Towards 100-m resolution prediction of local convective storms: predictability and nowcasting

Shigenori Otsuka (RIKEN AICS)

Gulanbaier Tuerhong, Ryota Kikuchi,
Yoshikazu Kitano, Yusuke Taniguchi, Juan Ruiz,
Shinsuke Satoh, Tomoo Ushio, Takemasa Miyoshi

RIKEN Data Assimilation Team

BDA BIG DATA ASSIMILATION

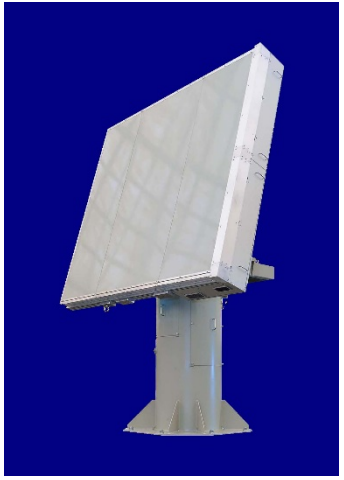
Background

- Frequent meteorological disasters in Japan
  - Typhoon
  - Baiu front
  - Rapid development of local severe storms ("guerilla" torrential rain)
- Needs for rapid observation and forecasts

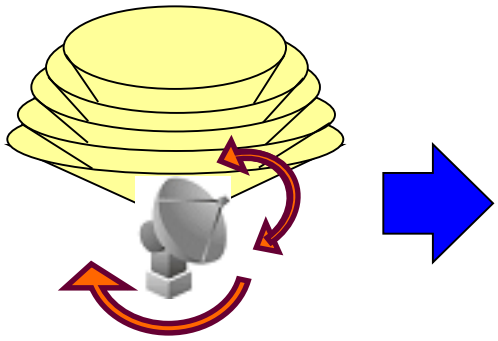
Flash flood in Togagawa, Kobe (July 2008)

Landslide in Hiroshima (August 2014)
(report by Japan Soc. Civil Eng.)

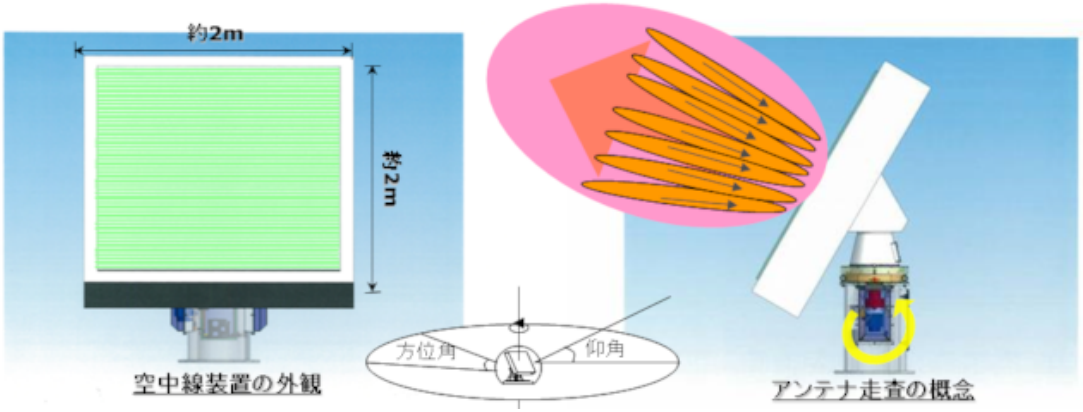
Phased Array Weather Radar (PAWR)



- Rapid scan
  (10-30 seconds for 3D volume scan)
- High density (100 m resolution, 110 elevation angle)
- Data rate becomes 100 times larger than conventional radar

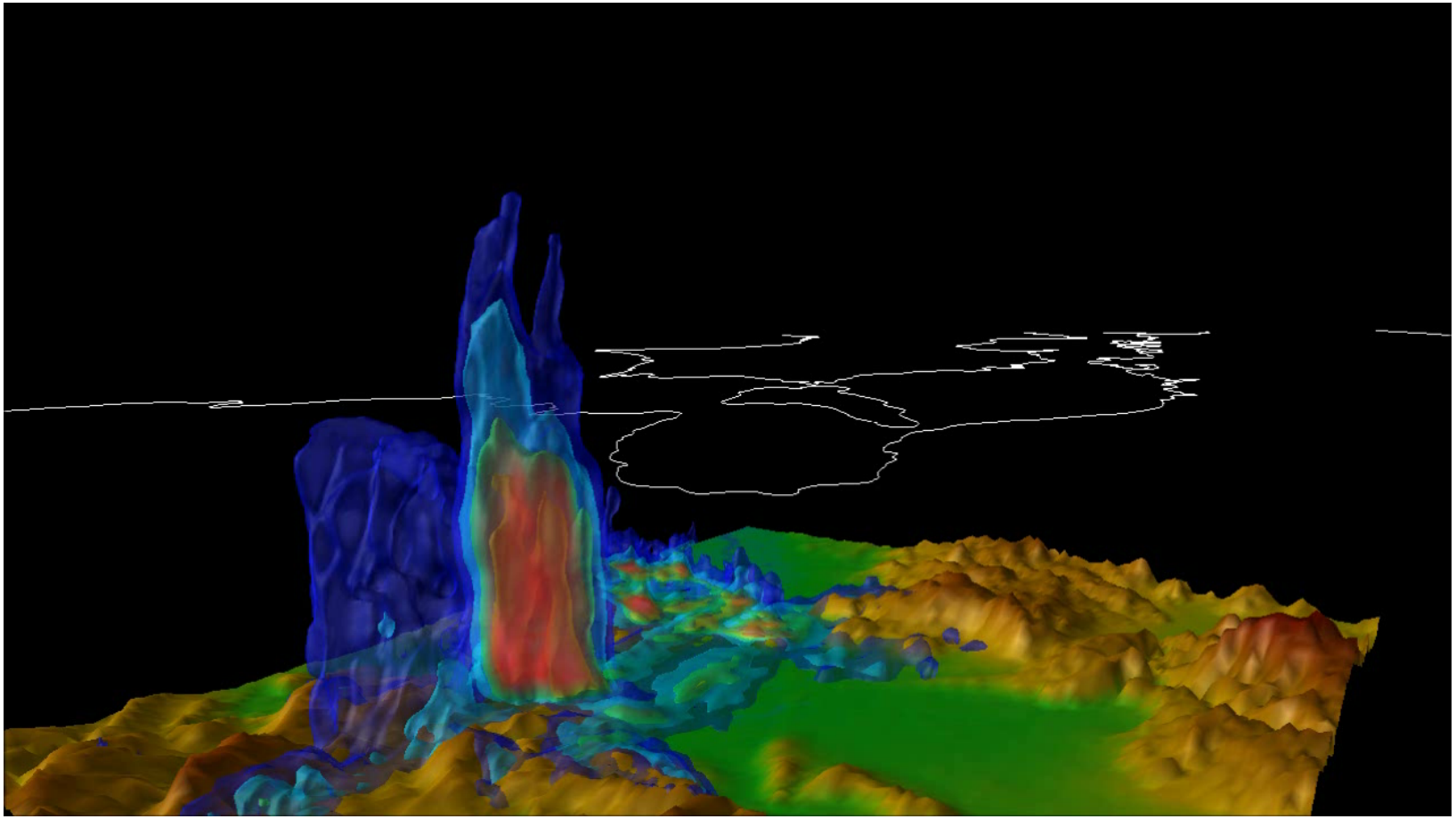


3D volume scan by conventional parabola antenna
(15 elevation angle ⇒ 5 min)

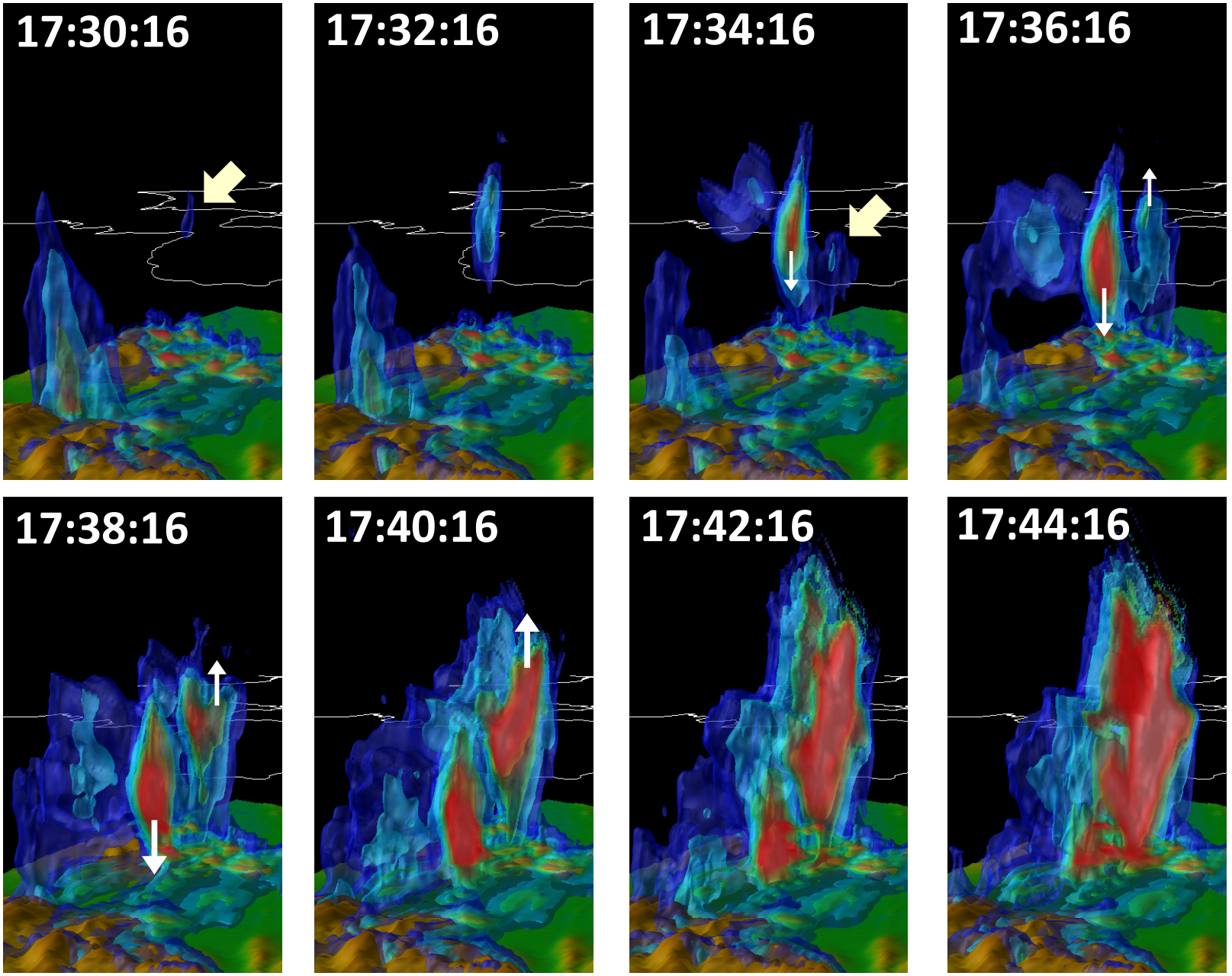


3D volume scan by 1D phased array antenna
(110 elevation angle ⇒ 30 s)

Motion of rain particles in the sky (PAWR at Osaka Univ.)



