The 5th Research Meeting of Ultrahigh Precision
Meso-scale Weather Production
Nagoya University, March 9, 2015

Challenges in Cloud-resolving Data Assimilation

Introduction to SPIRE Field 3 Meso-scale Weather Prediction Theme 1

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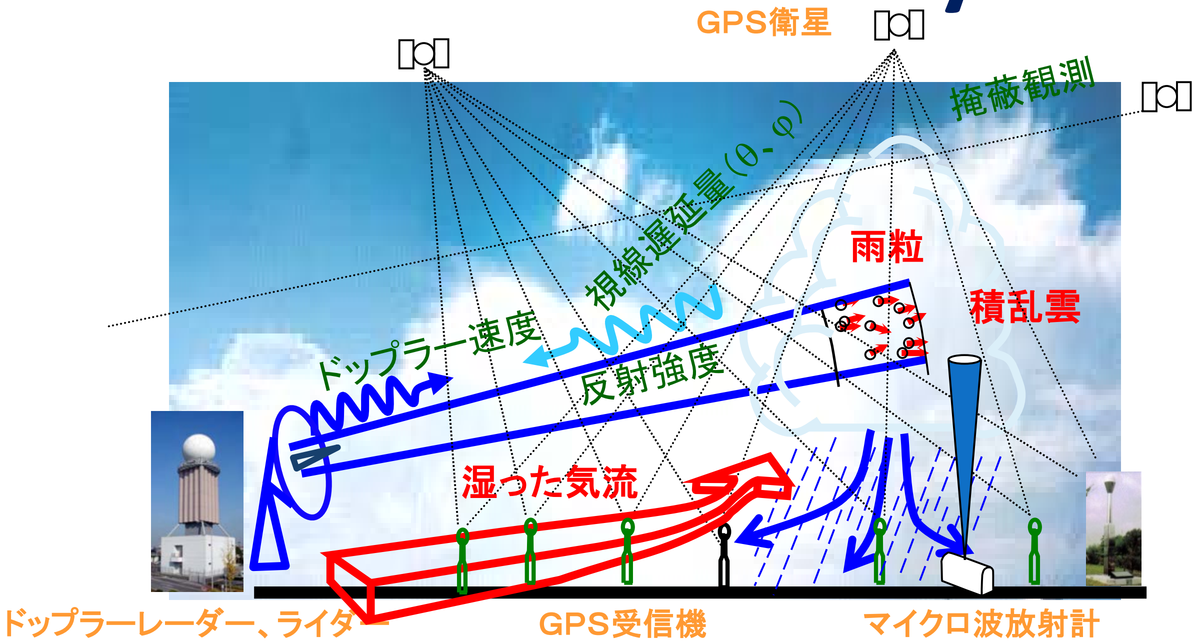
Meteorological Research Institute, JMA

Development of Cloud-resolving Data Assimilation Systems



- To develop advanced data assimilation methods for cloud-resolving models.
- To develop techniques to assimilate dense observational data from multi-parameter radar, Doppler lidar, GPS slant delays, geostationary satellite rapid scan, etc.
- To demonstrate the feasibility of numerical prediction of **local heavy rainfalls** and **tornadoes**.

To-do List

- Development of advanced data assimilation systems for cloud-resolving models

CRMs	Assimilation methods	Research institutes
NHM	LETKF	MRI, JAMSTEC, NPD
NHM	4DVar	MRI, JAMSTEC, U. Ryukyus
NHM	EnVar	MRI
CReSS	Hybrid	NIED
NHM	Particle filter	ISM

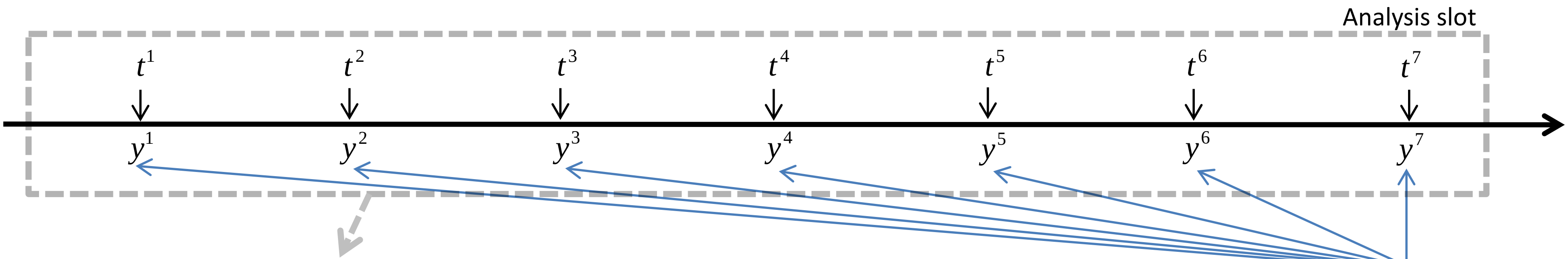
- Assimilation of dense observational data (DPRI, NIED, MRI)
- Intercomparison of data assimilation systems (MRI, JAMSTEC, …)

The 5th Research Meeting of Ultrahigh Precision Meso-scale Weather Prediction
Mar. 9 (Mon), 2015 Nagoya

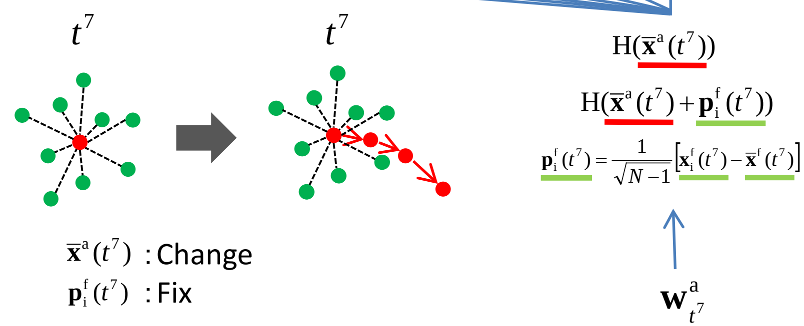
An investigation of flow-dependency and a comparison of time-mapping methods using a NHM-EnVar System

Seiji ORIGUCHI, Kazumasa AONASHI, Takuya KAWABATA, Masaru KUNII
（MRI/JMA)

Time mapping method of EnVar　3DEnVar-FGAT



The assimilated observation data for each slot are weighted by Gauss function with a distance between observation and analysis slots.



3DEnVar-FGAT

Ensemble perturbation in analysis slot is fixed for a cycle.
All slots are considered as with analysis slot.

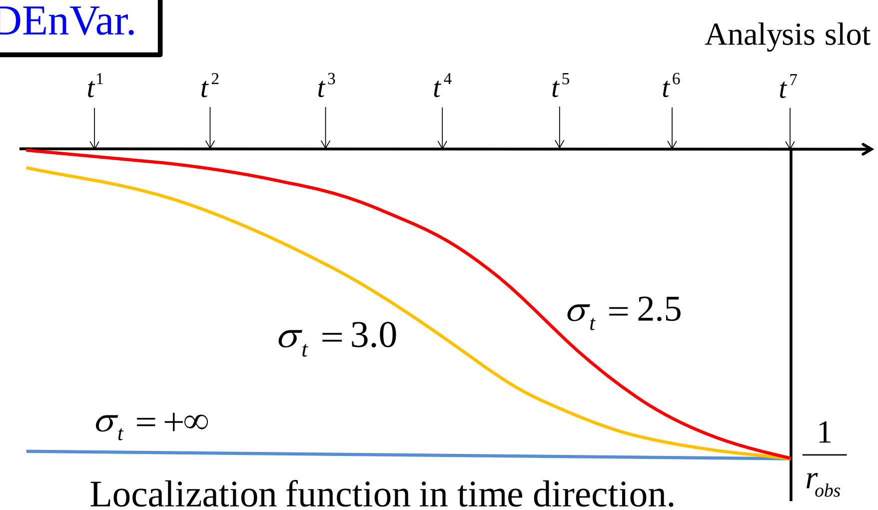
Temporal localization corresponds to a FGAT in the 3DEnVar.

