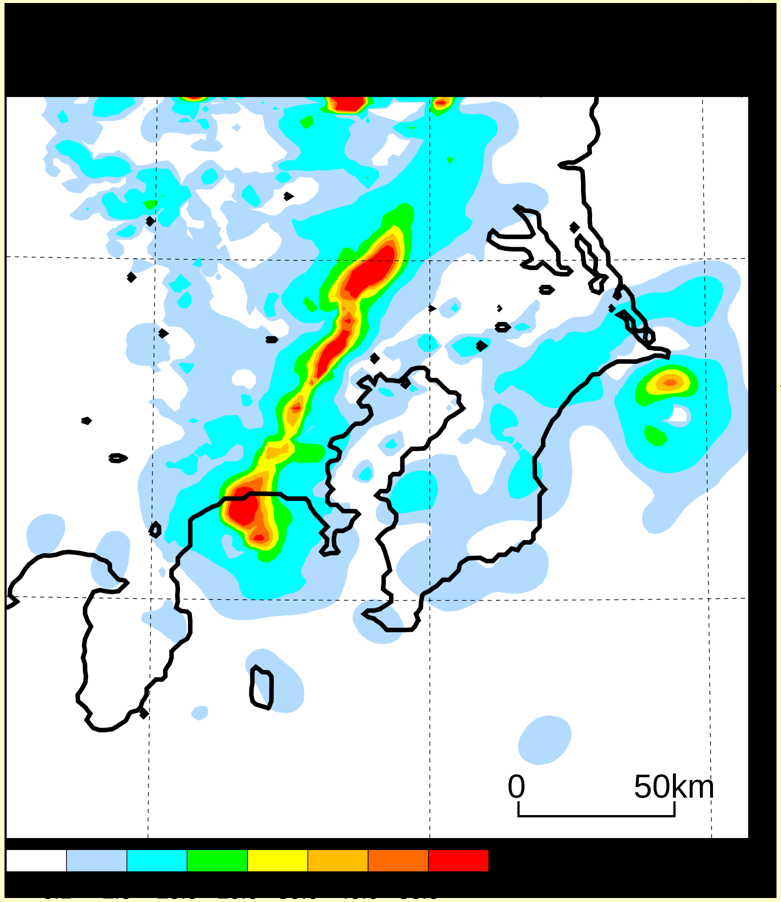


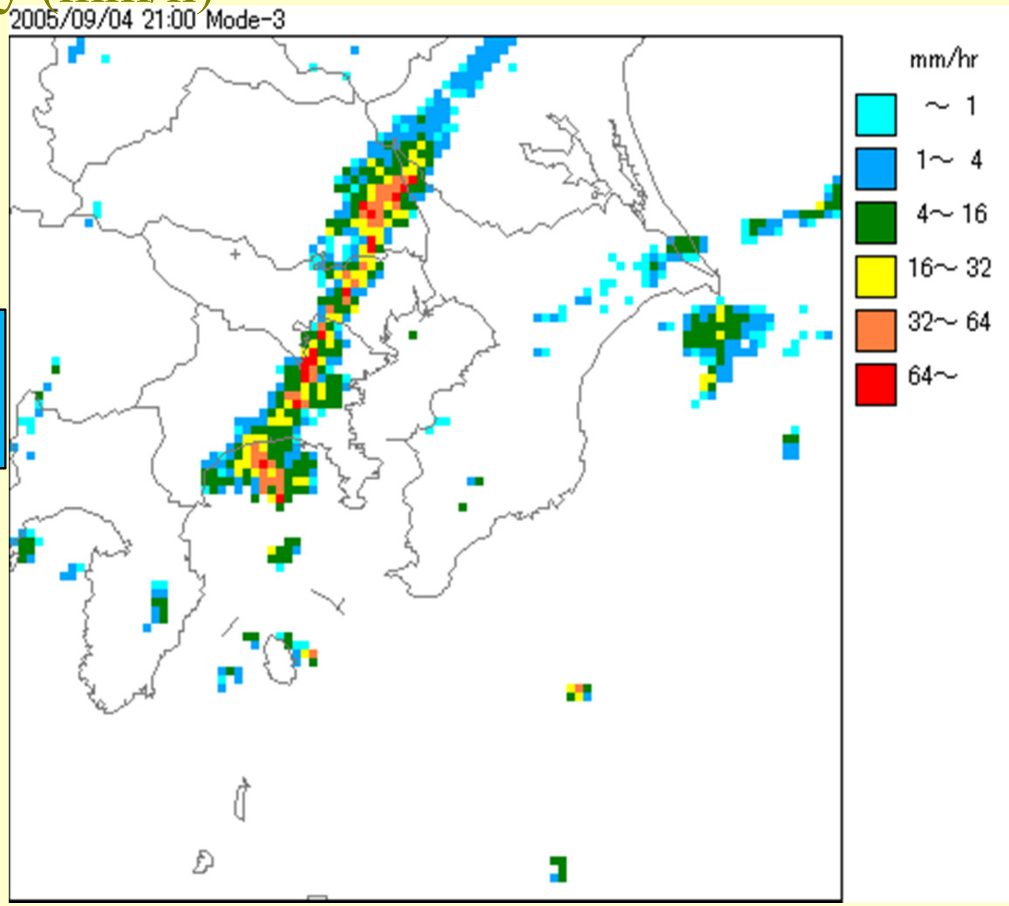
FIG. 9. Schematic diagram of assimilation experiment.

4DVAR analysis

Precip. intensity (mm/h)