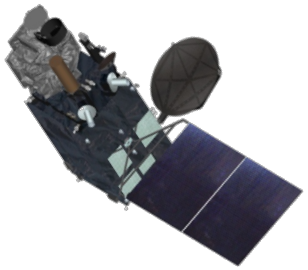
Egg of rain: 10 min before the touchdown



Revolutionary super-rapid 30-sec. cycle

Phased Array Radar
1GB/30sec/2 radars

Himawari
500MB/2.5min



A-1. Quality Control
A-2. Data Processing

B-1. Quality Control
B-2. Data Processing

①30-sec Ensemble
Forecast Simulations
2 PFLOP

②Ensemble
Data Assimilation
2 PFLOP

Analysis Data
2GB

Ensemble Forecasts
200GB

Ensemble Analyses
200GB

③30-min
Forecast Simulation
1.2 PFLOP

Repeat every 30 sec.

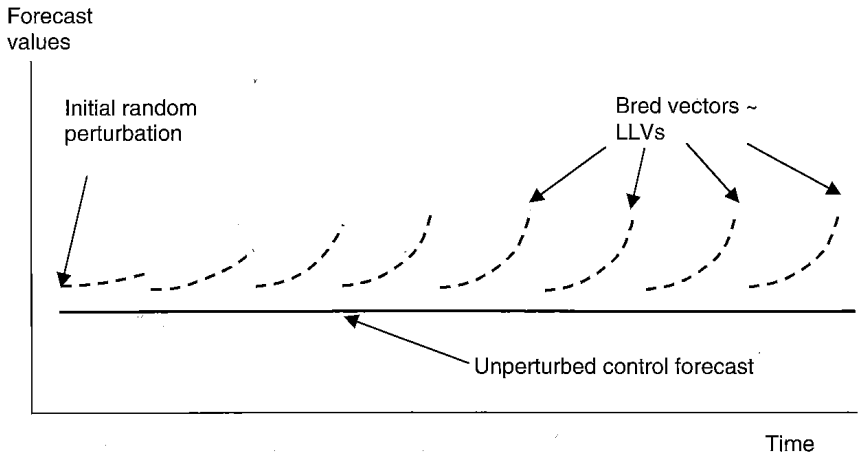
30-min Forecast
2GB

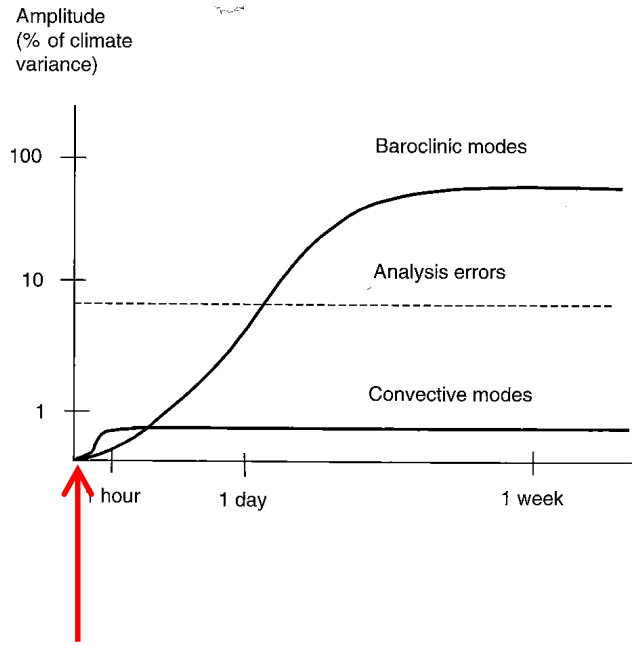
100 m mesh

Breeding experiments

Breeding

- Extracting fast growing modes by rescaling perturbation
- Our target:
  Growing modes
  in O(sec.) – O(min.)
- What would be the effective assimilation frequency?





O(sec.) – O(min.)

(Kalnay, 2003)

Case study: July 13, 2013, a disaster in Kyoto

讀賣新聞

2013年(平成25年)
7月14日日曜日

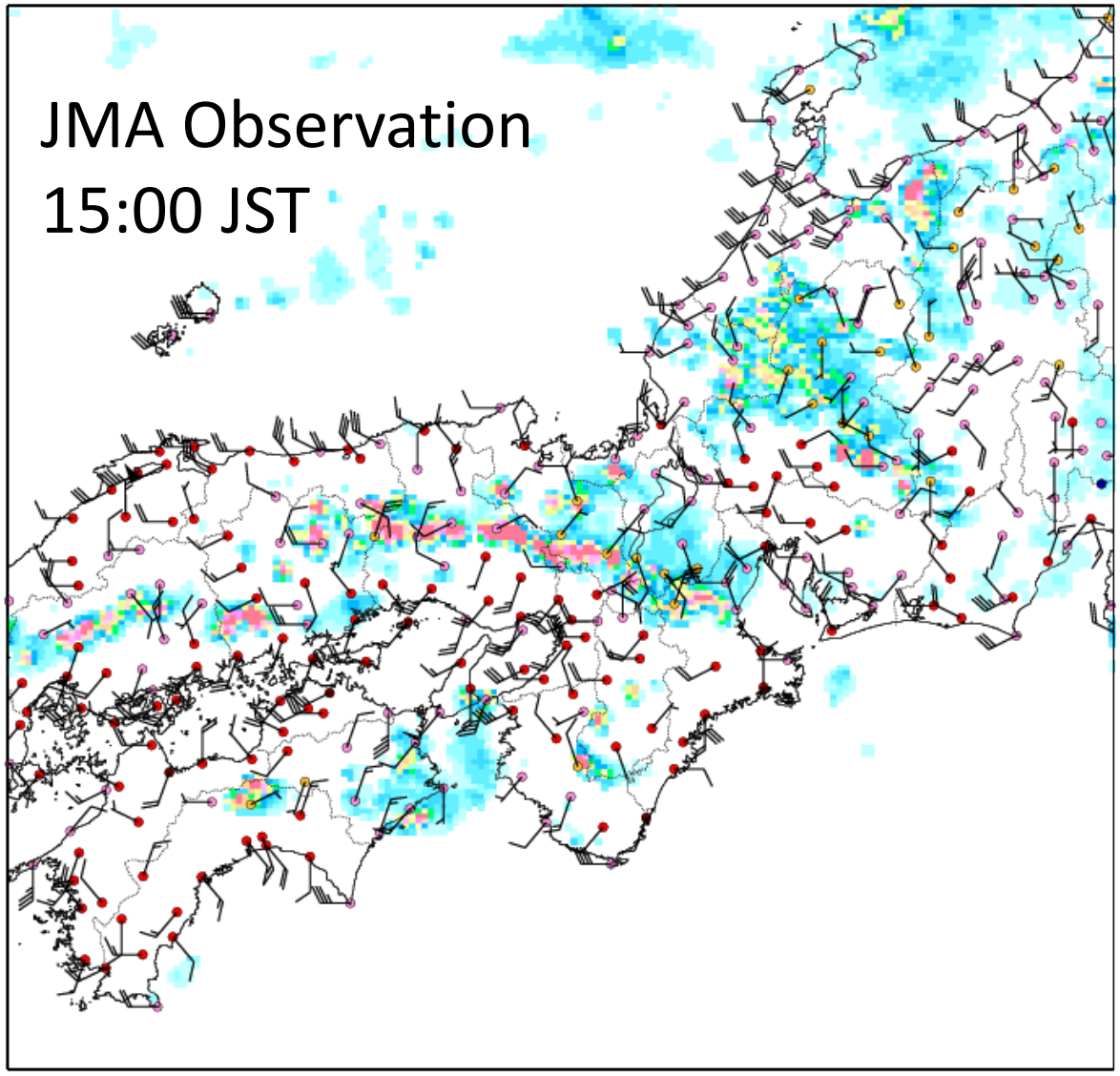
猛暑のち局地的豪雨

日本列島は13日、西日本を中心に引き続き猛暑となったが、午後には上空の寒気の影響で大気の状態が不安定になり、近畿や中国では局地的に落雷や激しい雨に見舞われた。

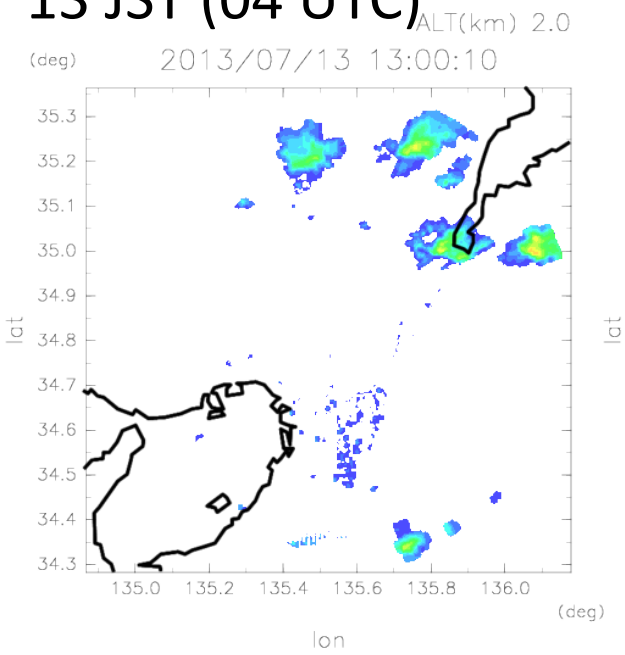
大阪管区気象台によると、1時間の降水量では、京都府京田辺市で56・5ミリ（午後4時27分まで）、広島県北広島町で50・5ミリ（午後5時半まで）を記録した。京都府宇治、城陽両市で床上浸水1軒、床下浸水22軒の被害が出たほか、京都市内で一時、約3300軒が停電した。