Temporal localization is implemented by multiplying the reciprocal of the localization function for observation error.

$$R_{obs,t} = diag(r^2_{obs,t^1}, \cdots, r^2_{obs,t^i} \cdots, r^2_{obs,t^n} \cdots)$$

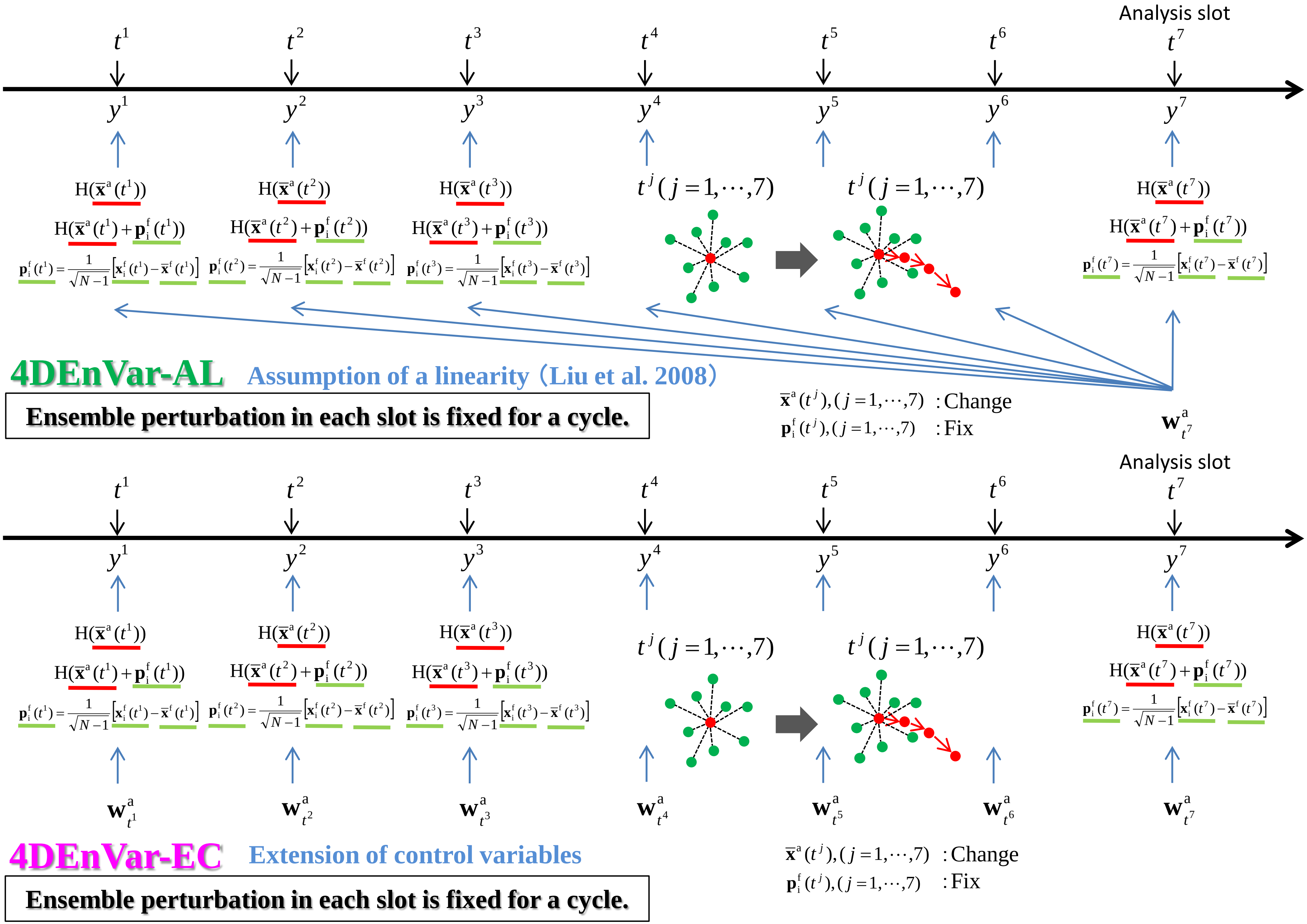
$$r_{obs,t^i} \sim r_{obs} \cdot \exp\left(\frac{1}{2}\cdot\left(\frac{t^i_{obs}-t_{anl}}{\sigma_t}\right)^2\right)$$

σ_t :　Localization scale　　i :　Slot number



Localization function in time direction.
No localization, if standard deviation is +∞.

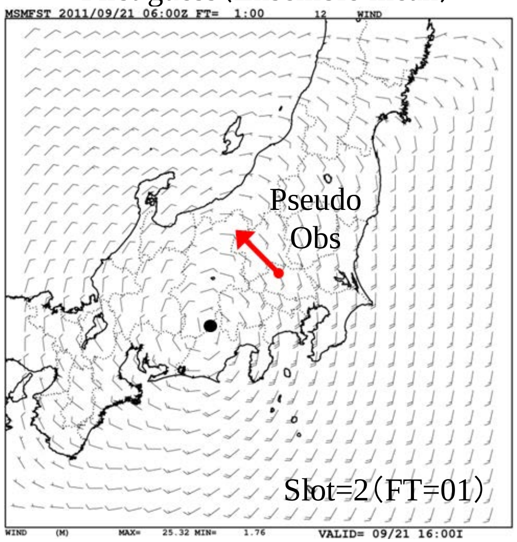
Time mapping methods of EnVar   4DEnVar-AL and 4DEnVar-EC



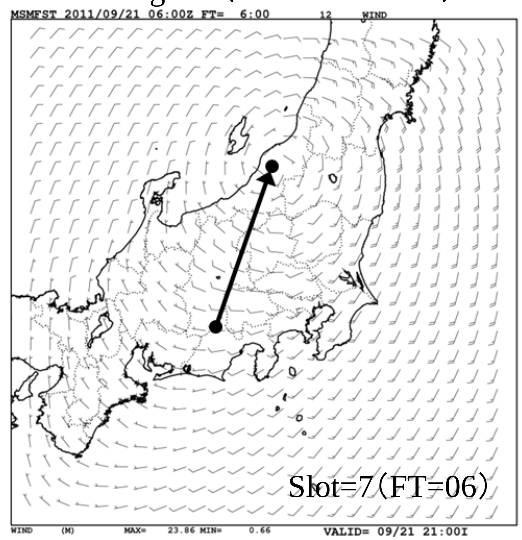
Single Observation Assimilation Experiment, comparison of time-mapping methods

- Event：Typhoon Roke in 2011 that moved with a fast speed
- Pseudo obs：Wind data U=−40.0(m/s), V=40.0(m/s)

First guess（Ensemble mean）



First guess（Ensemble mean）



In case that typhoon moved with a fast speed …

➢ 3DEnVar-FGAT

The wind velocity was increased at the northeast side of the central position compared with the that of first guess. However, unnatural wind flow was formed at the rearside of the typhoon.

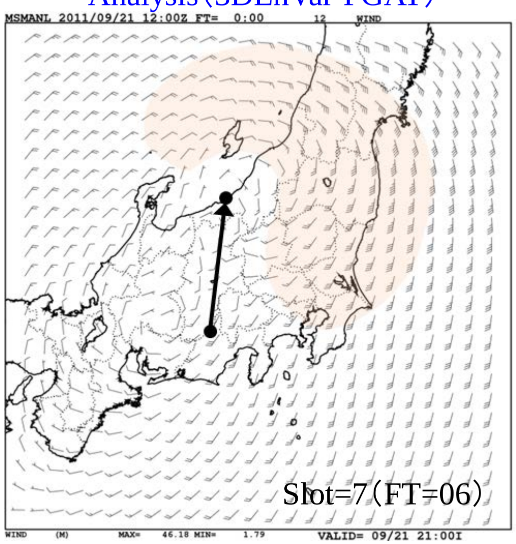
➢ 4DEnVar-AL

In contrast to the 3DEnVar-FGAT, the unnatural wind flow at the rearside was improved appropriately by considering an information propagation of time direction.

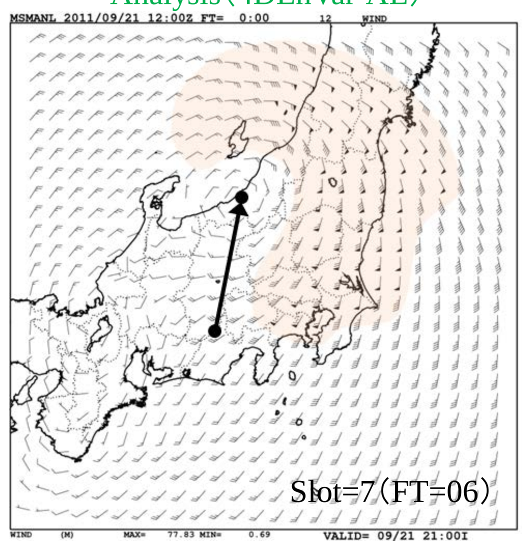
➢ 4DEnVar-EC

The flow-dependent pattern was made a natural flow better than that of the other schemes.