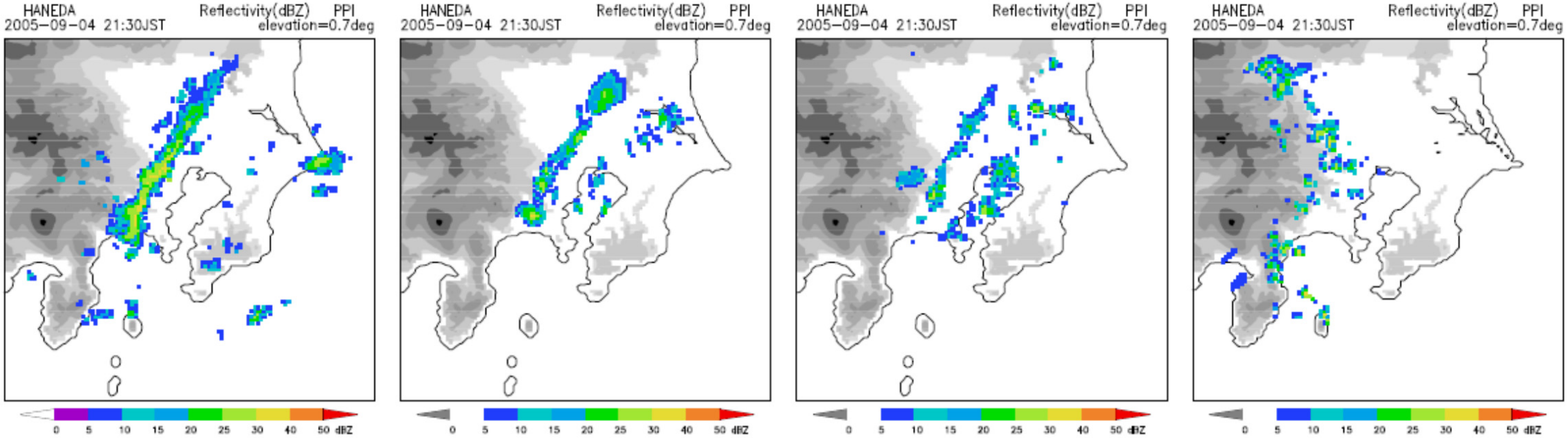
Observation





Assimilation of radar reflectivity 2030-2100JST

(Kawabata et al., 2011; *Mon. Wea. Rev.)*



2130 JST
Obs

4DVAR with
assimilation of
radar reflectivity

4DVAR without
radar reflectivity

1st guess

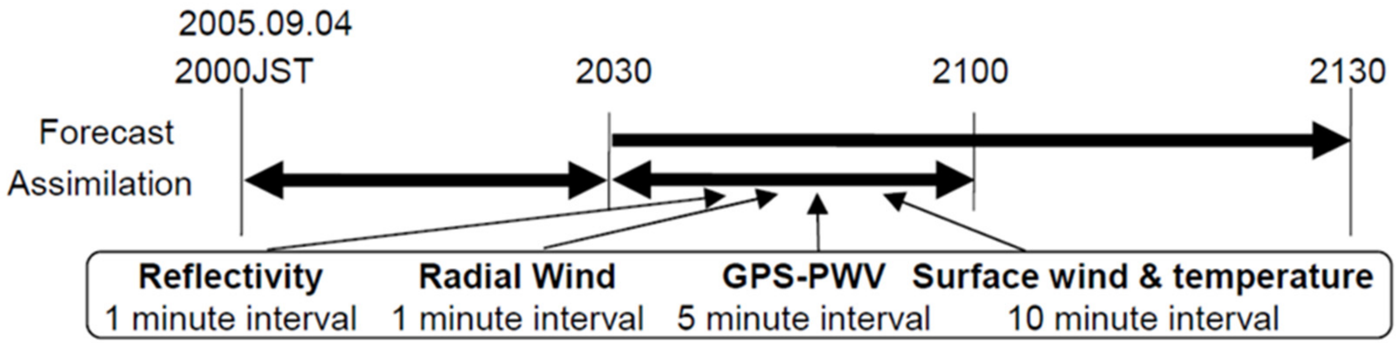
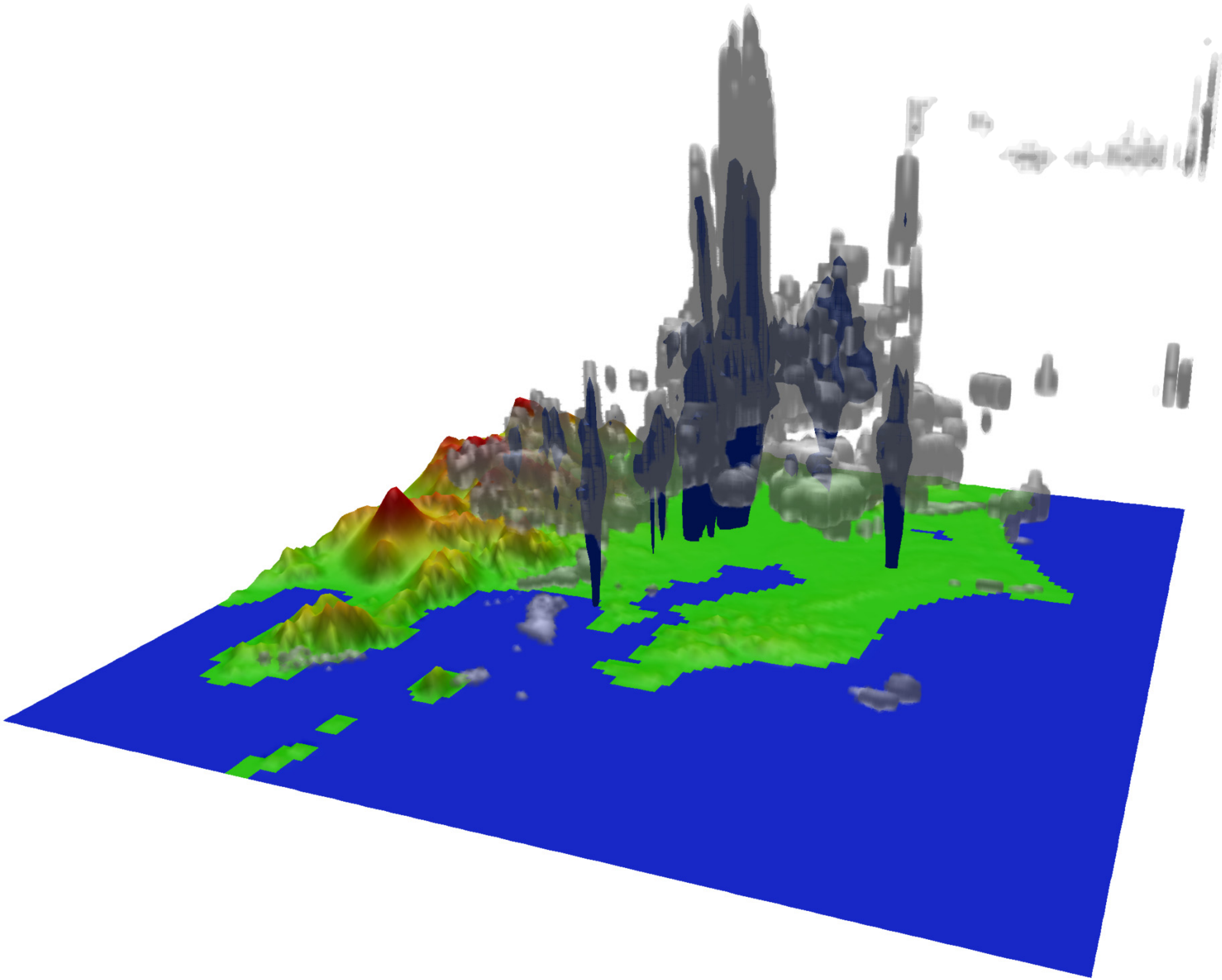
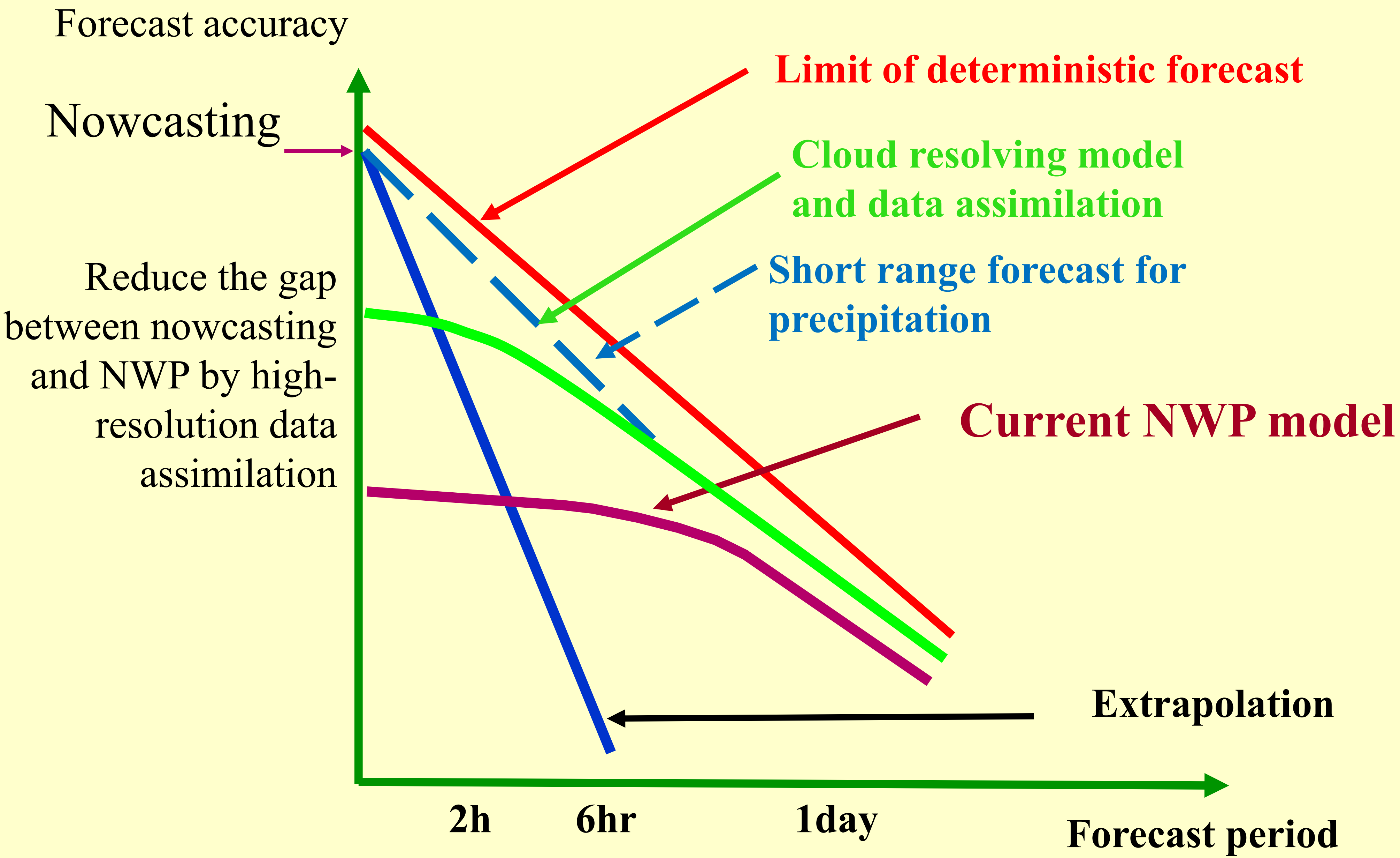