祇園祭の山鉾が並ぶ同市中心部では、午後2時過ぎから雷を伴う強い雨が降った。観光客らはアーケードの下で雨宿りするなか、芸舞妓が足元を気遣いながら道を急いでいた＝写真＝。（宇那木健一撮影）

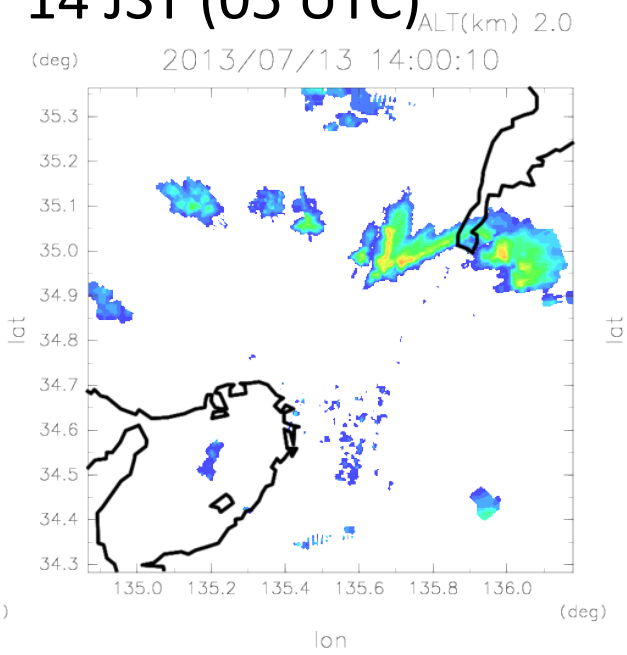
The top page of Yomiuri newspaper on 14 July, 2013


JMA Observation
15:00 JST
2013/07/13 15:00(JST)

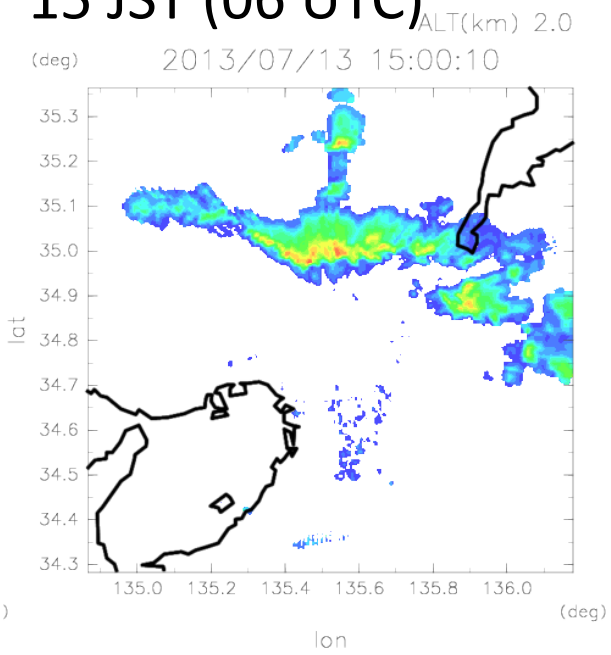
13 JST (04 UTC)



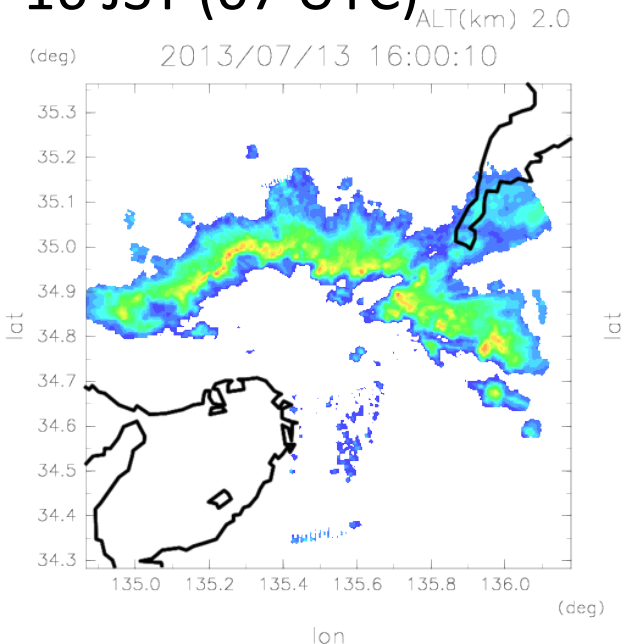
14 JST (05 UTC)



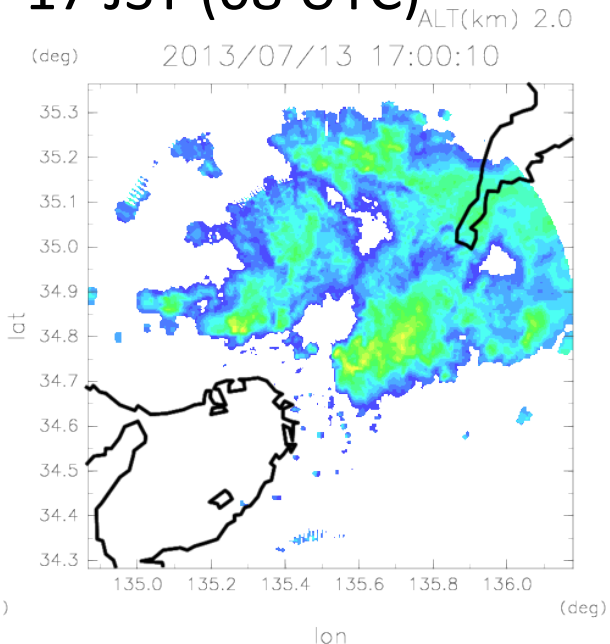
15 JST (06 UTC)

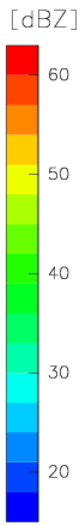


16 JST (07 UTC)



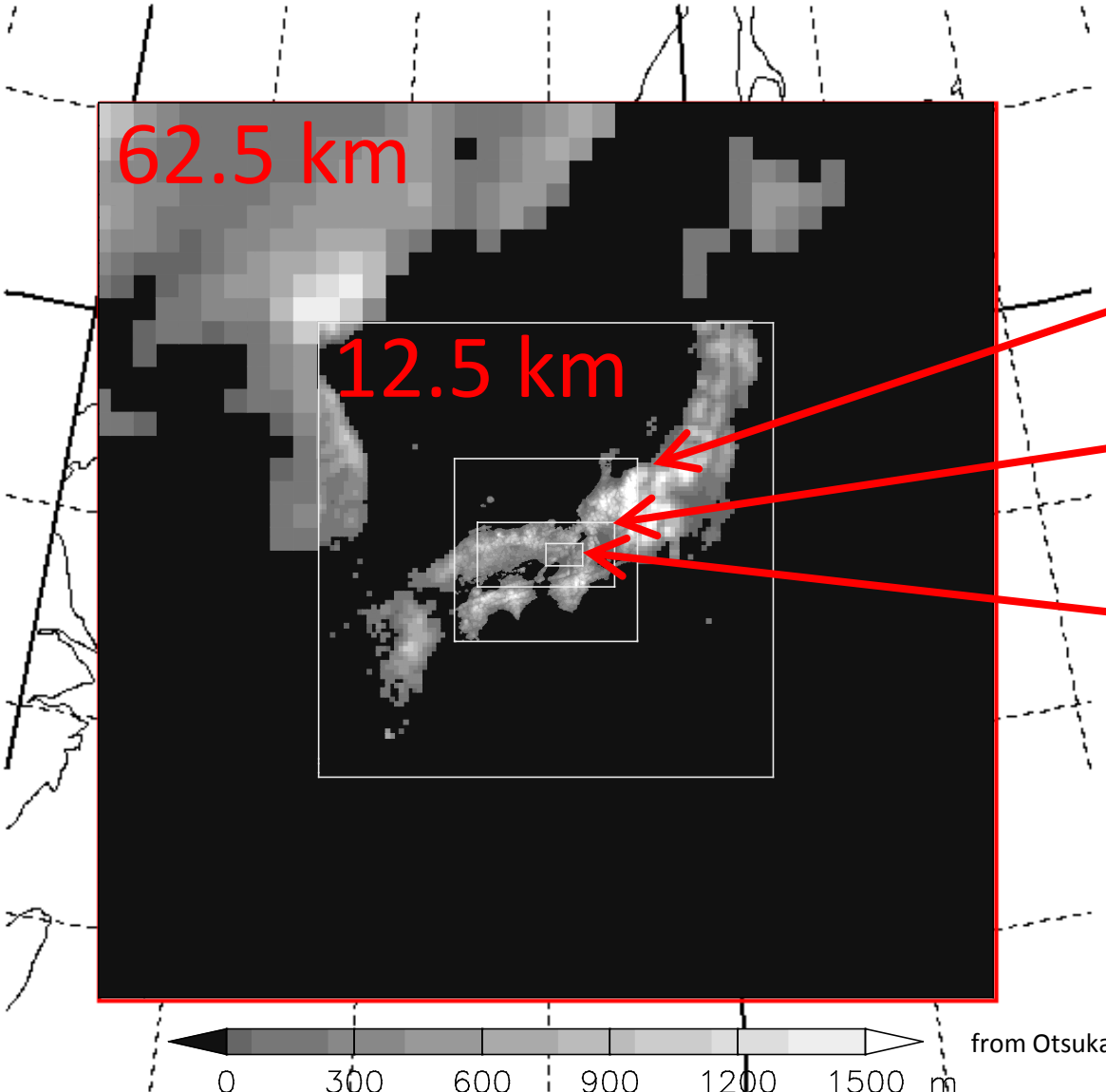
17 JST (08 UTC)