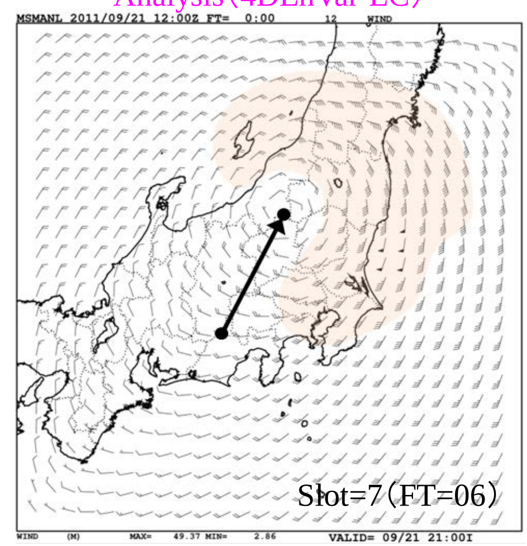
Analysis（3DEnVar-FGAT）



Analysis（4DEnVar-AL）



Analysis（4DEnVar-EC）



Development of an Ensemble-Based Variational Data Assimilation System Using Observation Localization

Sho Yokota, Seiji Origuchi, Masaru Kunii, and Kazumasa Aonashi
(Meteorological Research Institute, Japan Meteorological Agency)

ENVAR formulation

ENVAR Analysis

$$\overline{x_{i,t}^{a}} = \overline{x_{i,t}^{f}} + \sum_{j} \delta x_{ij,t}^{f} w_{ij}$$

$$J = \frac{1}{2}\sum_{i}\left\{(M-1)\sum_{j} w_{ij}^{2} + \sum_{k,t}\frac{L_{ik}}{R_{k,t}}\left[H_{k}\left(\overline{\mathbf{x}_{t}^{a}}\right) - y_{k,t}\right]^{2}\right\}$$

Observation localization

Observation operator

Observation error variance

$$\frac{\partial J}{\partial w_{ij}} = (M-1)w_{ij} + \sum_{k,t}\frac{L_{ik}}{R_{k,t}}\delta H_{kj,t}\left[H_{k}\left(\overline{\mathbf{x}_{t}^{a}}\right) - y_{k,t}\right] = 0$$

ENVAR Analysis Disturbances

$$\delta x_{ij,t}^{a} = \sum_{j_1} \delta x_{ij_1,t}^{f} T_{ij_1 j}$$

$$T_{ij_1 j} = \sqrt{M-1}\sum_{j_2}\frac{U_{ij_1 j_2} U_{ijj_2}}{\sqrt{\lambda_{ij_2}}}$$

Eigenvalue of Hessian of cost function

$$\frac{\partial^{2} J}{\partial w_{ij_1}\partial w_{ij}} = (M-1)\delta_{j_1 j} + \sum_{k,t}\frac{L_{ik}}{R_{k,t}}\delta H_{kj_1,t}\delta H_{kj,t} = \sum_{j_2}\lambda_{ij_2} U_{ij_1 j_2} U_{ijj_2}$$

ENVAR is good for assimilating nonlinear observations (e.g., radar, satellite, …)

i: grid points(1～N)
k: obs. points(1～K)
t: time slots(1～T)
j: members(1～M)

Difference between LETKF and ENVAR

1. Observation operator

LETKF $$H_k\left(\overline{\mathbf{x}_t^a}\right)=H_k\left(\overline{\mathbf{x}_t^f}\right)+\sum_j \delta H_{kj,t} w_{ij}$$

ENVAR $$H_k\left(\overline{\mathbf{x}_t^a}\right)=H_k\left(\overline{\mathbf{x}_t^f}+\sum_j \delta\mathbf{x}_{j,t}\circ\mathbf{w}_j\right)$$

LETKF assumes linearity of H and uses only w at the analysis point.

ENVAR can solve H implicitly.

2. Perturbation of H

LETKF $$\delta H_{kj,t}=H_k\left(\overline{\mathbf{x}_t^f}+\delta\mathbf{x}_{j,t}^f\right)-\overline{H_k\left(\mathbf{x}_t^f\right)}$$

ENVAR $$\delta H_{kj,t}=H_k\left(\overline{\mathbf{x}_t^a}+\delta\mathbf{x}_{j,t}^f\right)-H_k\left(\overline{\mathbf{x}_t^a}\right)$$

LETKF uses δH around the first guess.

ENVAR uses δH around the analysis.

If H is linear, δH of LETKF = δH of ENVAR.

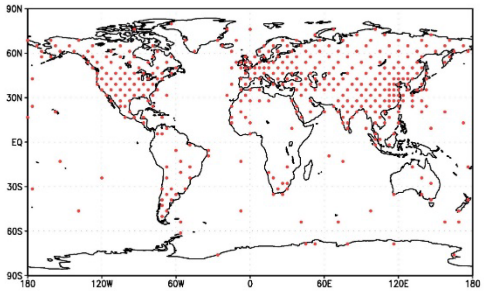
i: grid points(1～N)
k: obs. points(1～K)
t: time slots(1～T)
j: members(1～M)

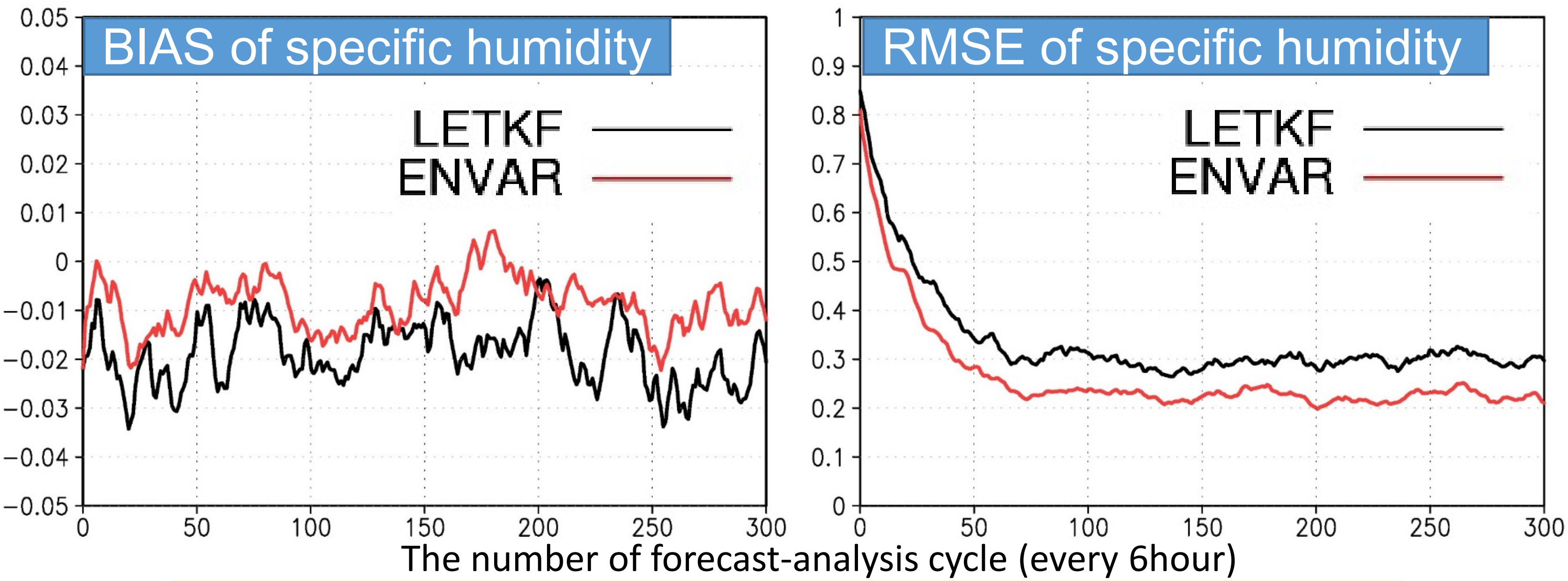
Comparison between LETKF and ENVAR

OSSE using SPEEDY model

The number of Ensemble members: **20**
Assimilation window: **6 hour**
Radius of localization: **σ_H=1000(km), σ_V=0.1(ln p)**
Inflation: **Multiplicative (δx → 1.1δx)**
Observations: **U, V, T, RH, Ps (t=1h, 3h, 5h)**
Analysis time: **Center of assimilation window (t=3h)**