FIG. 9. Schematic diagram of assimilation experiment.

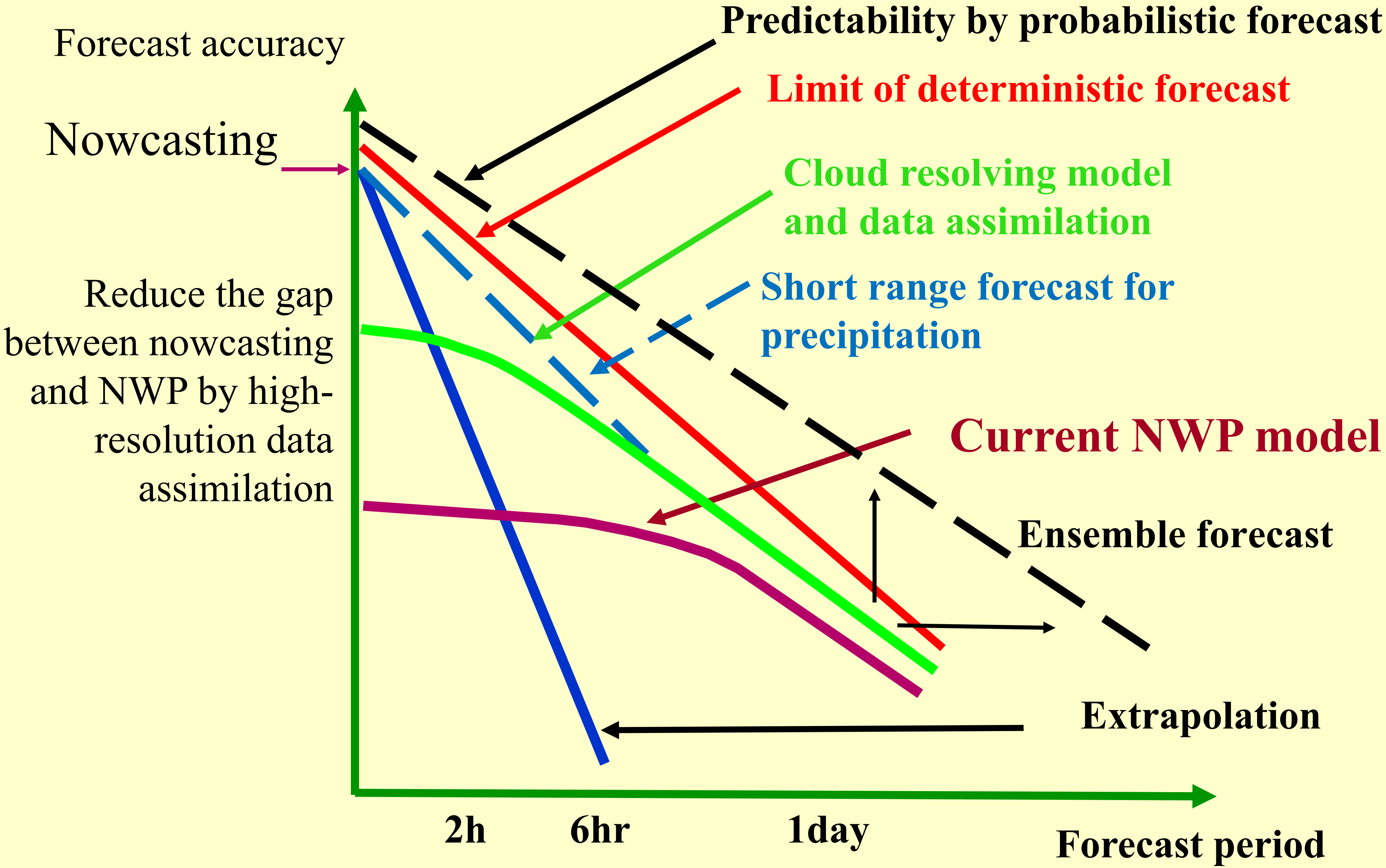
Kawabata, T., T. Kuroda, H. Seko, and K. Saito, 2011: A cloud-resolving 4D-Var assimilation experiment for a local heavy rainfall event in the Tokyo metropolitan area, *Mon. Wea. Rev.* **139**, 1911-1931.



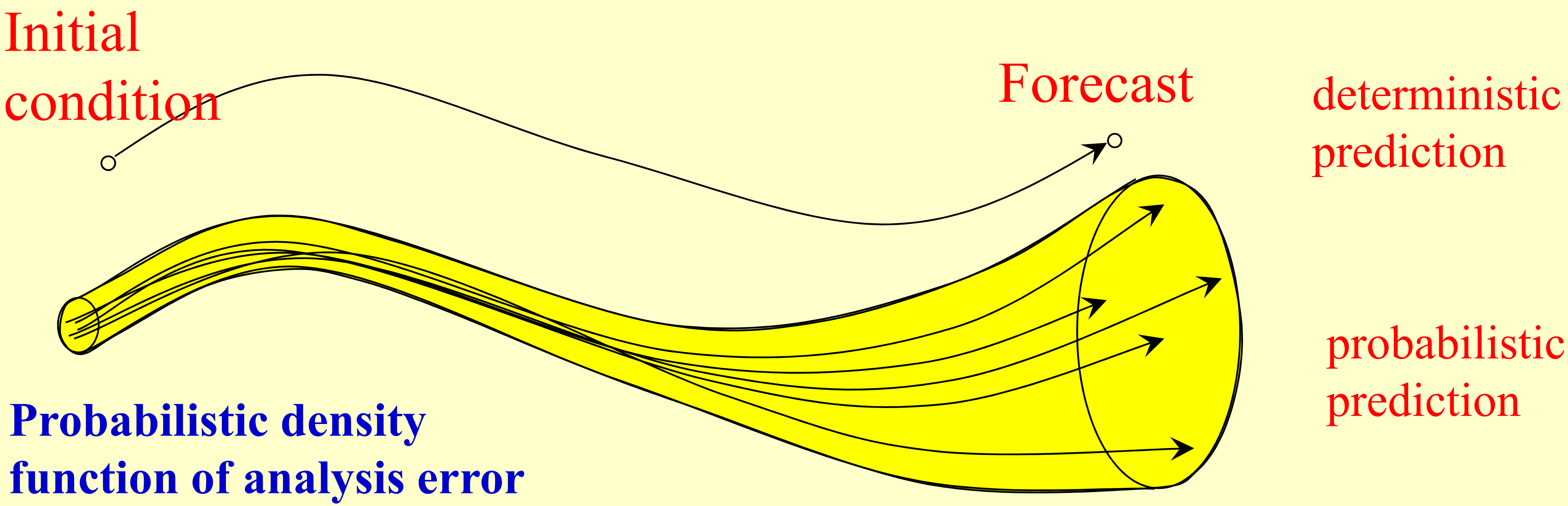
Approaches to predict local heavy rain



Approaches to predict local heavy rain (3)