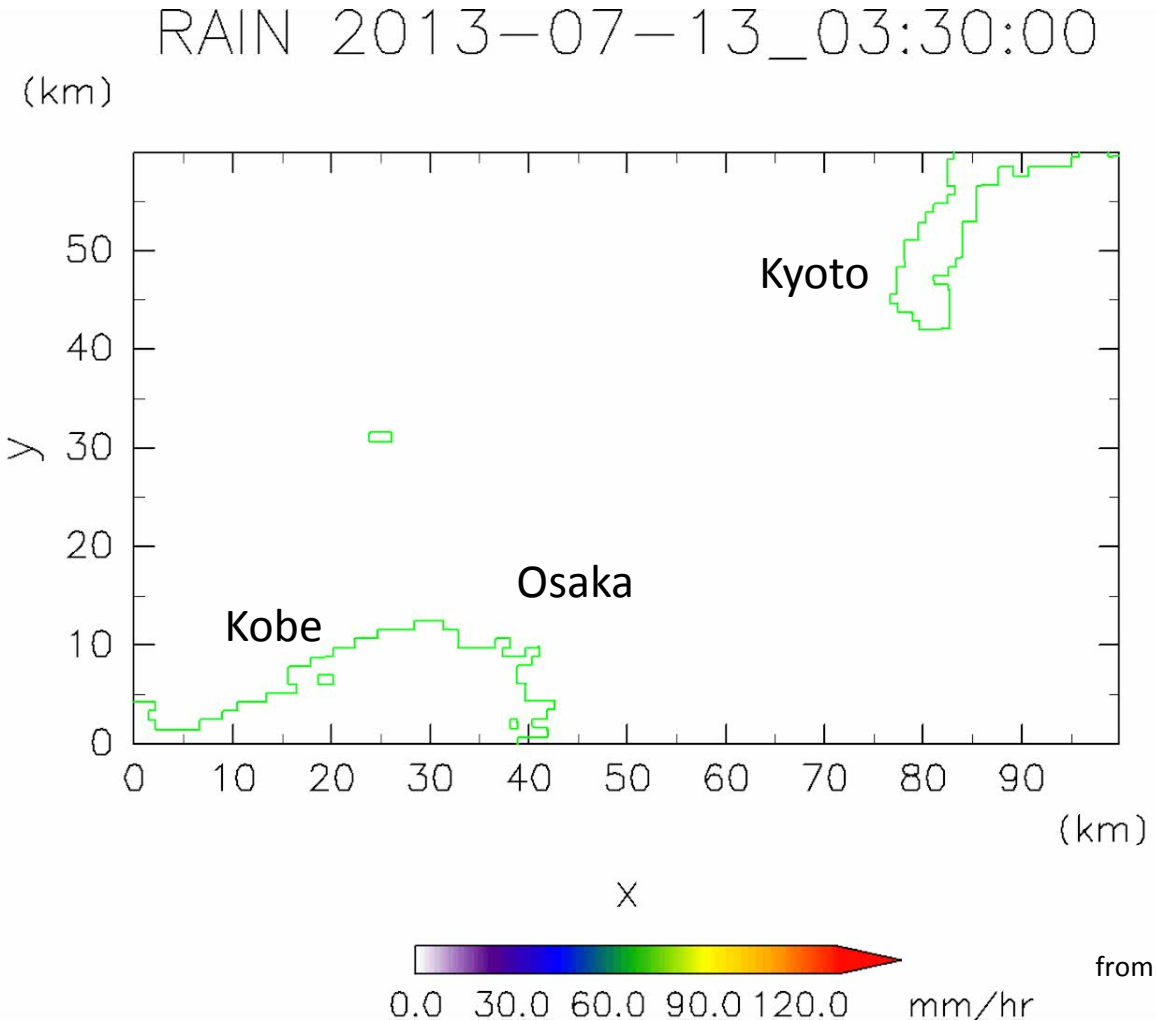
Osaka Univ.
PAWR
observation

WRF computational domains



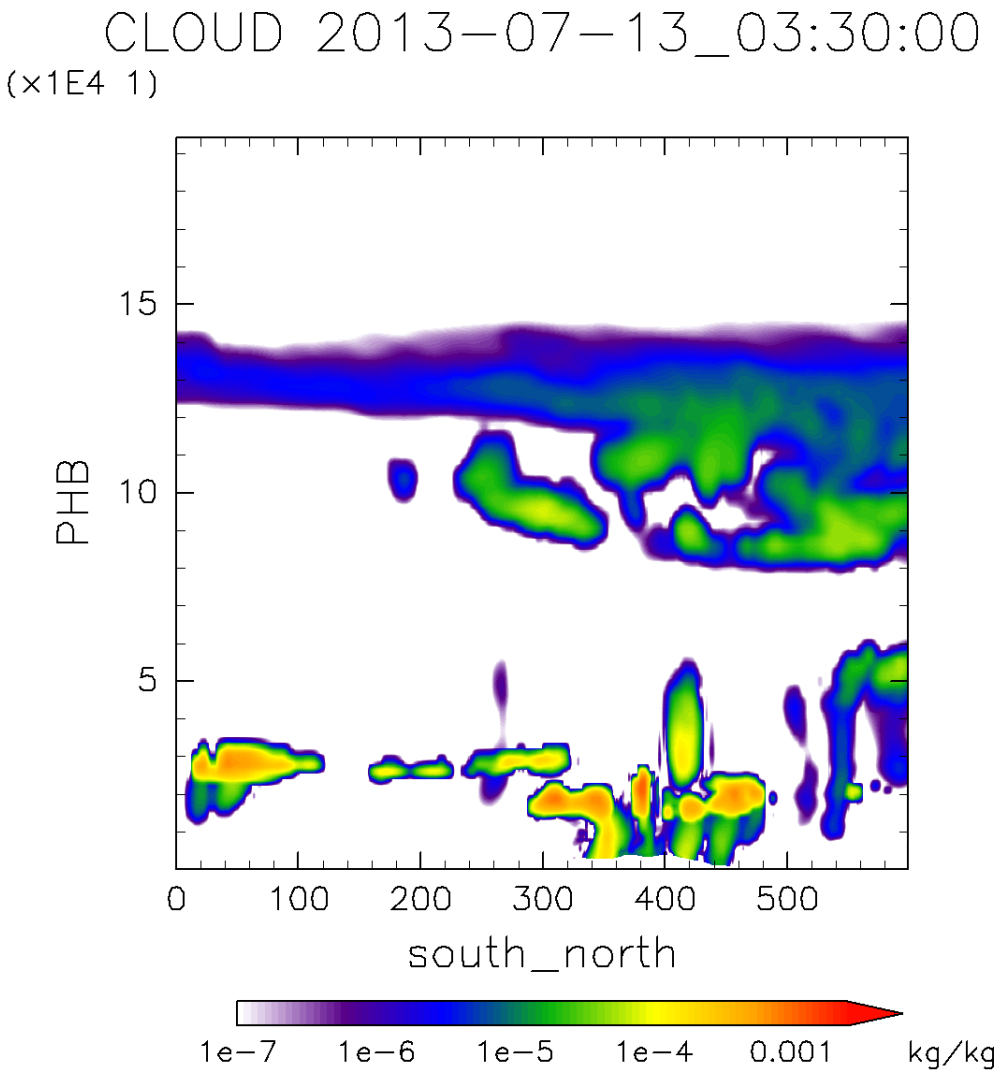
from Otsuka and Miyoshi (2015, in prep.)

Surface rain at a 100-m resolution



from Otsuka and Miyoshi (2015)