Positions of observations





ENVAR analysis is better than LETKF

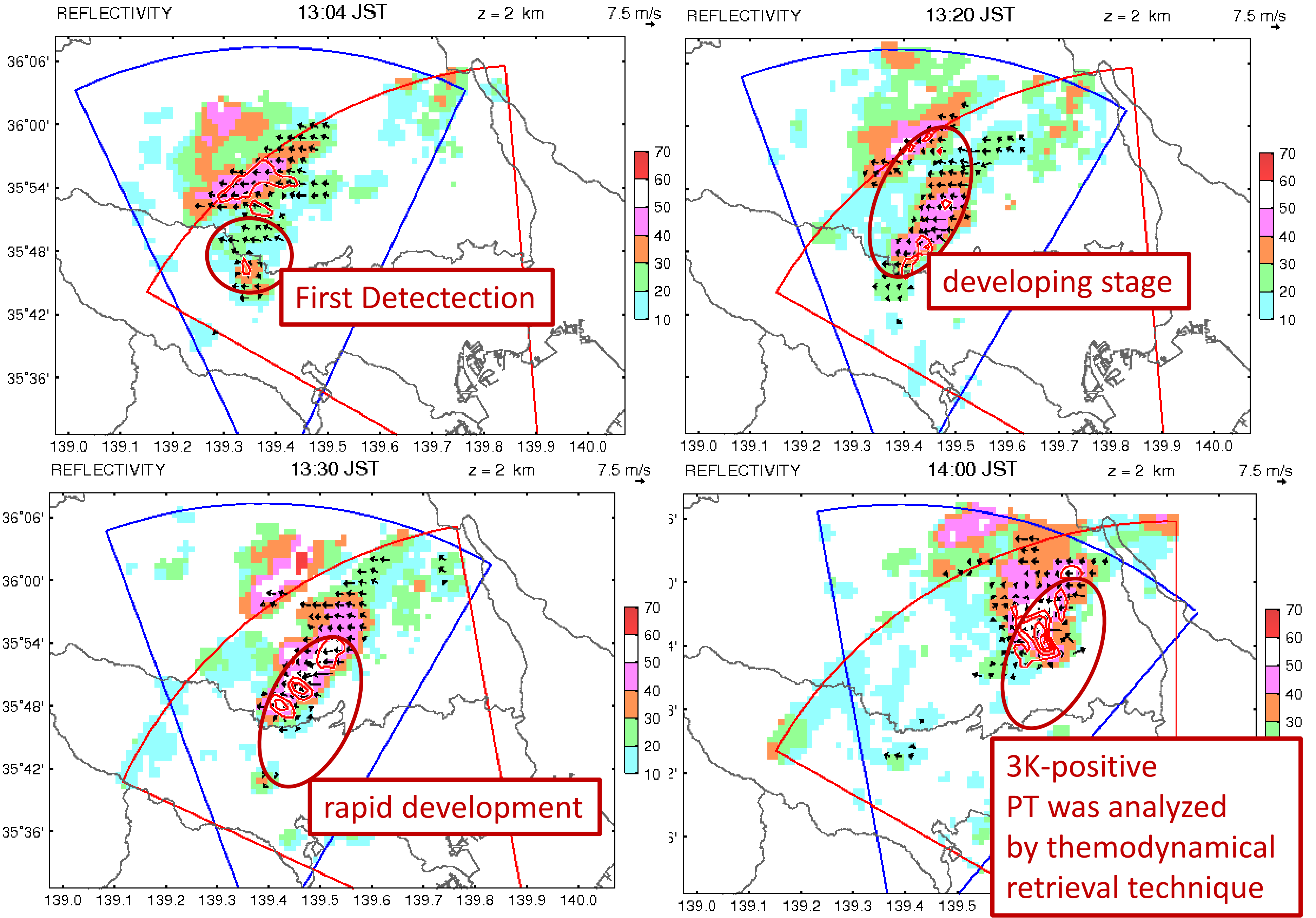
3DVAR Assimilation Experiment with Thermodynamical Retrieval Technique for Short-range Convective Scale Forecast

S. Shimizu (NIED)

CReSS
Cloud Resolving Storm Simulator

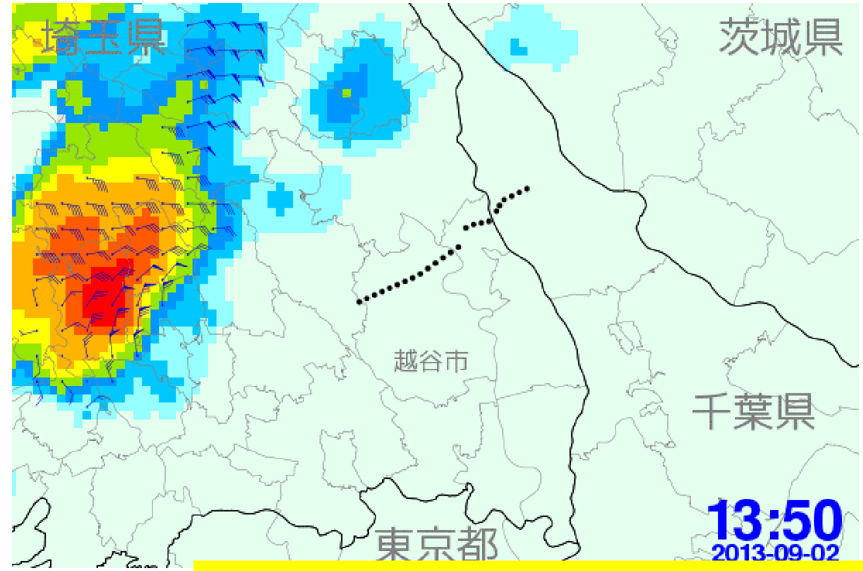
- Basic equations: the non-hydrostatic and compressible equation system.
- Coordinate system: a terrain-following in a two or three dimensional domain.
- Spatial representation: finite difference method (Arakawa C grid in horizontal, Lorenz grid in vertical).
- Time integration: mode-splitting scheme (acoustic terms implicit in vertical)
- Ground model: *n*-layer 1-dim. thermal conductivity model.
- Ocean model: *n*-layer 1-dim. diffusion model.
- Surface process: bulk scheme (Louis scheme).
- Map projections: Lambert, Polar stereo, Mercator, Lat-lon.
- Parallel processing: inter-node: the Message Passing Interface (MPI) , intra-node: OpenMP. (CReSS showed high performance in Kei-super computer and Earth Simulator)
- Two-moment cold bulk scheme (option: warm bin scheme is available)
- NIED developed 3DVAR and Incremental Analysis Update scheme

Sector scan observation by two X-band MP radars (dt=1min) was operated when tornadic storm was observed around Koshigaya city on Sep 2th, 2013



CReSS-3DVAR Assimilation

Initial Condition: 12 JST from JMA-MSM
Assimilation data: Two MP-radars with sector scanning
Available observation parameters:
1) Radial velocity
2) reflectivity
3) potential temperature perturbation deduced from thermodynamical retrieval technique (Roux, 1985) with rapid scanning observation.
Assimilation window: 13:00 - 13:45 JST
Assimlation method : 3DVAR (Hybrid method in near future)

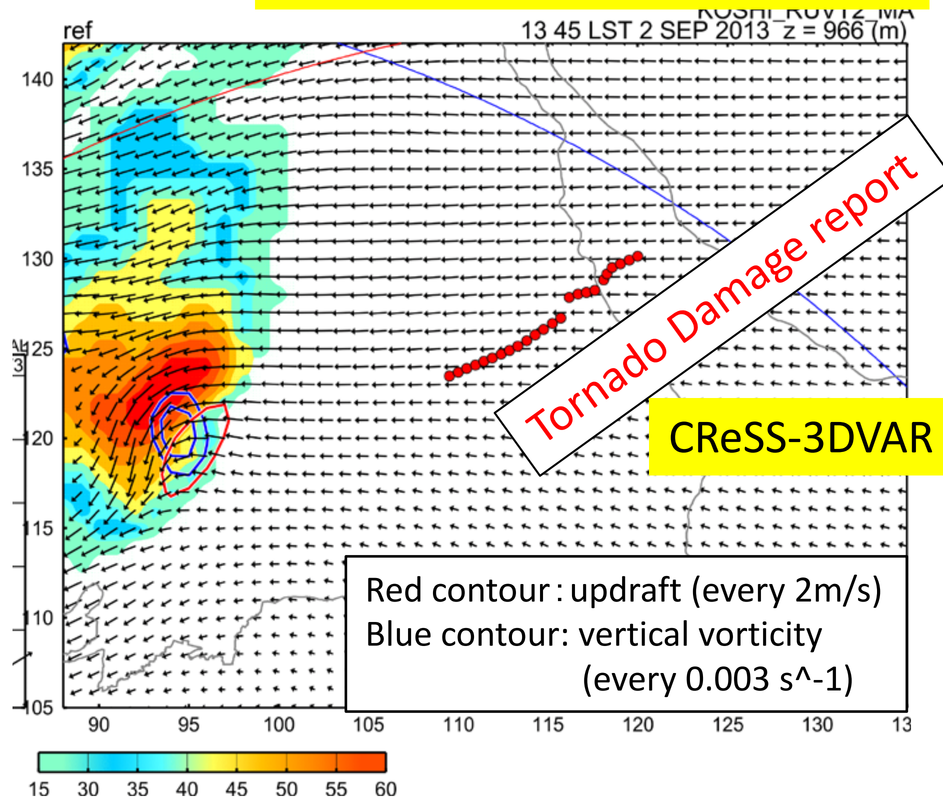


Observation (Dual-Doppler ANL)

After 13:45 JST (end of assimilation window), CReSS successfully simulated strong vertical vorticity over 6.0x10-3 s-1 with a updraft over 4 m/s at 1km ASL.

Reflectivity pattern was very similar to the observed rainfall pattern after 13:50 JST.

Hybrid method (3DVAR+Ensemble Forecast (PO method)) is now tested for this case.