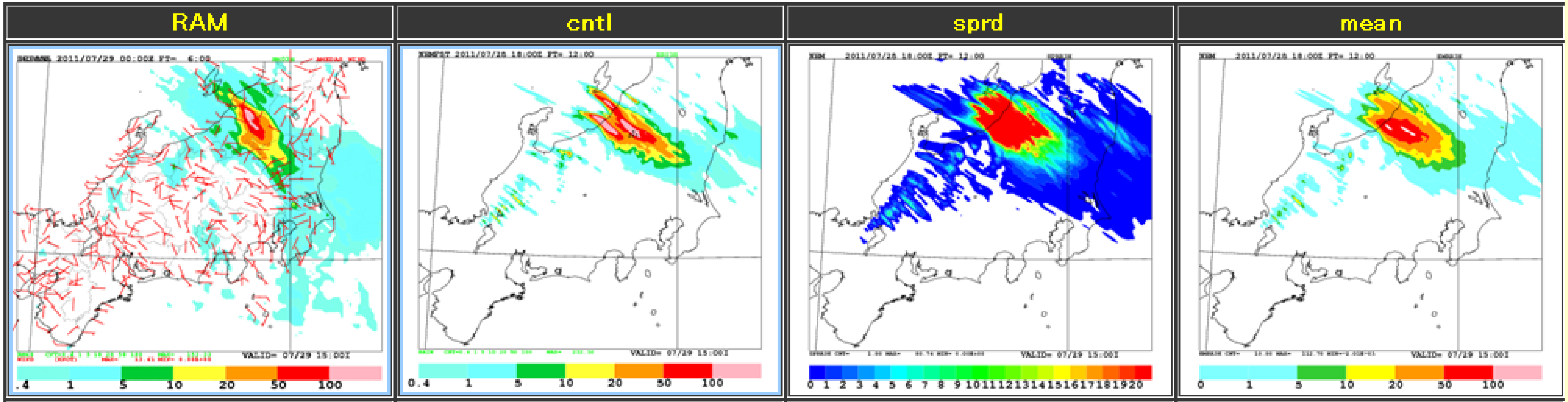


Ensemble Forecast

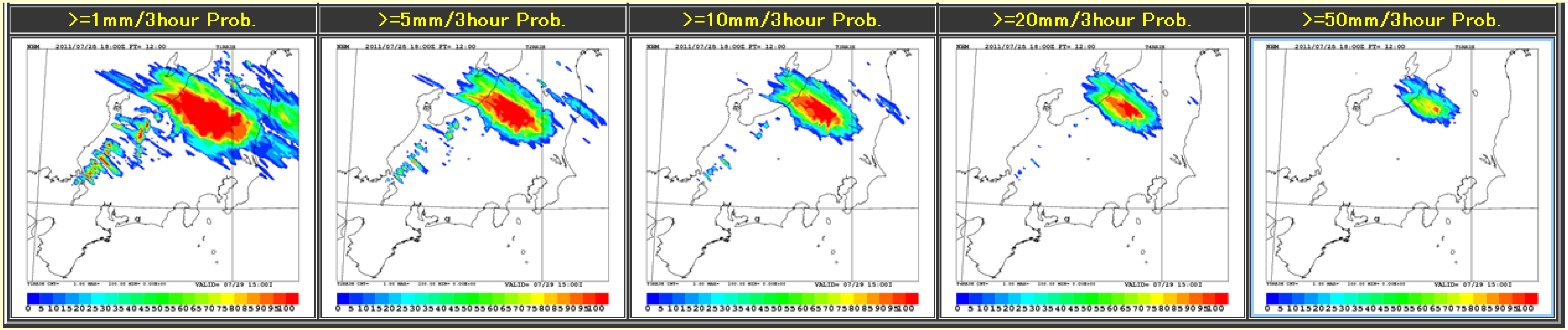


Time integration of the probabilistic density function is practically impossible. In the ensemble forecast, finite members approximate the features of probabilistic density function of atmospheric states.

2km ensemble prediction from JMA nonhydrostatic 4D-VAR analysis for 2011 Niigata-Fukushima heavy rainfall



Observation 03-06 UTC, 29 July 2011 | Control run | Ensemble spread | Ensemble mean

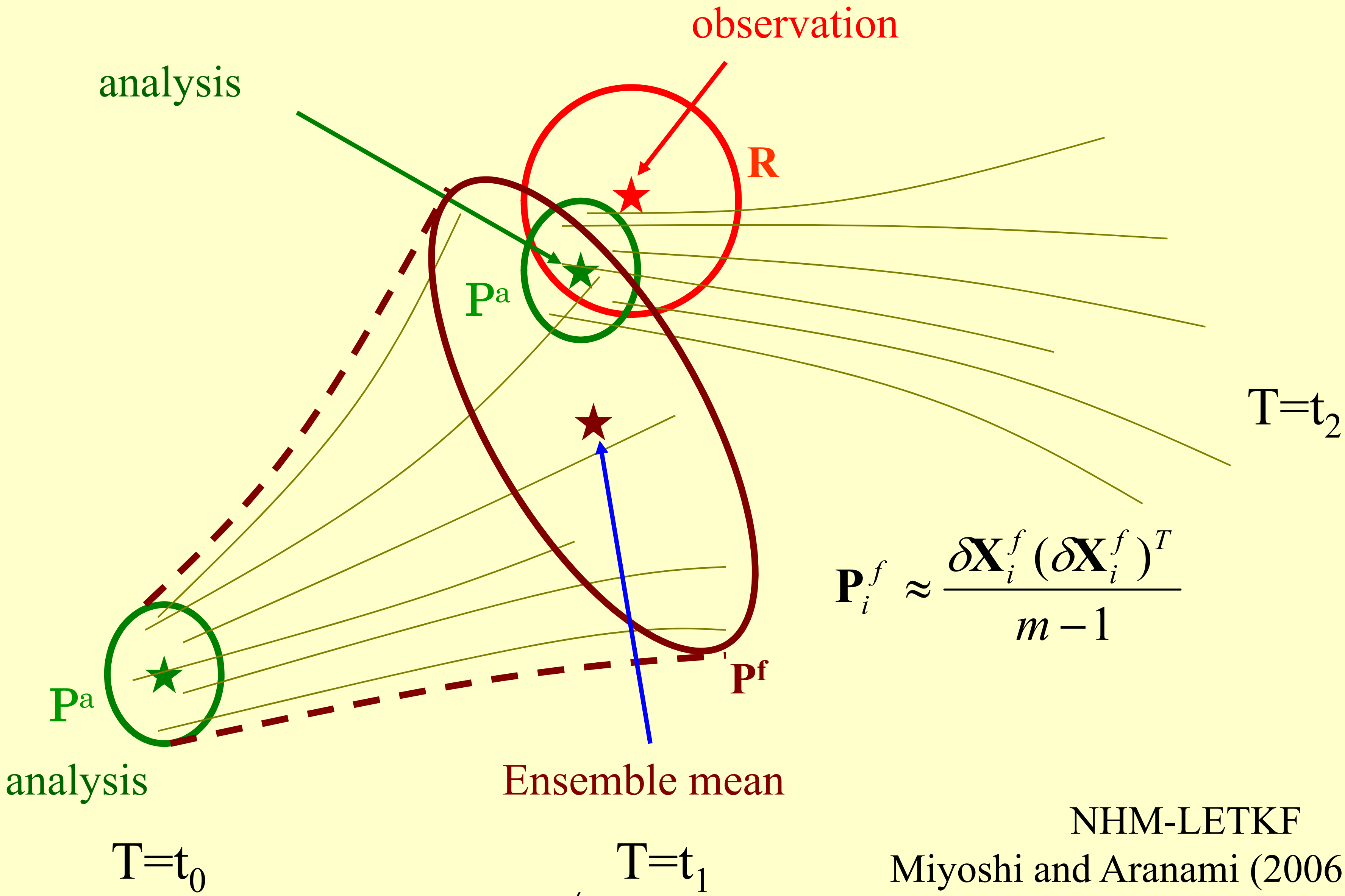


1mm/3h | 5mm/3h | 10mm/3h | 20mm/3h | 50mm/3h

Probability of precipitation at FT=18

Solid probability even for 50mm/3h

Ensemble Kalman Filter



$$\mathbf{P}_i^f \approx \frac{\delta\mathbf{X}_i^f(\delta\mathbf{X}_i^f)^T}{m-1}$$