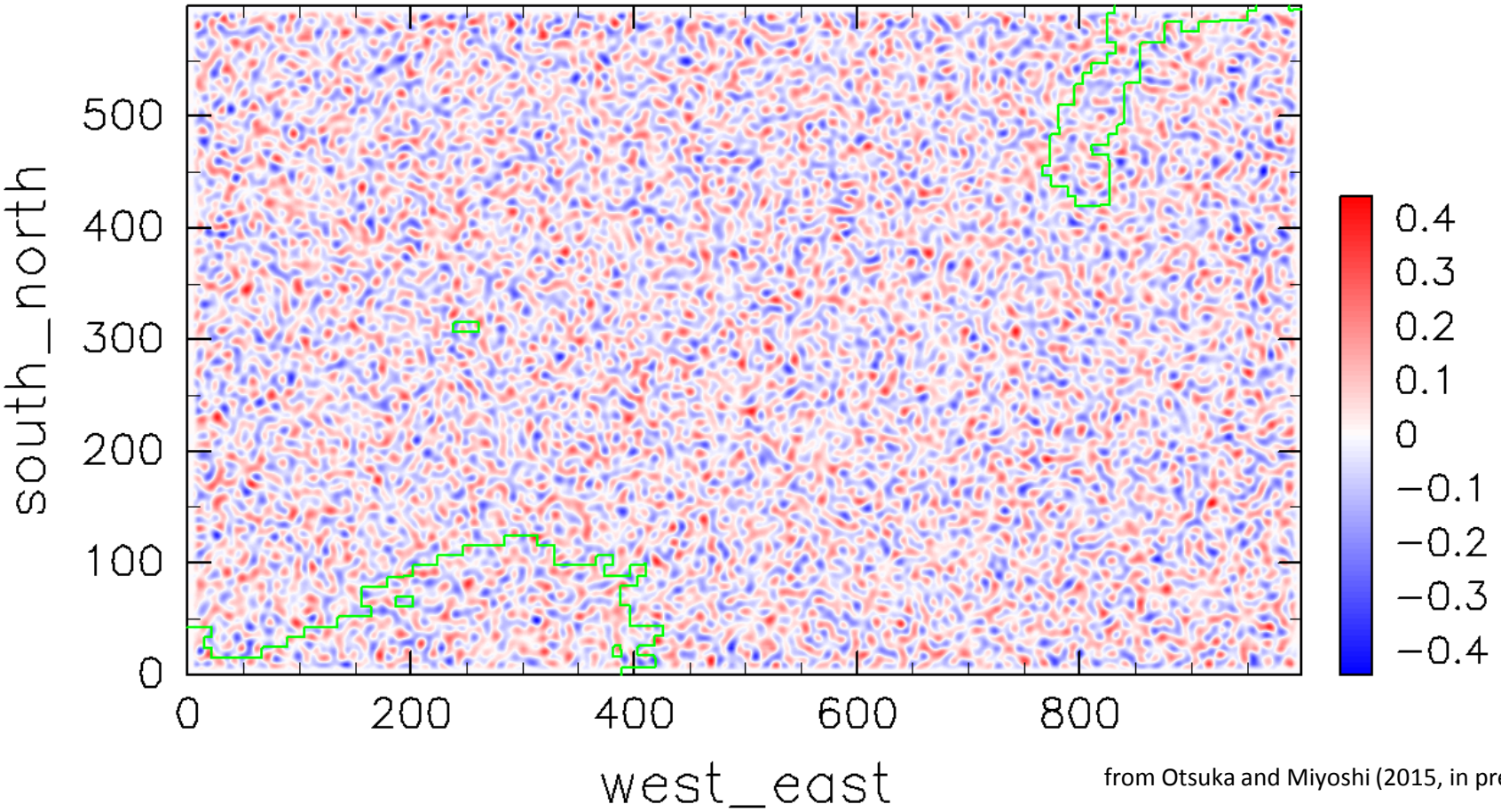
Vertical structure of the storm



from Otsuka and Miyoshi (2015, in prep.)

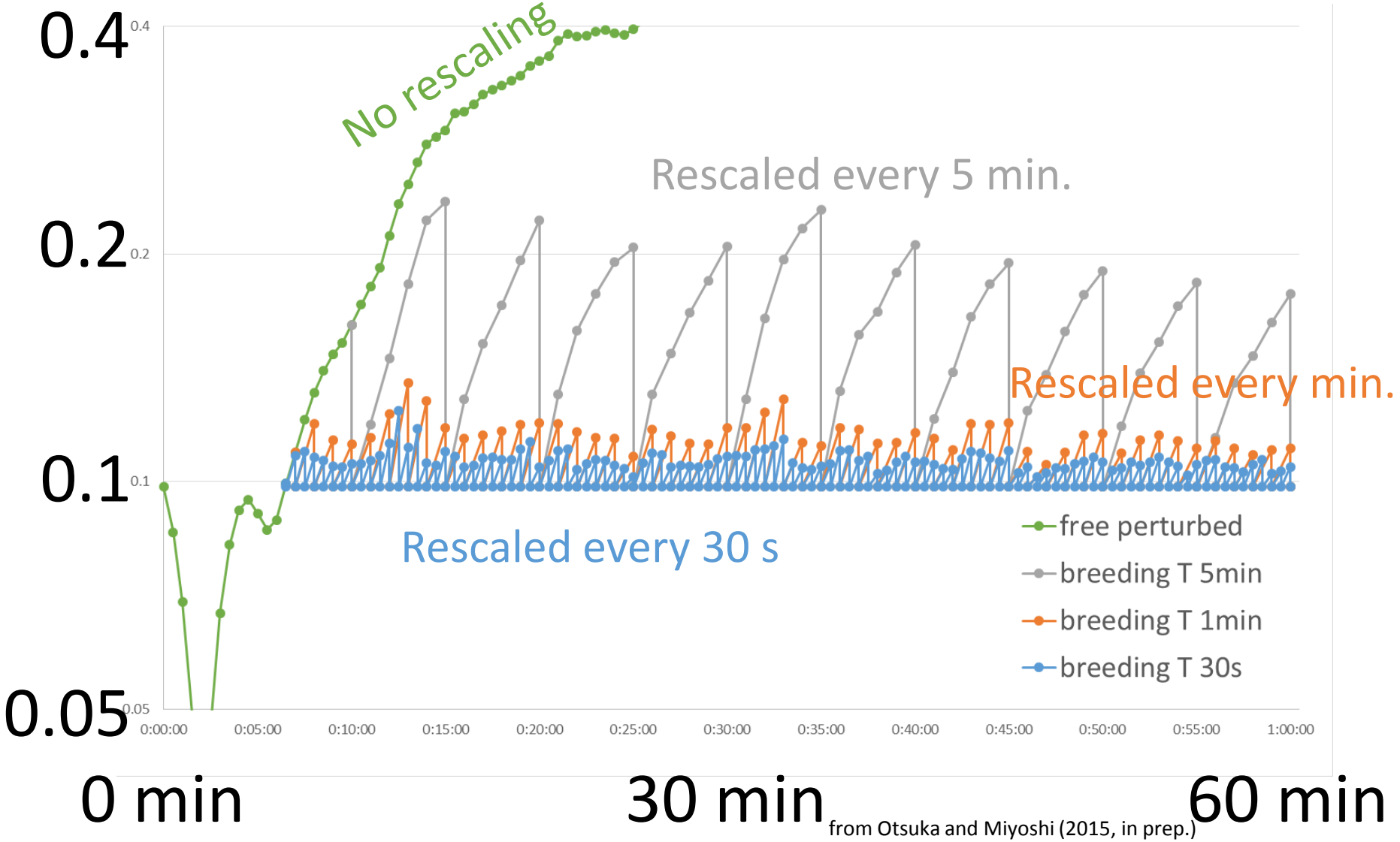
Breeding experiments

- Initial perturbations: potential temp. at 1-2 km scales
- Rescaling: factor = 0.1 K / rms(θ'(z = 5 km))
  - Rescaled only if larger than the initial size



from Otsuka and Miyoshi (2015, in prep.)

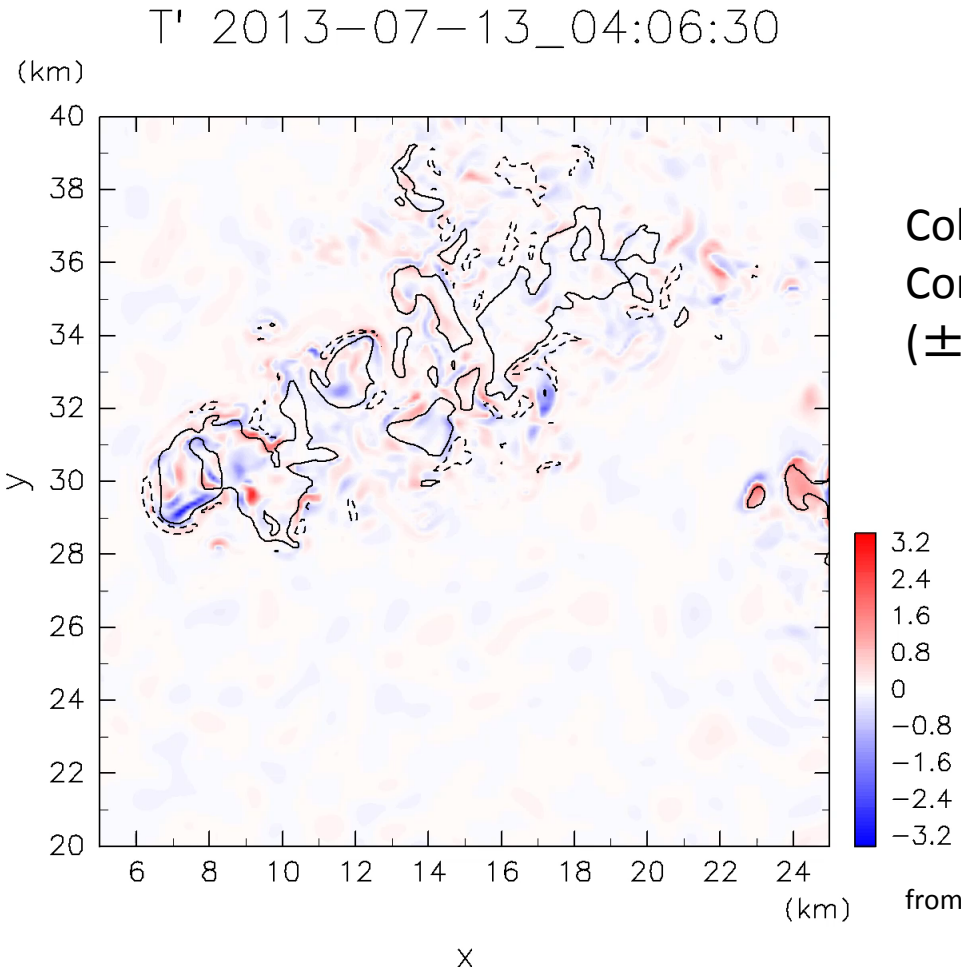
Time series of Potential Temperature perturbation (z = 5 km)



from Otsuka and Miyoshi (2015, in prep.)