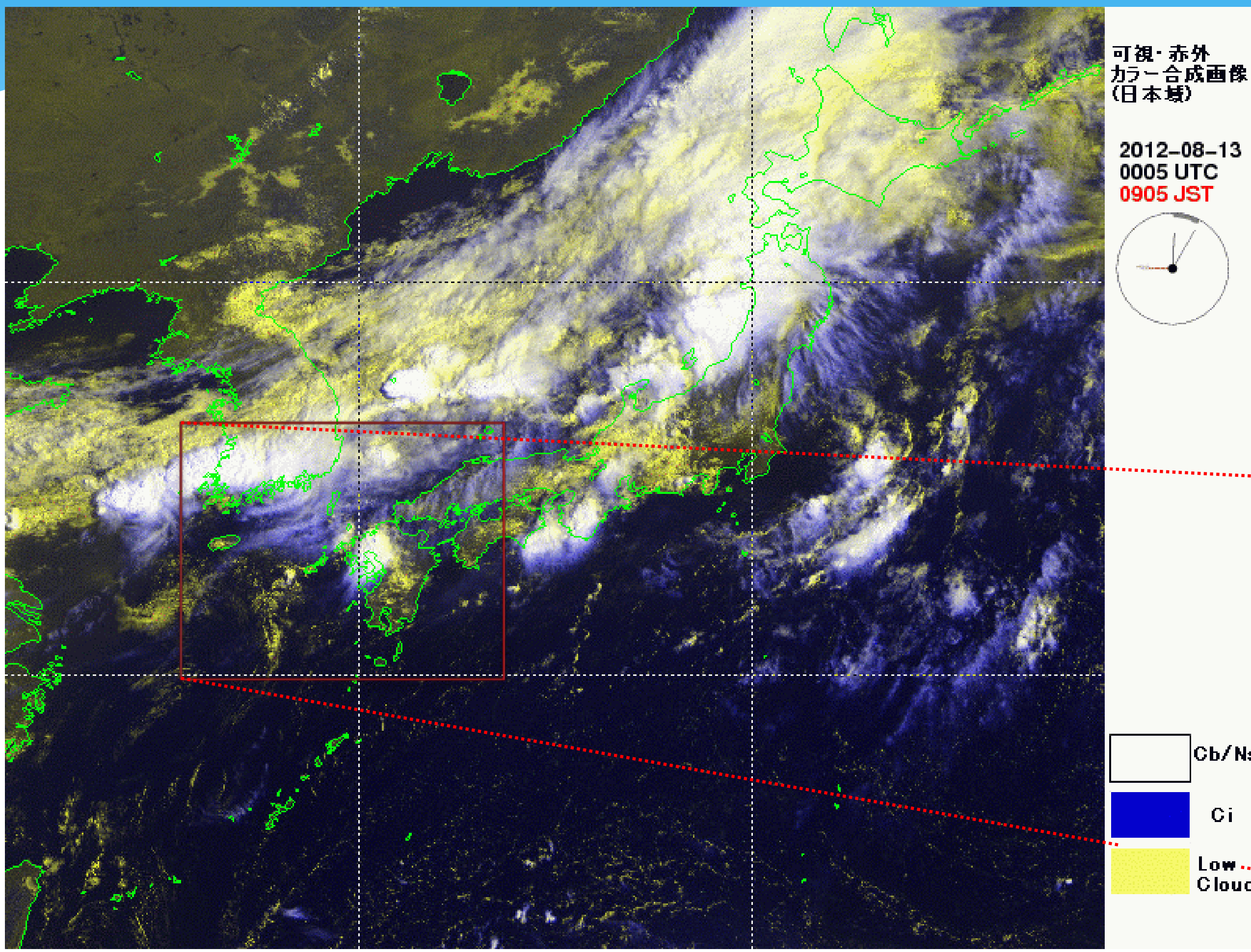
CReSS-3DVAR

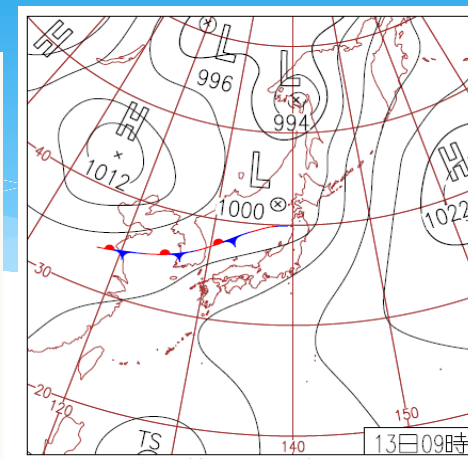
Assimilation Experiments of MTSAT Rapid Scan Atmospheric Motion Vectors

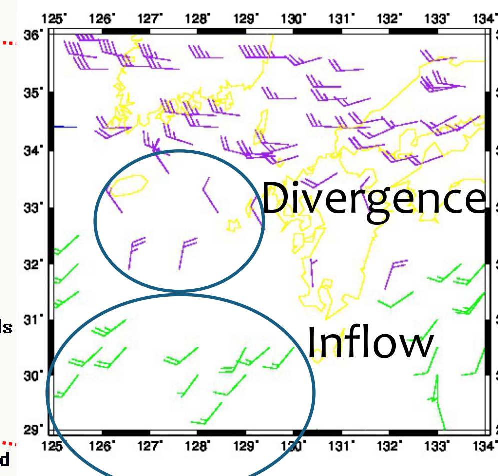
M. Otsuka[1], M. Kunii[1,2], H. Seko[1,2,3], K. Shioji[4], M. Hayashi[4]

1: MRI/JMA, 2: AICS, 3: JAMSTEC, 4: MSC/JMA

A heavy rainfall event (on 13th August 2012)







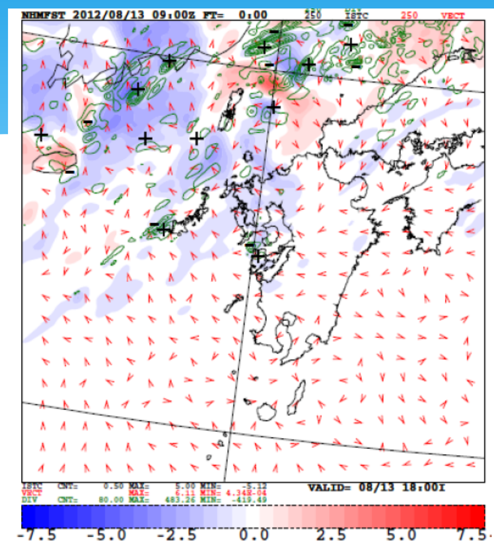
IR and VIS combined image by MTSAT-1R at 0005 - 0090 UTC on August 13th in 2012