NHM-LETKF
Miyoshi and Aranami (2006; SOLA)

$$\mathbf{X}^a = \bar{x}^f e + \delta\mathbf{X}^f\left(\widetilde{\mathbf{P}}^a(\mathbf{H}\delta\mathbf{X})^T\mathbf{R}^{-1}(y^o - \overline{H(x^f)})e + \sqrt{m-1}\,\mathbf{U}\mathbf{D}^{-1/2}\mathbf{U}^T\right)$$

$$= \bar{x}^f e + \delta\mathbf{X}^f\widetilde{\mathbf{P}}^a(\mathbf{H}\delta\mathbf{X})^T\mathbf{R}^{-1}(y^o - \overline{H(x^f)})e + \delta\mathbf{X}^f\mathbf{T}$$

LETKF

$$\mathbf{P}^f \approx \frac{\delta\mathbf{X}^f(\delta\mathbf{X}^f)^T}{m-1} = \delta\mathbf{X}^f \underline{\widetilde{\mathbf{P}}^f} (\delta\mathbf{X}^f)^T \qquad \widetilde{\mathbf{P}}^f = \frac{\mathbf{I}}{m-1} : [m \times m]$$

In the space spanned by $\delta\mathbf{X}^f$

$$\widetilde{\mathbf{P}}^a = [\underline{(m-1)\mathbf{I}/\rho + (\delta\mathbf{Y})^T \mathbf{R}^{-1} \delta\mathbf{Y}}]^{-1} = \mathbf{U}\mathbf{D}^{-1}\mathbf{U}^T$$

→ Eigenvalue decomposition: $\mathbf{U}\mathbf{D}\mathbf{U}^T : [m \times m]$

Analysis equations

$$\overline{\mathbf{x}}^a = \overline{\mathbf{x}}^f + \delta\mathbf{X}^f \widetilde{\mathbf{P}}^a (\delta\mathbf{Y})^T \mathbf{R}^{-1}(\mathbf{y}^o - \overline{H(\mathbf{x}^f)})$$

$$\delta\mathbf{X}^a = \delta\mathbf{X}^f[(m-1)\widetilde{\mathbf{P}}^a]^{1/2} = \underline{\delta\mathbf{X}^f \sqrt{m-1}\,\mathbf{U}\mathbf{D}^{-1/2}\mathbf{U}^T}$$

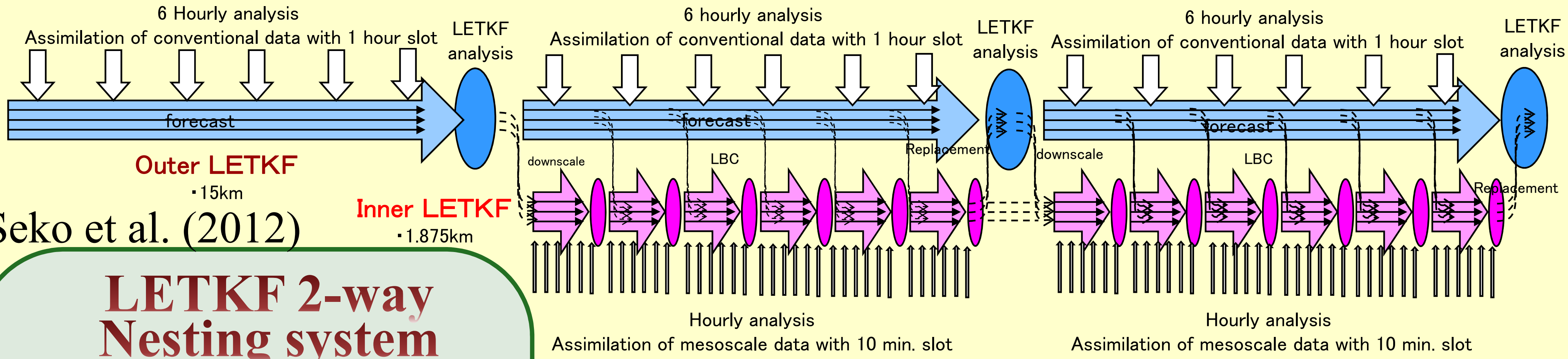
Ensemble Transform Update

LETKF analysis

$$\mathbf{X}^a = \underline{\overline{\mathbf{x}}^f} + \delta\mathbf{X}^f\left(\underline{\widetilde{\mathbf{P}}^a (\delta\mathbf{Y})^T \mathbf{R}^{-1}(\mathbf{y}^o - \overline{H(\mathbf{x}^f)})} + \sqrt{m-1}\,\mathbf{U}\mathbf{D}^{-1/2}\mathbf{U}^T\right)$$

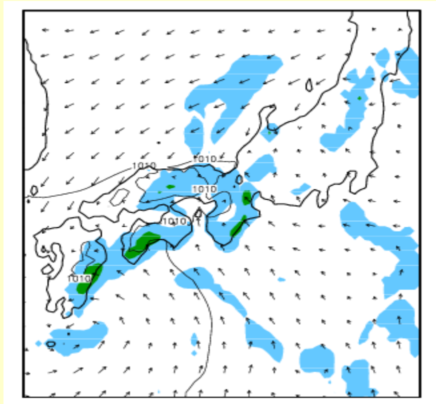
Analysis Update

Seko et al. (2012)



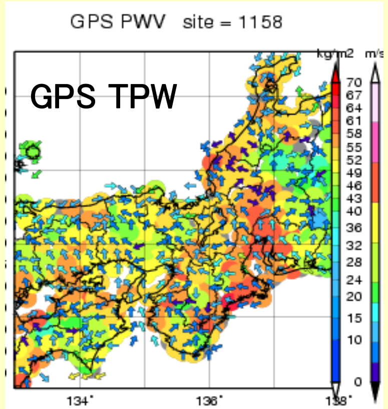
LETKF 2-way Nesting system

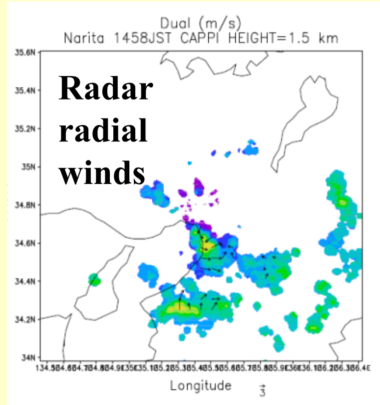
① Modifies the large scale convergence by LETKF no-cost smoother
② Predicts convective rains by assimilating storm scale data with 10 min. slot
③ First guess of father EPS is modified by CR LETKF.