Spatial pattern of Temp. bred vectors at 5 km

- 30-second cycle (enlarged view)



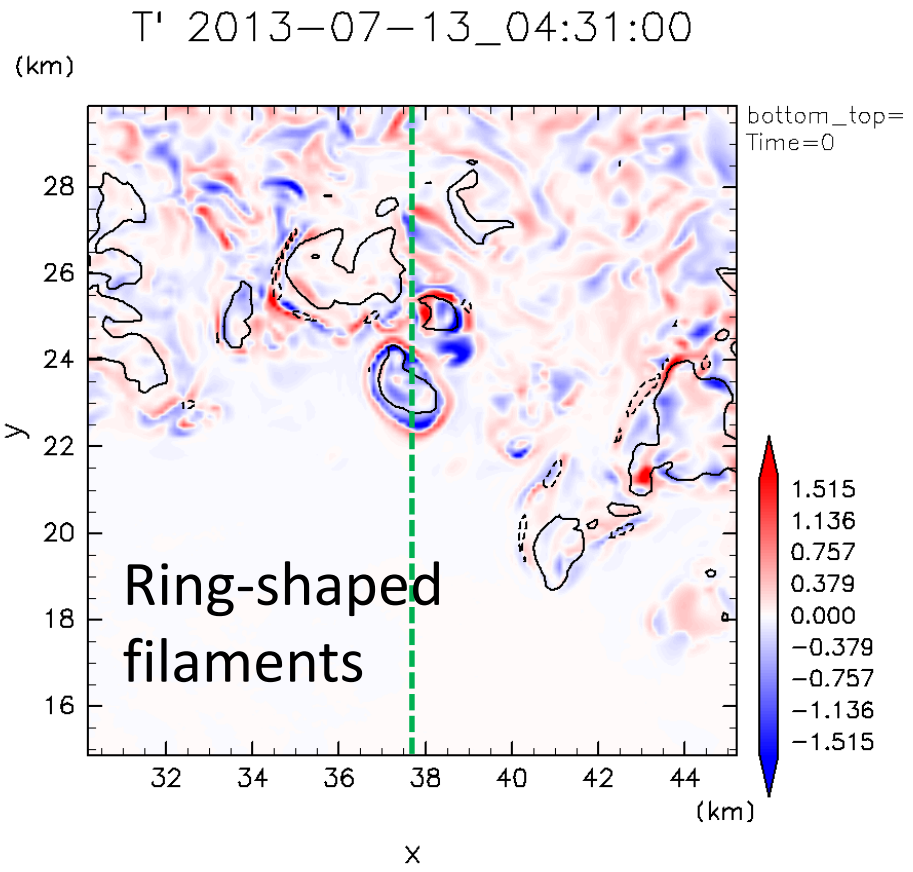
Ring-shaped filaments around conv. cores

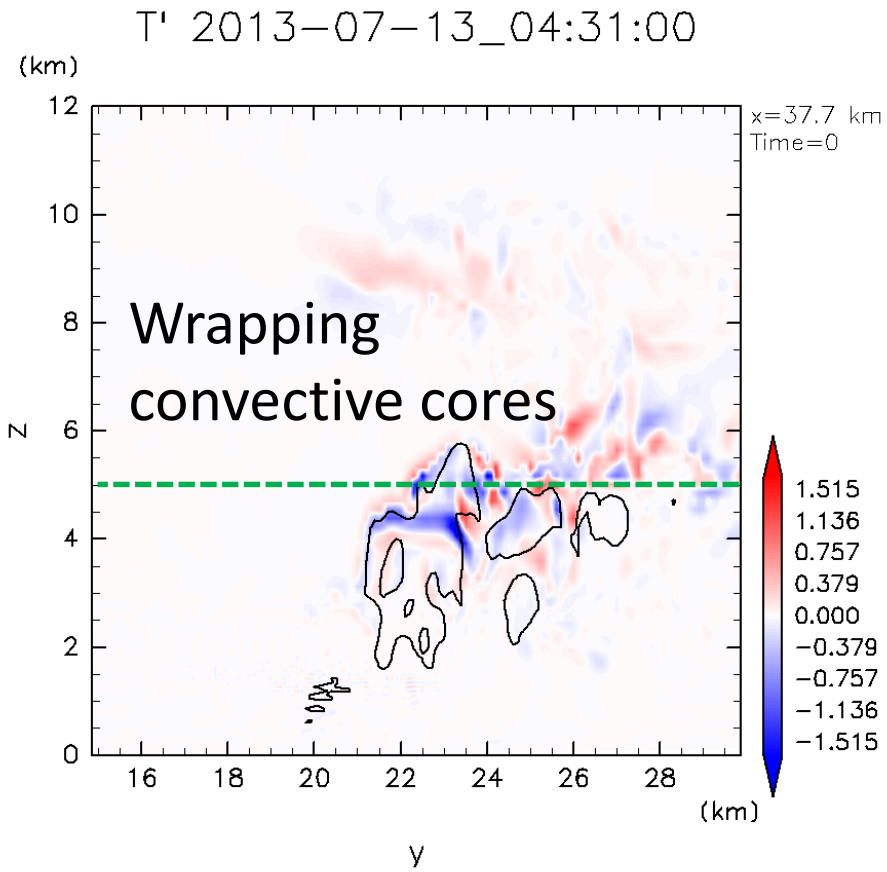
Spread away from conv.

Color: θ’
Contour: vertical winds (±5 m/s)

from Otsuka and Miyoshi (2015, in prep.)

Spatial structure of bred vectors





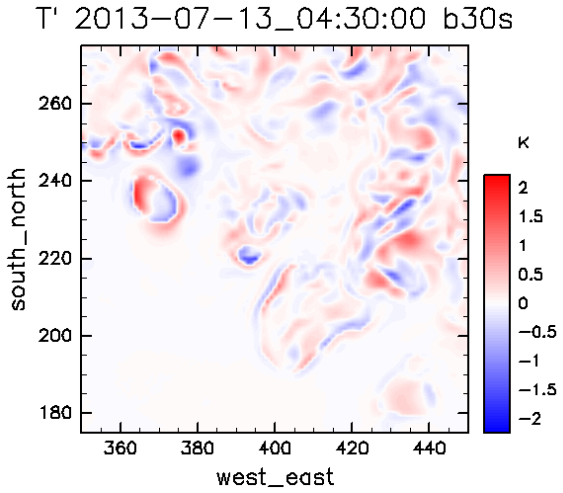
- 30-s cycle
- Contour: vertical winds (±5 m/s)

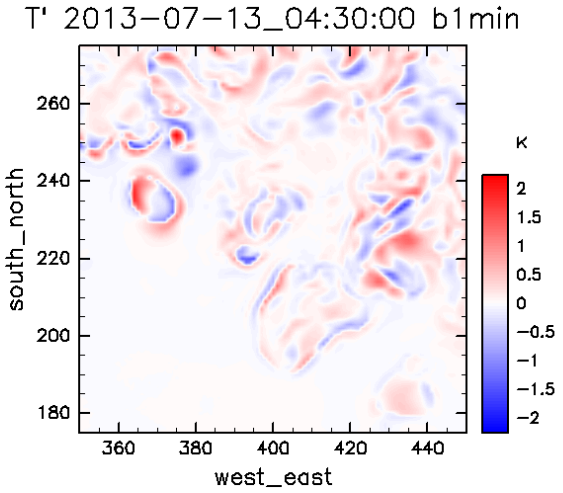
from Otsuka and Miyoshi (2015, in prep.)

Different breeding intervals

All similar: ring-shaped filaments

30 seconds

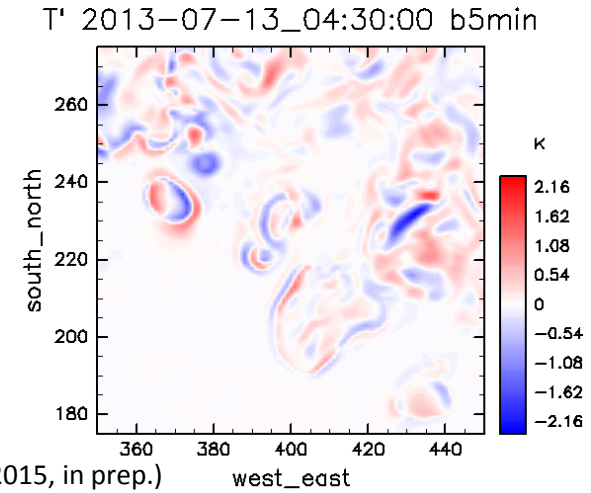


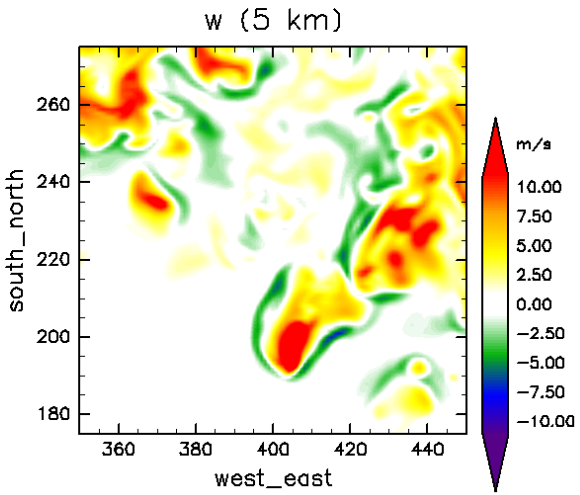


1 minute

Potential Temp. bred vectors at 5 km

5 minutes



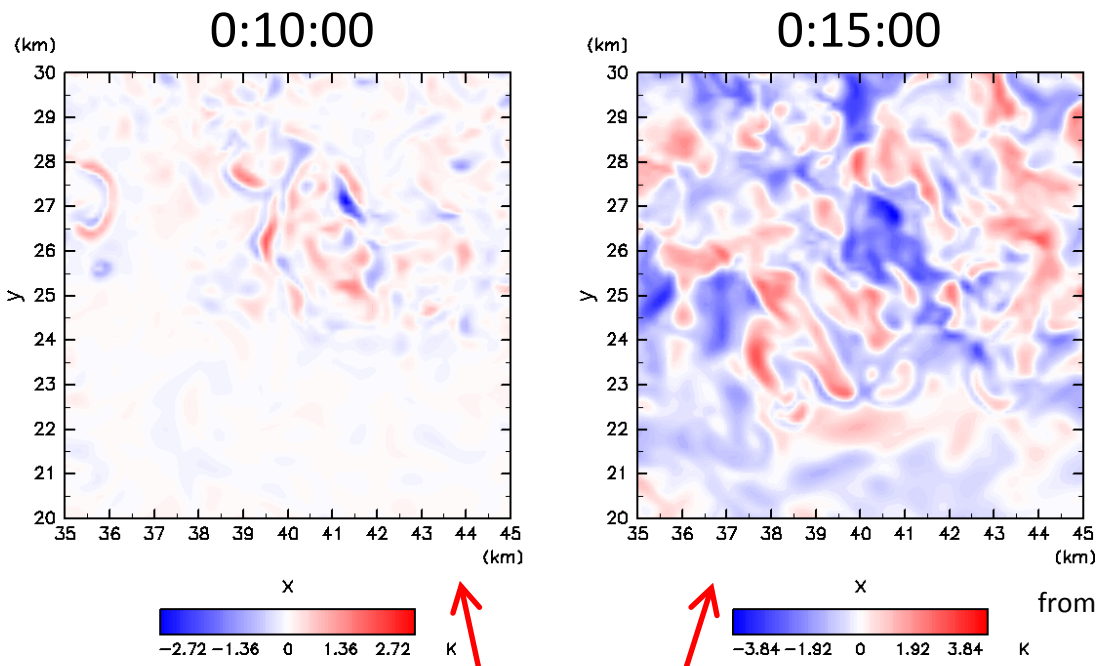


Vertical winds

from Otsuka and Miyoshi (2015, in prep.)