RS-AMVs assimilated during 00 – 09 UTC

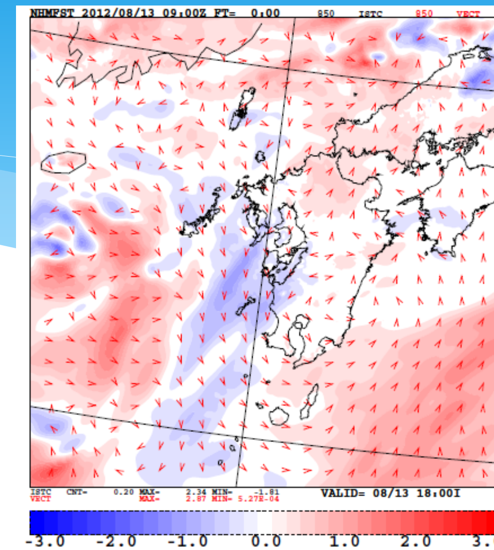
Upper (purple) and lower (green) winds

Result – Difference in wind analysis

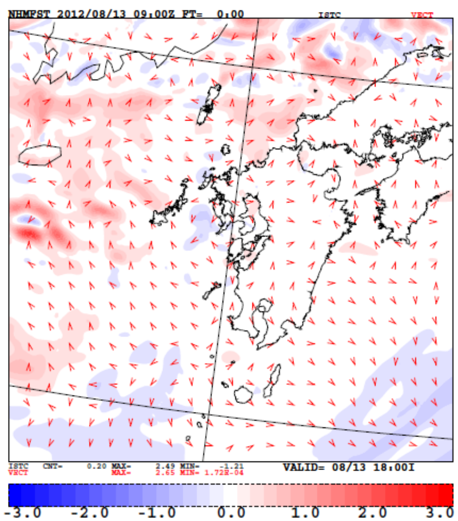
250hPa

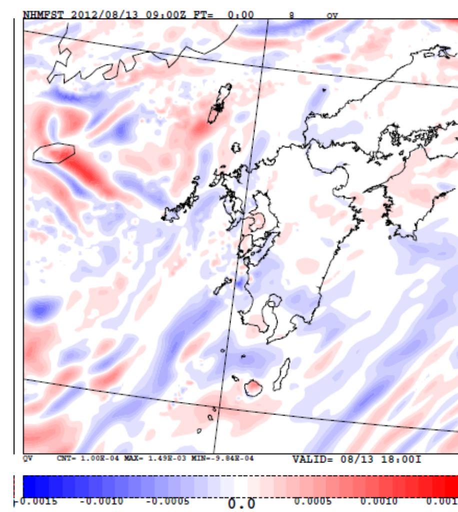


850hPa



surface





Water vapor at 500 m above the surface

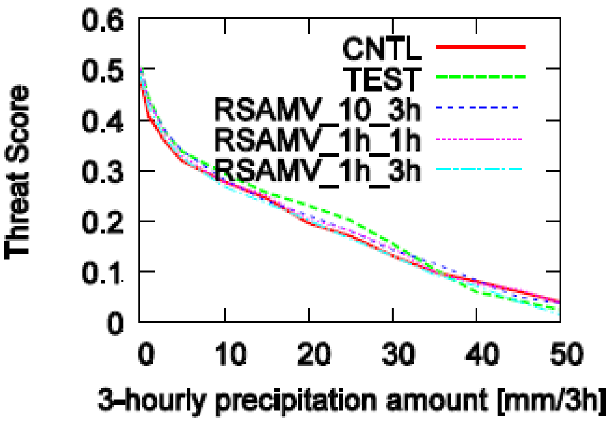
QV[kg/kg] (color shading)

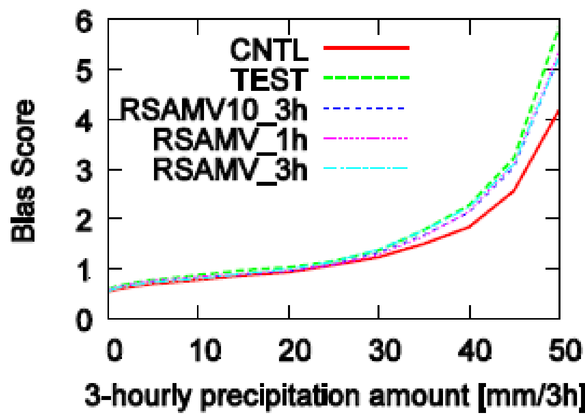
Difference in analysis at 0900 UTC initial time (TEST minus CNTL)

Wind vector (arrows) , wind speed (color shadings) and divergence (green contours)

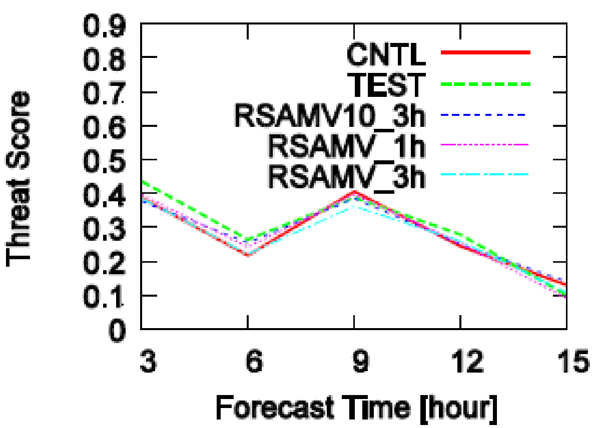
Result - Precipitation verification scores

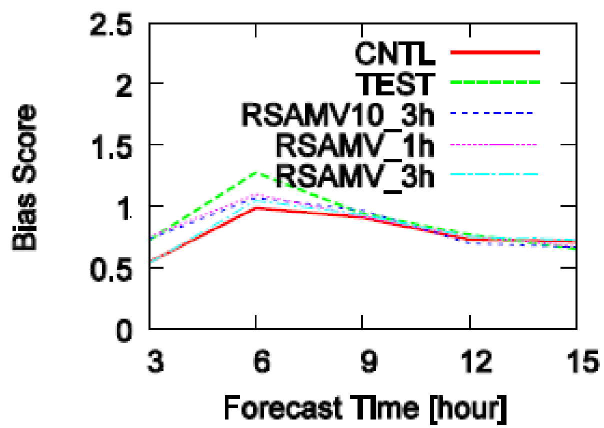
against Observation (the radar/rain gauge-analyzed precipitation data)





	Time slot	Time interval for thinning	Number of RS-AMVs assimilated
TEST	10 min.	10 min.	1640
RSAMV10_3h	10 min.	3 hrs.	838
RSAMV_1h	1 hr.	1 hr.	1624
RSAMV_3h	1 hr.	3 hrs.	838





Threshold :10mm /3h

Intercomparison of Convective Scale Data Assimilation Systems

[1]Takuya Kawabata, [2]Le Duc,
[1]Seiji Origuchi, [1]Sho Yokota, and [1]Tadashi Tsuyuki
[1]Meteorological Research Institute, Japan Meteorological Agency
[2]Japan Agency for Marine-Earth Science and Technology

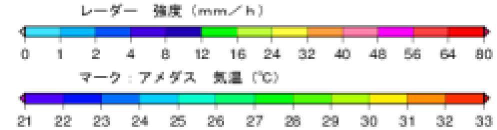
Comparison of data assimilation systems

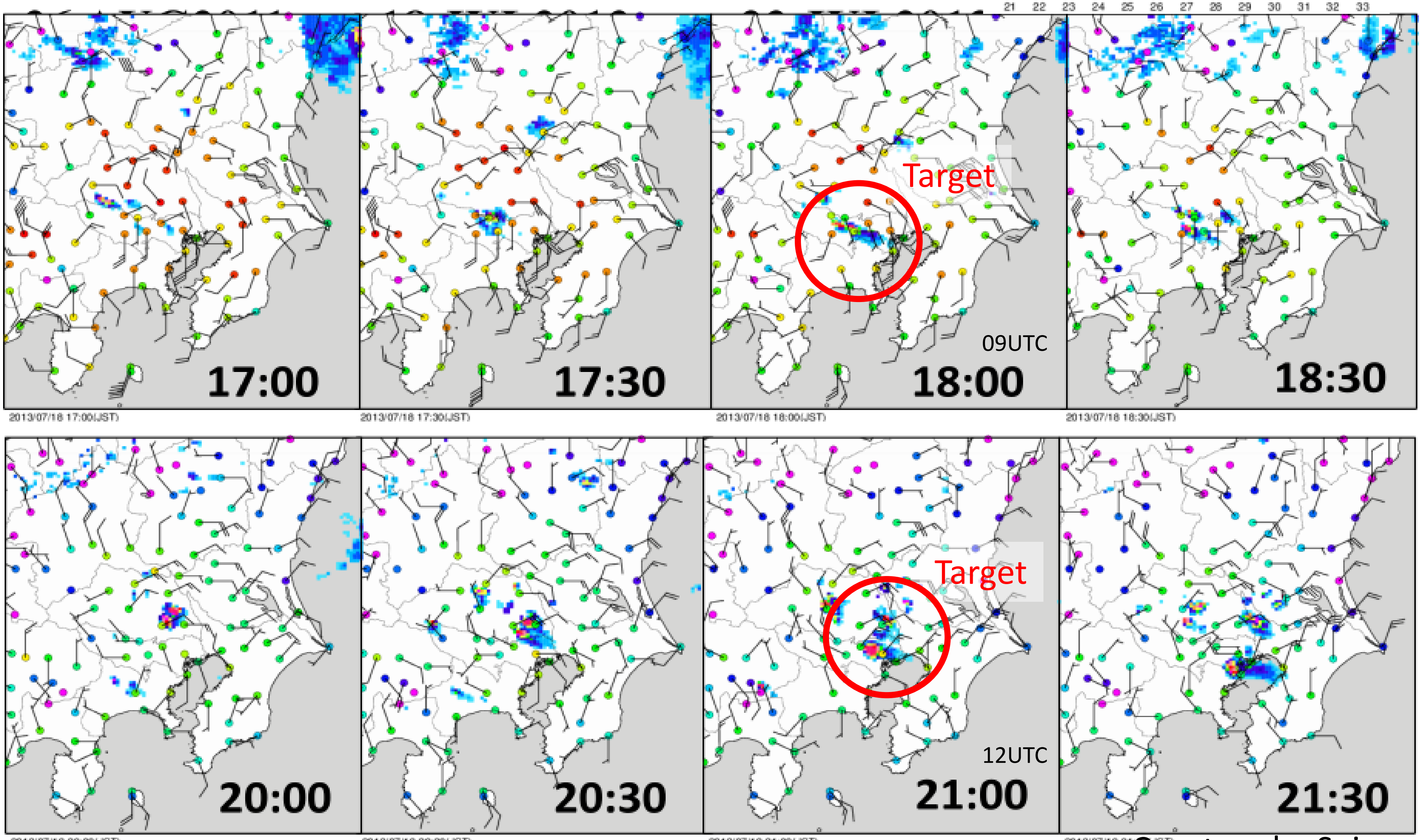
Heavy rain in 18 July 2013

AMeDAS and Radar data

Radar precipitation (mm/hour)