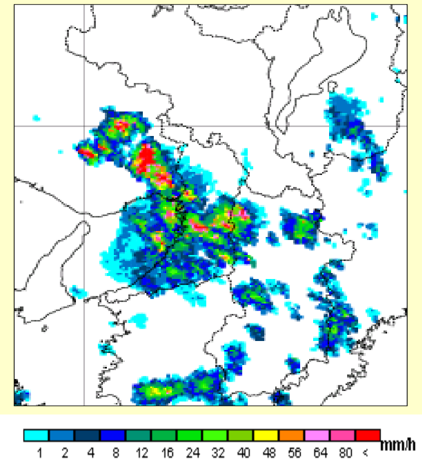


① Ensemble mean of outer LETKF

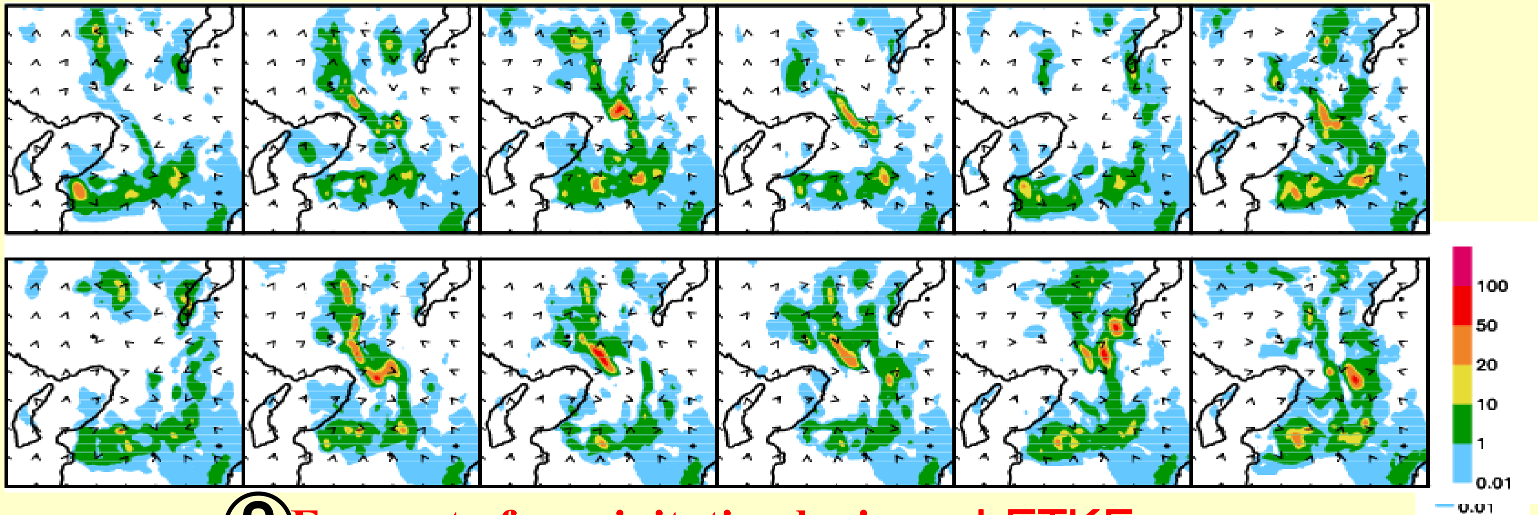
③ mesoscale observation data







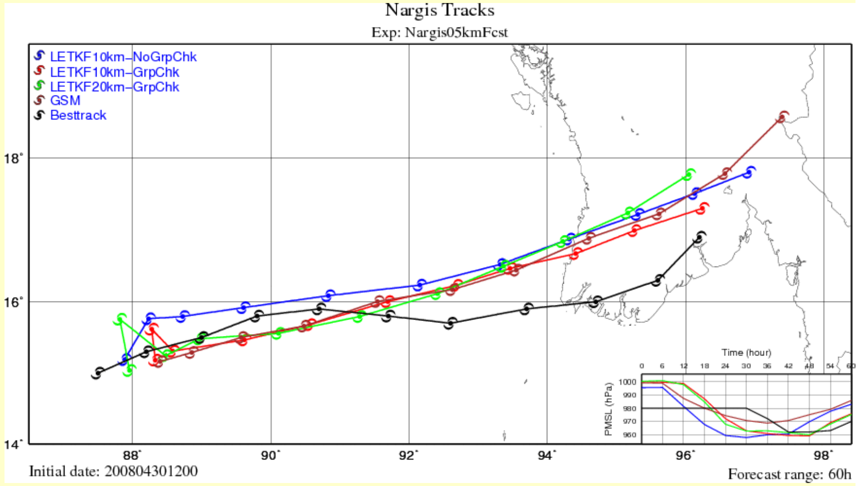
④ Observed precipitation



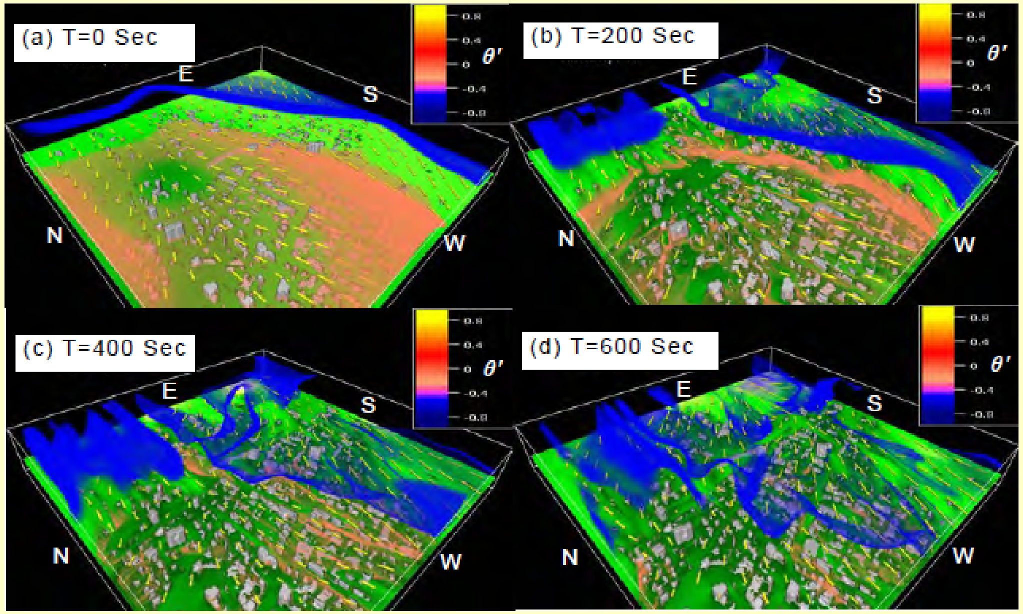
② Forecast of precipitation by inner LETKF