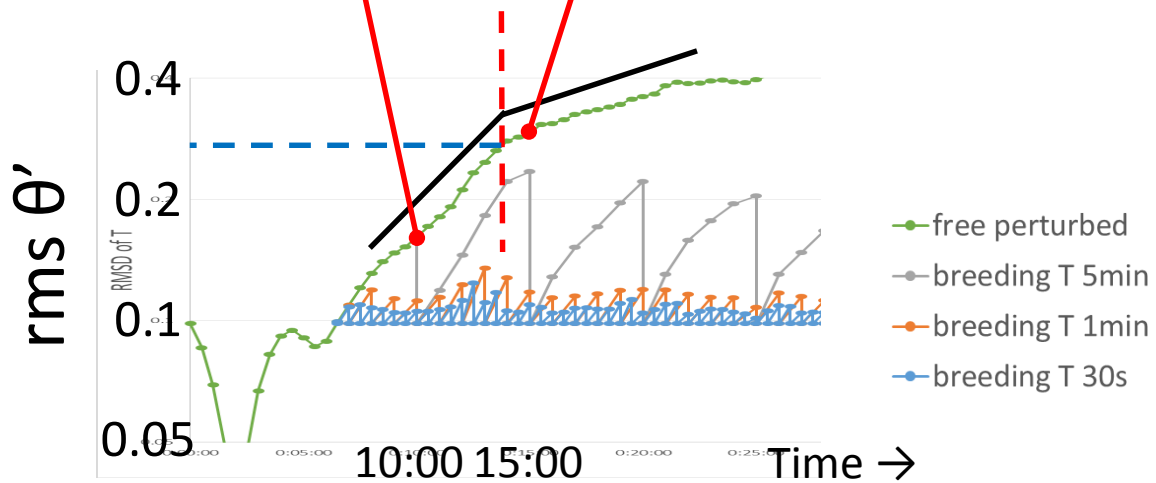
Perturbations in the free run

Ring-shaped filaments



Different structure

from Otsuka and Miyoshi (2015, in prep.)



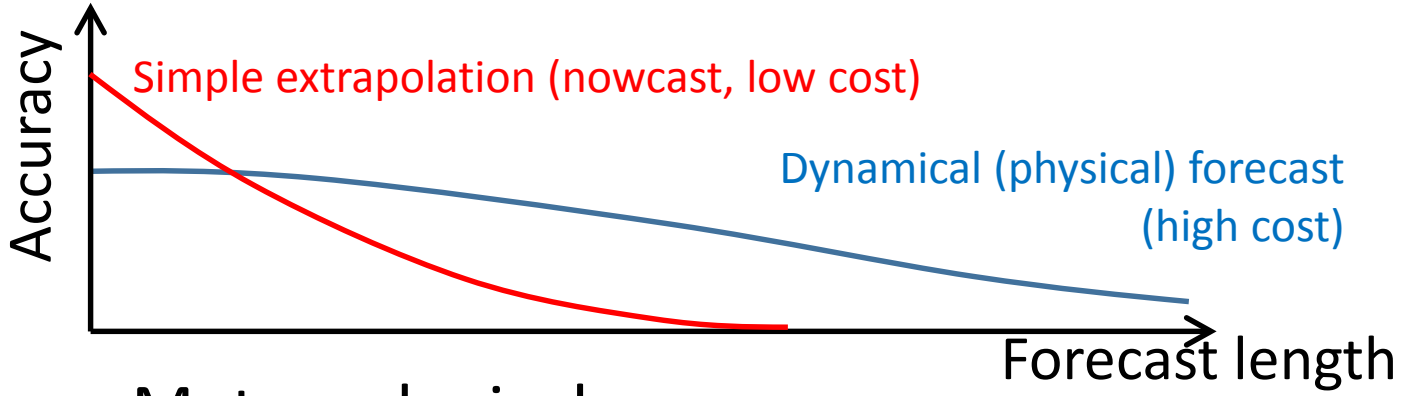
Summary of breeding experiments

- Bred vectors at a 100-m resolution with a 30-second interval
  - Ring-shaped filaments at the edge of newly developing convective cells
  - Spread away from the convective cells
- Similar bred vectors with 30-s, 1-min, and 5-min intervals
  - may depend on the rescaling factor, not the interval
- Future plan
  - Deferent rescaling factor, lineality, dependence on initial perturbation

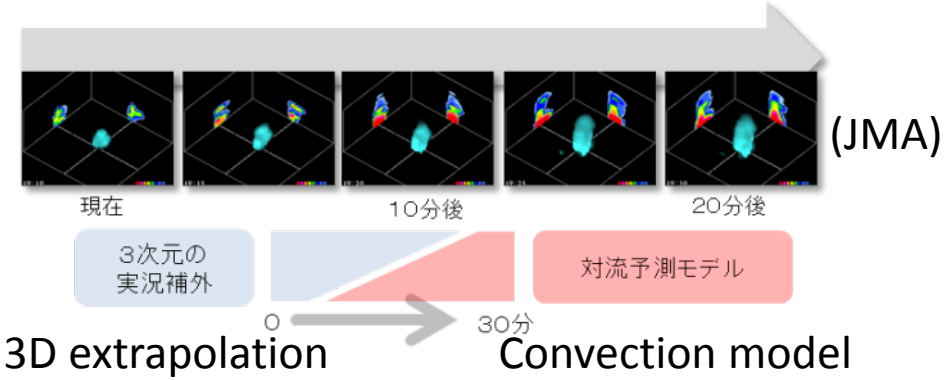
Nowcasting experiments

Background

- Nowcast outperforms dynamically-based forecast in short range precipitation forecast

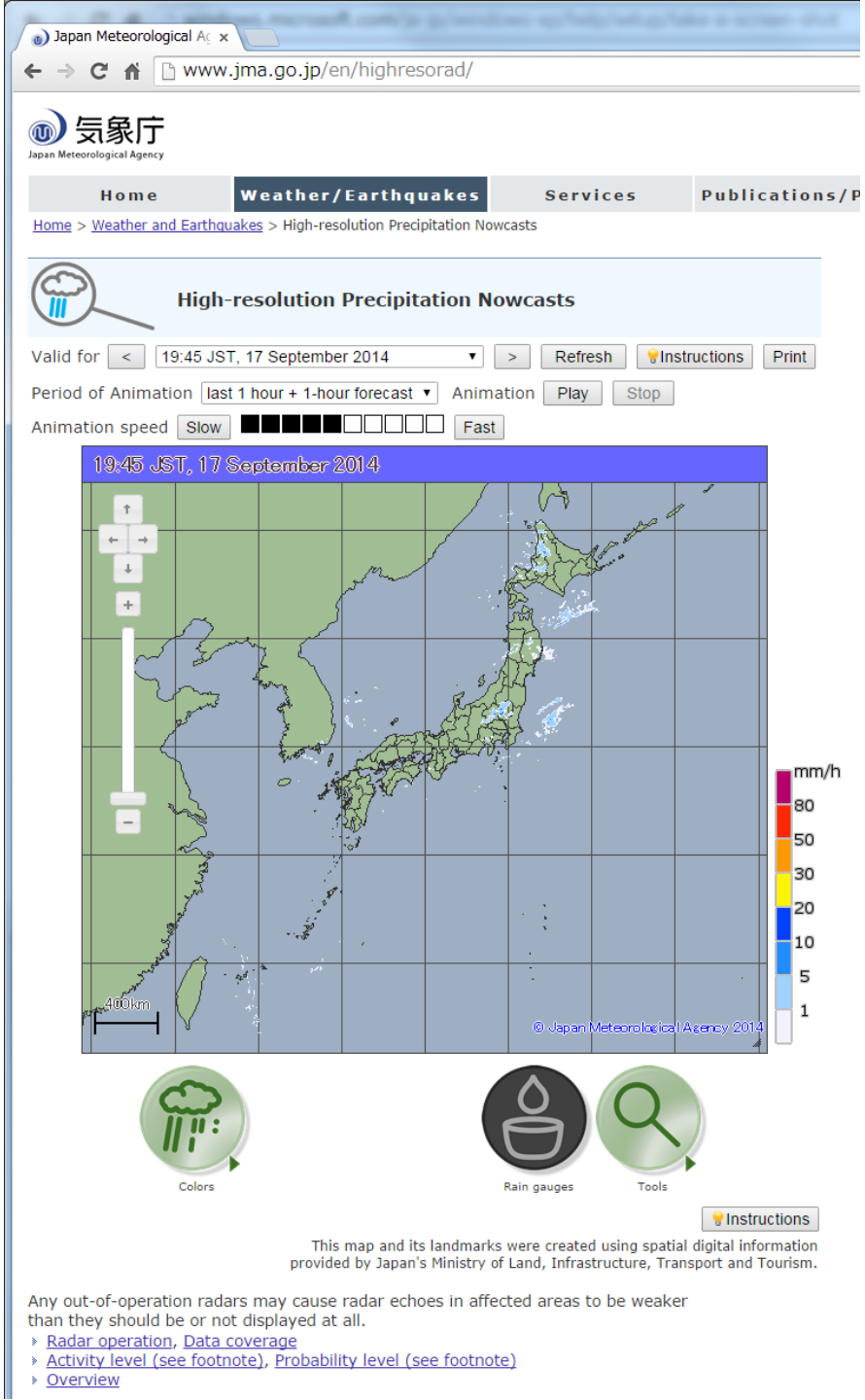


- Japan Meteorological Agency (JMA) combines simple extrapolation and convection model for short-range nowcast