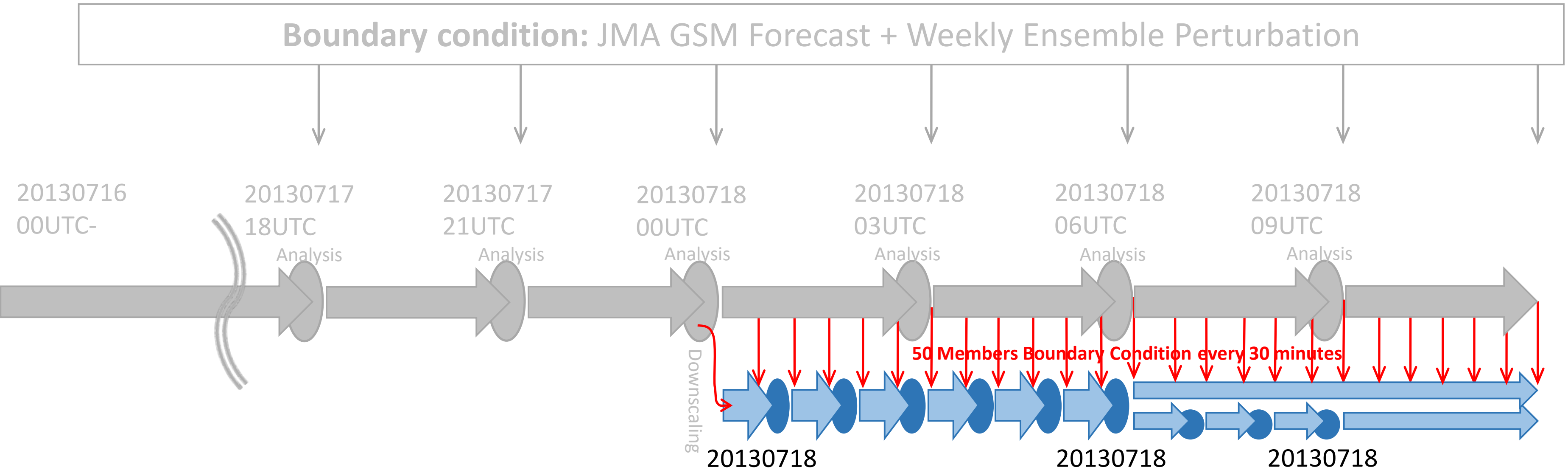
AMeDAS temperature (℃)





Courtesy by Seino

Flow of the experiment



Outer
Grid interval: 10 km
Grid number: 361x289x50
Ensemble size: 50
Analysis window: 3 hour
(Operational Observations used in JMA Meso-DA every 30 minutes)

Inner
Grid interval: 2 km
Grid number: 200x200x60
Ensemble size: 50
Analysis window: 1 hour
(Dense Surface, Upper, GPS and Radar Observations)

Target:
Local rain near Tokyo in 20130718 08-09UTC and 11-12UTC

Red: Initial and boundary data
Blue: Participants' work
Gray: Duc-san's assimilation experiment

Observation data

They are in “text” format.

Standard deviation

Azimuth (degree) if it is radar data

Data order:
“[Observation data] [Observation error] [Longitude] [Latitude] [Height(m)] [Dummy data]”

JMA Surface observation:
Obs/Da/Sfc (U, V, T every 10 minutes in 7/18 00-15UTC)
AMeDAS:
Obs/Da/Amd (U, V, T every 10 minutes in 7/18 00-15UTC)
JMA Upper observation (sonde):
Obs/Da/Upper (U, V, T, P at 7/18 00UTC and 12 UTC)
GPS :
Obs/Da/GPS-PWV (Precipitable water vapor every 5 minutes in 7/18 00-15UTC)
Radar (QC):
Obs/Da/Radar/Data/KASIWA (HANEDA, NARITA) (Radial wind in 7/18 00-15UTC)
Reflectivity data are contained, but they may not be used.

If you would like to make QC by yourself, please use following “r-theta” data.
Radar (raw data):
Obs/Da/Radar/Draft/KASIWA (HANEDA, NARITA) (Radial wind in 7/17 15-7/18 15UTC)

Thank you for your attention.

Predictability of Mesoscale Phenomena

Power spectrum

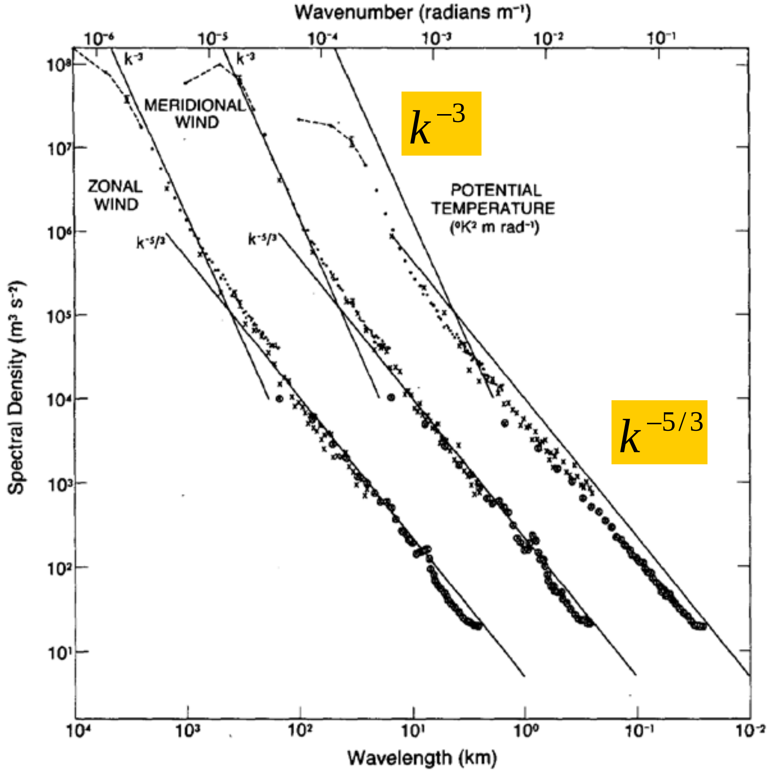


FIG. 3. Variance power spectra of wind and potential temperature near the tropopause from GASP aircraft data. The spectra for meridional wind and temperature are shifted one and two decades to the right, respectively; lines with slopes −3 and −5/3 are entered at the same relative coordinates for each variable for comparison.

Nastrom and Gage (1985)

Moist process

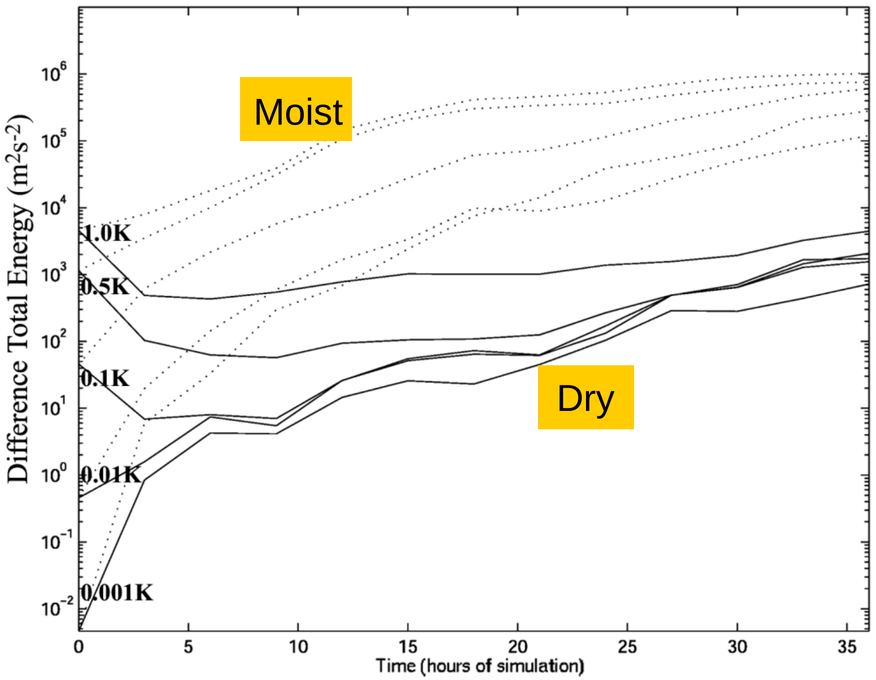


FIG. 7. As in Fig. 4 but for the fake dry experiments (solid curves). The dotted curves indicate the corresponding error evolution in the moist experiments.