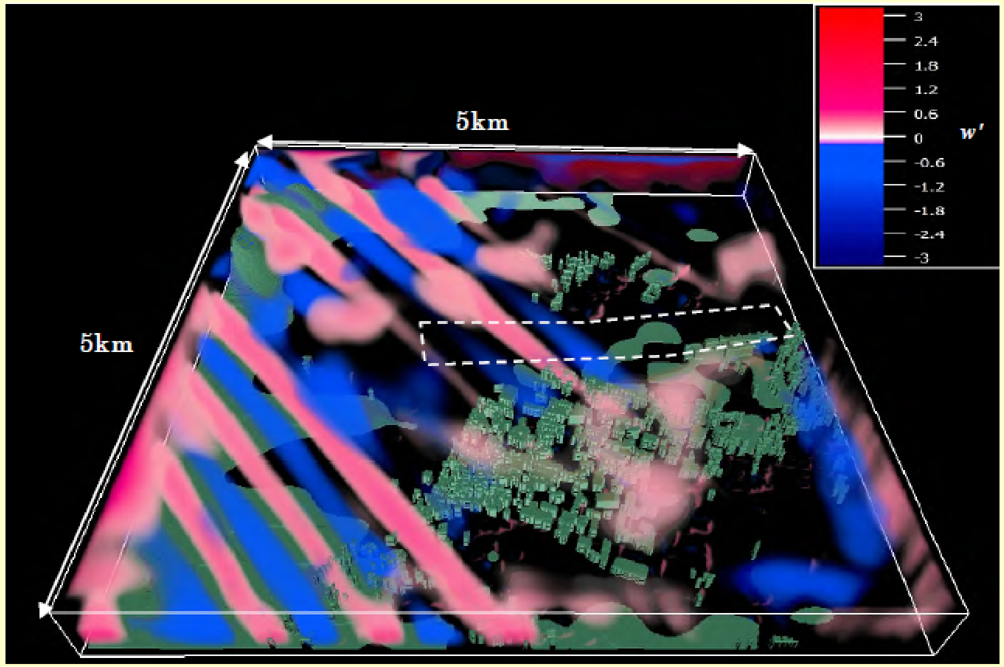
NHM-LETKF

- Application of NHM and its DA systems to K-computer
- LETKF experiment of Myanmar cyclone Nargis and the Niigata-Fukushima heavy rainfall
- Nesting simulation with a building resolving model with a horizontal resolution of 10 m



2008年4月30日-5月2日、ミャンマーサイクロンNargisの
LETKF同化実験、京を使用した結果。



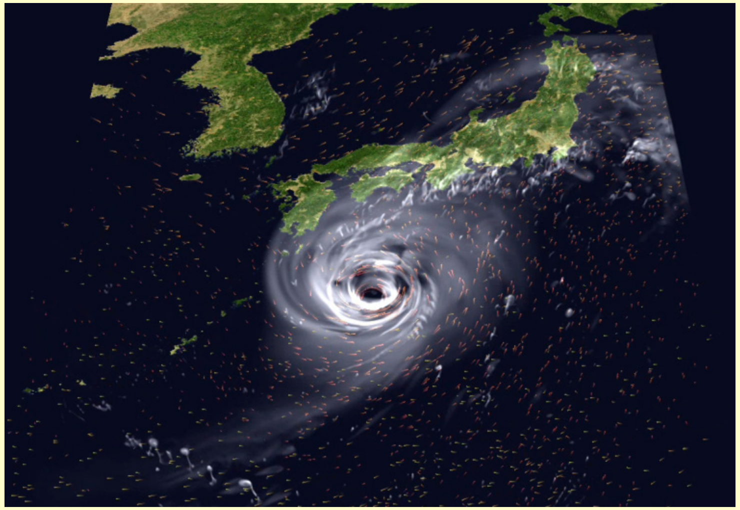


Intrusion of see breeze for Sendai for 9 July 2007. i

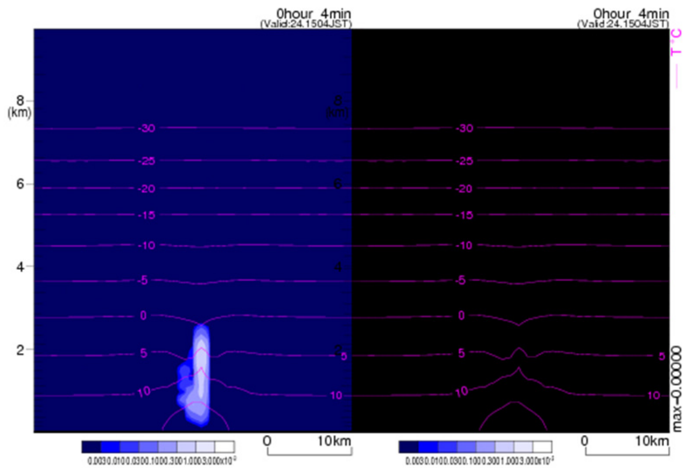
Sub-subject 3

Evaluation of uncertainty of cloud resolving model using LES and spectral BIN method

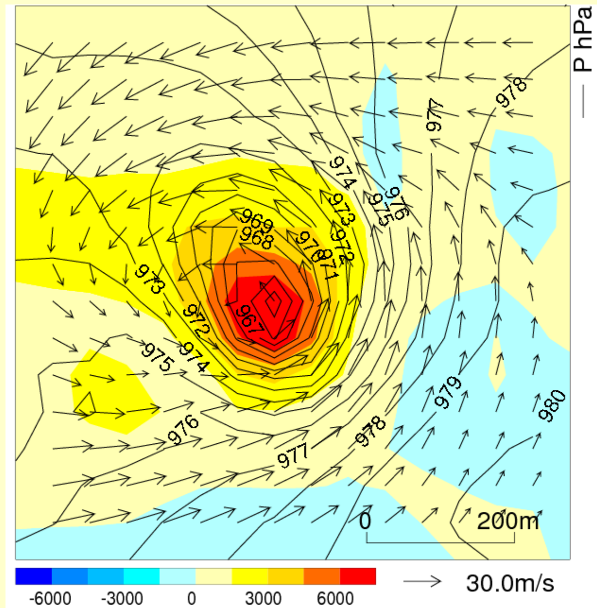
Super high resolution simulation of typhoon and tornadoes



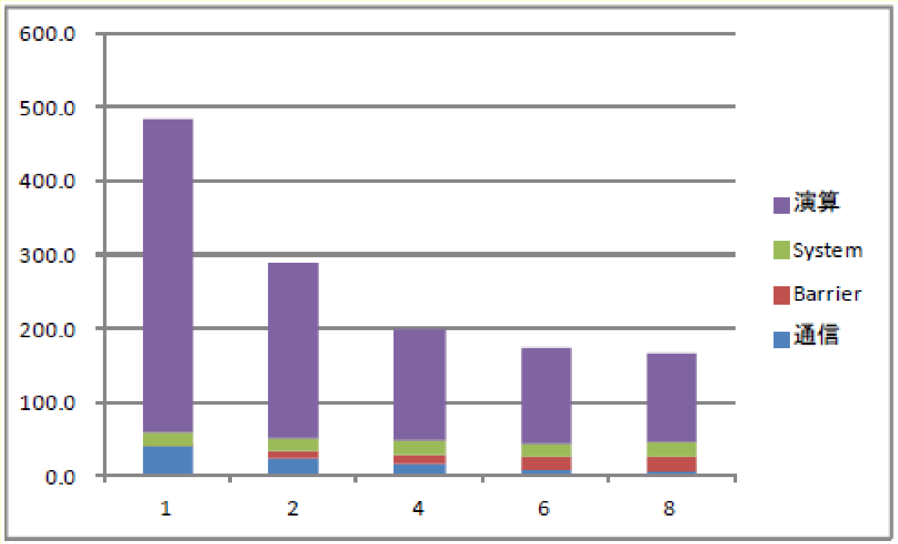
Numerical simulation of a super typhoon in global warming climate by CReSS, Nagoya University.

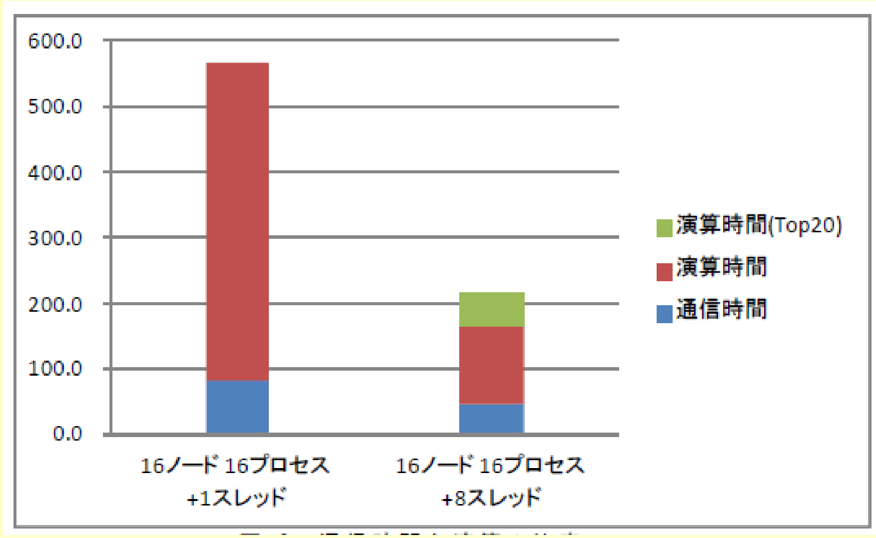


Numerical simulation of a tornado observed on 17 September 2006 by NHM with a horizontal resolution of 50 m. （Mashiko et al. Mon. Wea. Rev.）



Application of NHM to K computer





Elapse time using thread parallelization.

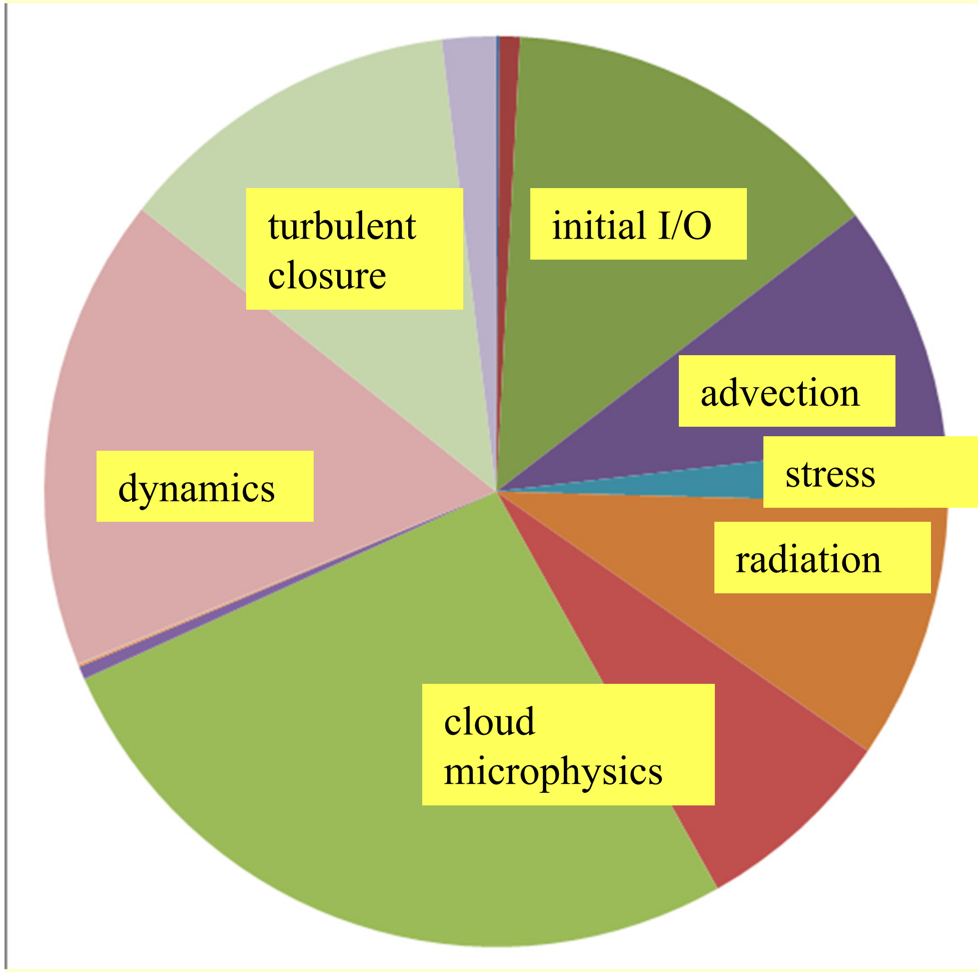
Communication and computation times .

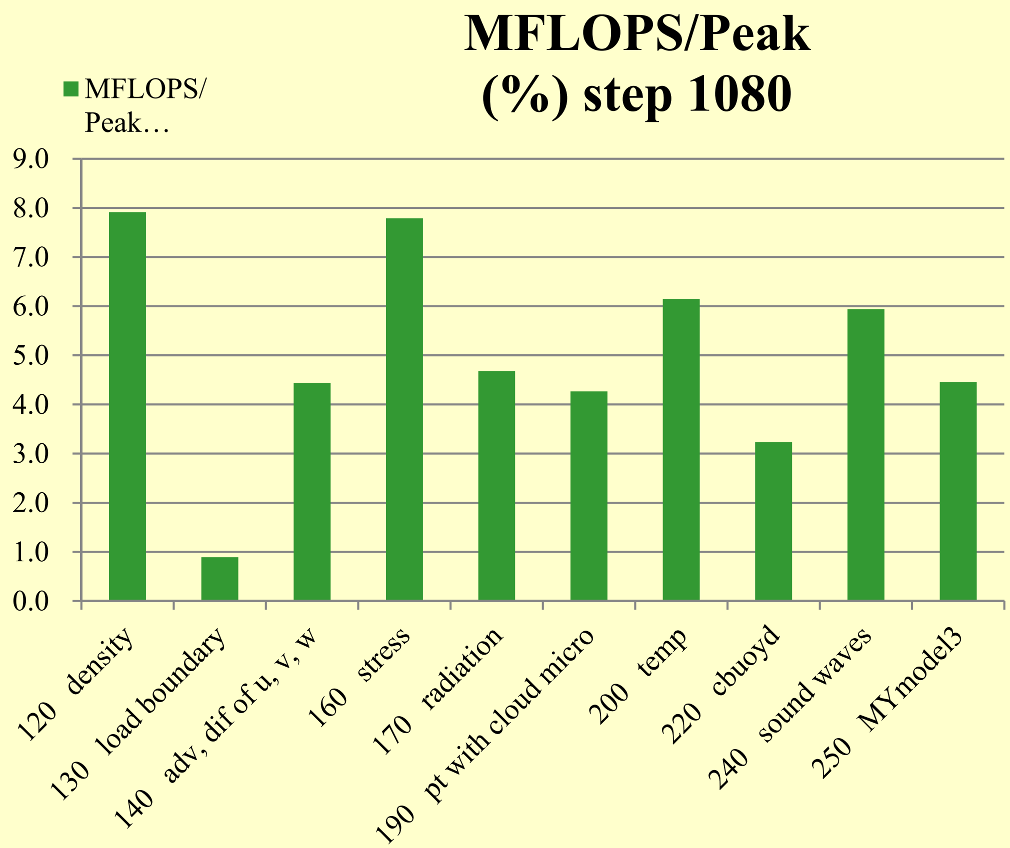
10 loops have been tuned for K-computer and acceleration of 10-15% in total elapse time was achieved.

処理区分	16 プロセス 8 スレッド			64 プロセス 8 スレッド		
	AS-IS 版 [sec]	チューニング版 [sec]	高速化率	AS-IS 版 [sec]	チューニング版 [sec]	高速化率
Main Loop 演算	118.533	102.810	115.3%	31.456	28.357	111.0%
Main Loop 通信	0.964	0.976	－	0.859	0.879	－

current performance for MSM domain (721x577x50) with 72 nodes is 5.1%

Performance at K-computer





performance for MSM domain (721x577x50)

For the case of 72 nodes of K-computer

Weak scalability at K computer

# of node	Elapsed (s) Application	MFLOPS	Parallelization ratio
6	611.9	37948.1	0.98
24	624.0	148855.1	
18	223.6	104894.6	0.98
72	228.7	410067.1	
72	70.3	340813.5	1.00
288	70.6	1357087.6	
288	29.8	840259.8	0.97
1152	30.5	3271411.7	
1152	18.2	1254245.0	0.97
4608	19.0	4887132.3	
4608	15.3	2089605.3	0.93
18432	16.4	7811590.6	