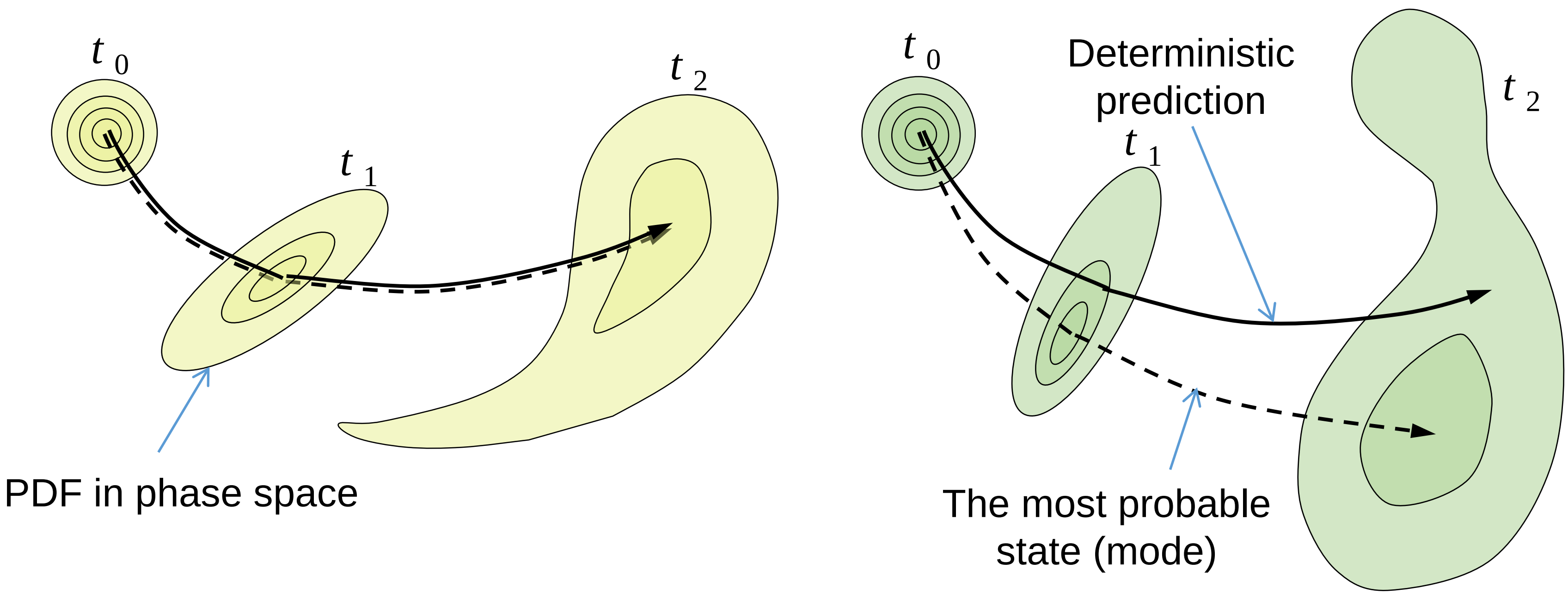
Zhang et al. (2003)

Schematic diagram of the evolution of PDFs

$$\frac{d\boldsymbol{x}}{dt} = \boldsymbol{F}(\boldsymbol{x}, t).$$

$$\frac{\partial}{\partial \boldsymbol{x}} \mathrm{div}\boldsymbol{F} \equiv \boldsymbol{0}\,.$$

$$\frac{\partial}{\partial \boldsymbol{x}} \mathrm{div}\boldsymbol{F} \neq \boldsymbol{0}\,.$$



- Canonical Hamiltonian system
- Quasigeostrophic equations

- **Cumulus convection**
- Climate system

Schematic diagram of the evolution of PDFs

$$\frac{d\boldsymbol{x}}{dt} = \boldsymbol{F}(\boldsymbol{x}, t).$$

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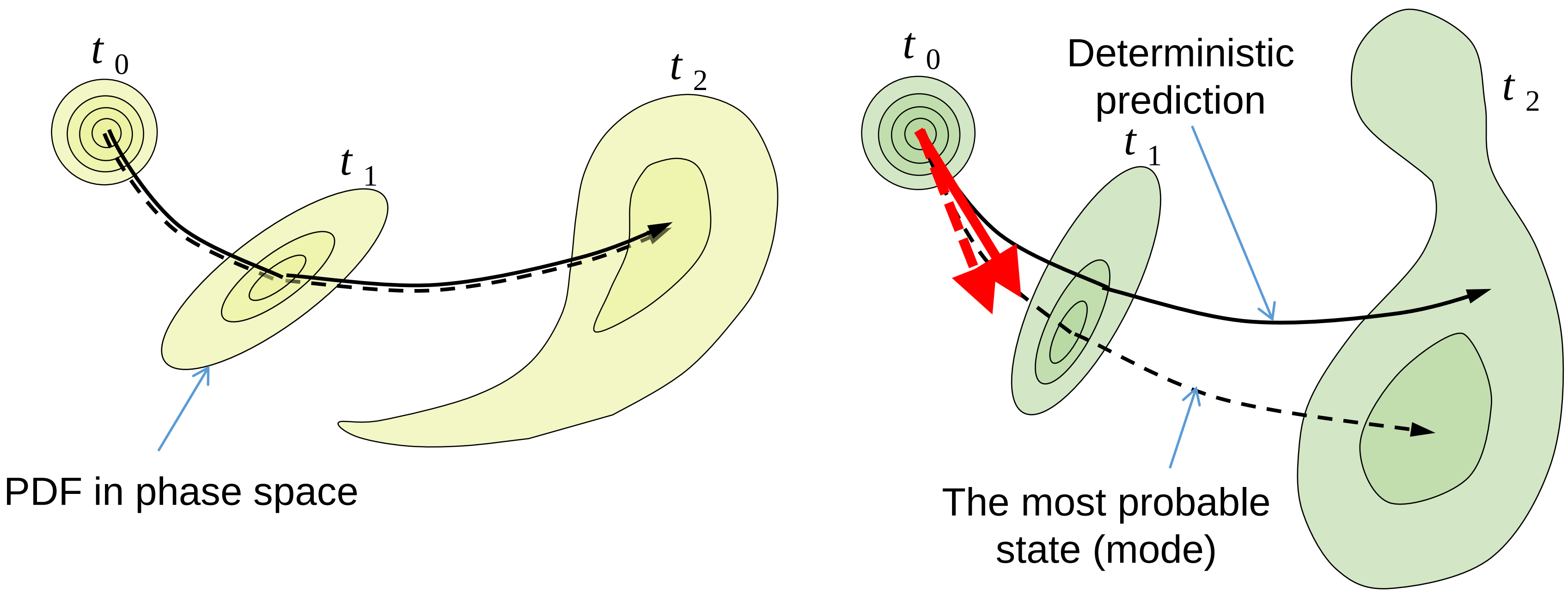

- Canonical Hamiltonian system
- Quasigeostrophic equations

- **Cumulus convection**
- Climate system

Summary

- The impact of RS-AMVs on numerical forecasting of a heavy rainfall near a stationary front was investigated using data assimilation experiments with JNoVA.
- Assimilation of RS-AMVs introduced diverging airflows at upper level and low-level inflow near the front in the initial wind fields, which slightly improved the rainfall amount and verification scores in the early forecast hours.

Initial and boundary data (NHM format)

They are in NHM initial and boundary data format.

Initial data (ensemble mean):
Kanto02km/analysis/201307180000/0000/mfin201307180000
Initial data (each members):
Kanto02km/analysis/201307180000/00yy/mfin201307180000

Boundary data for analysis cycle (ensemble mean):
Kanto02km/boundary/20130718xxxx/0000/mfex,ptgrd,sst,mfhm
Boundary data for analysis cycle (each members):
Kanto02km/boundary/20130718xxxx/00yy/mfex,ptgrd,sst,mfhm

Boundary data for extended forecast (from ensemble mean):
Kanto02km/extfcst/20130718xxxx/mfex,ptgrd,sst,mfhm
Boundary data for extended forecast (each members):
Kanto02km/extfcst/20130718xxxx/mfex00yy,ptgrd,sst,mfhm

Namelist of NHM forecast: Kanto02km/nhm02km.namelist

Initial and boundary data (general format)

They are outputs of outer DA cycle and can be read by Japan10km/read_letkf.f90

Initial data (ensemble mean):

Japan10km/analysis/201307180000/0000/ma201307180000

Initial data (each members):

Japan10km/analysis/201307180000/0000/ma201307180000
+ Japan10km/analysis/201307180000/00yy/pert201307180000

Boundary data (from ensemble mean):

Japan10km/forecast/20130718xxxx/0000/fg20130718zzzz

Boundary data (each members):

Japan10km/forecast/20130718xxxx/00yy/fg20130718zzzz

Following data are not required to perform the experiment.

if20130718zzzz: inflation factor
mf20130718zzzz: ensemble mean of first guess
sf20130718zzzz: spread of first guess
sa20130718zzzz: spread of analysis