Background

- JMA 3D High-resolution Precipitation Nowcasts
- Recently updated
  - 250 m resolution
  - 2D → 3D
- Still based on conventional radars
  - 5 min interval
  - Difficulties in capturing rapid development of convections



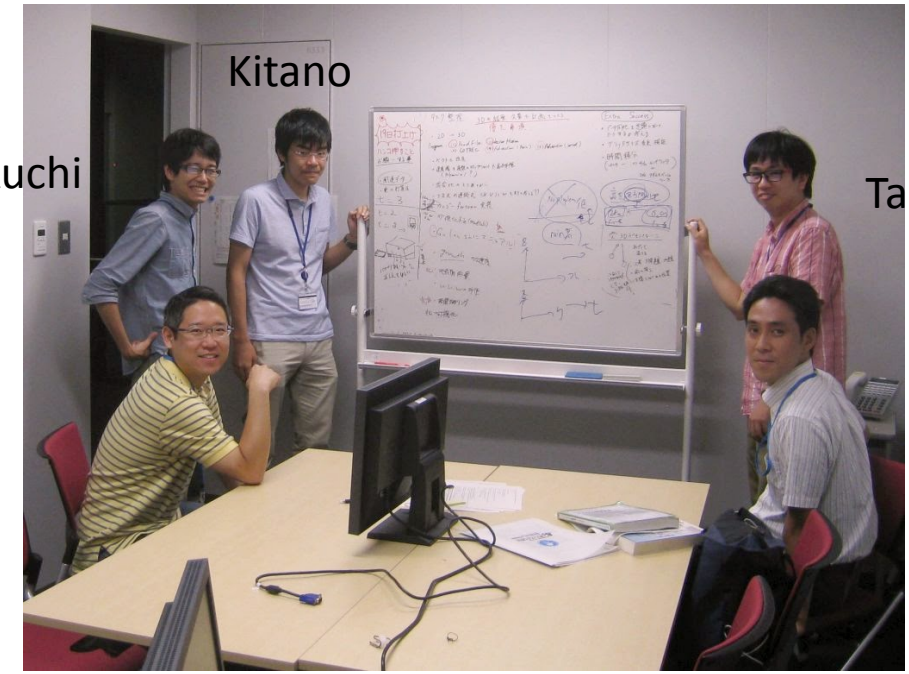
Our aim

- Fully utilize the new super-rapid PAWR
  - 100-m resolution 3D volume scan every 30 seconds
  - PAWR can capture high-precision 3D rain motion
- High-precision forecasts with a few minute lead
  - Purely based on PAWR data

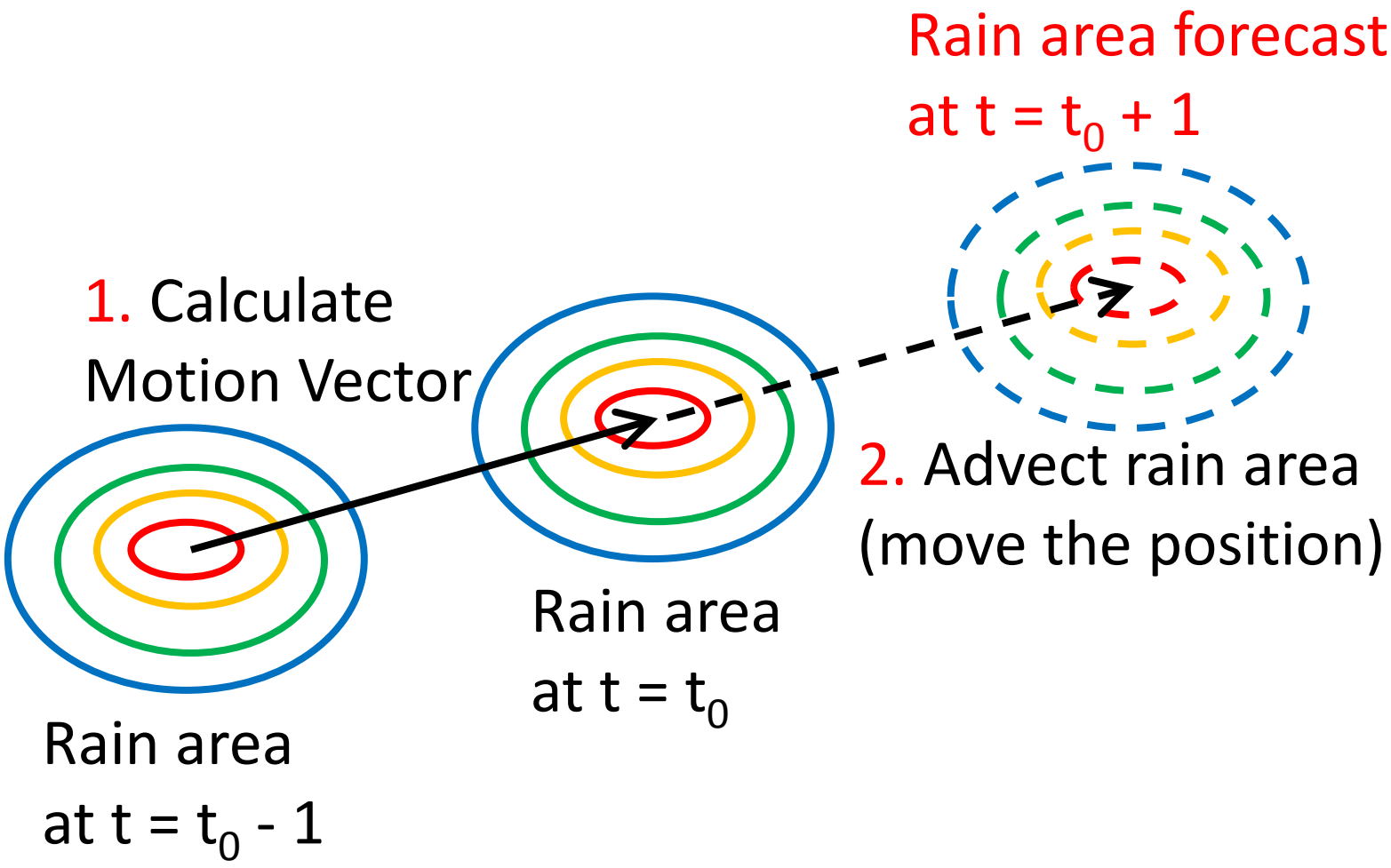
Development of rain extrapolation system

AICS HPC Internship program 2014

- Three intern students stay 29 Aug to 19 Sep
  - R. Kikuchi (Tohoku Univ.)
  - Y. Kitano (Hokkaido Univ.)
  - Y. Taniguchi (Univ. of Hyogo)



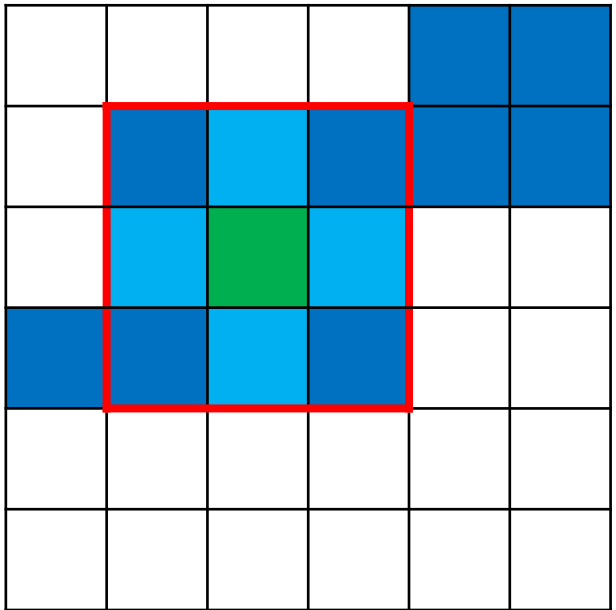
Basic idea of rain extrapolation

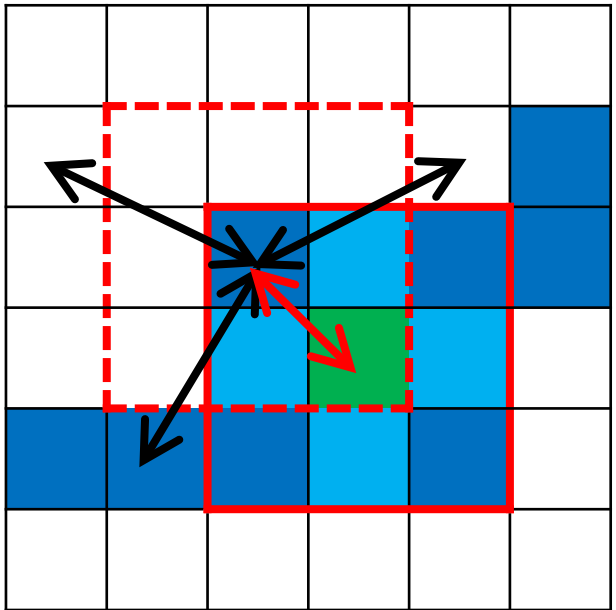


Motion vector

- A TREC (Tracking Radar Echoes by Correlation)-based method
- Find the most similar pattern between two consecutive radar images
  - Correlation coefficient, mean absolute difference

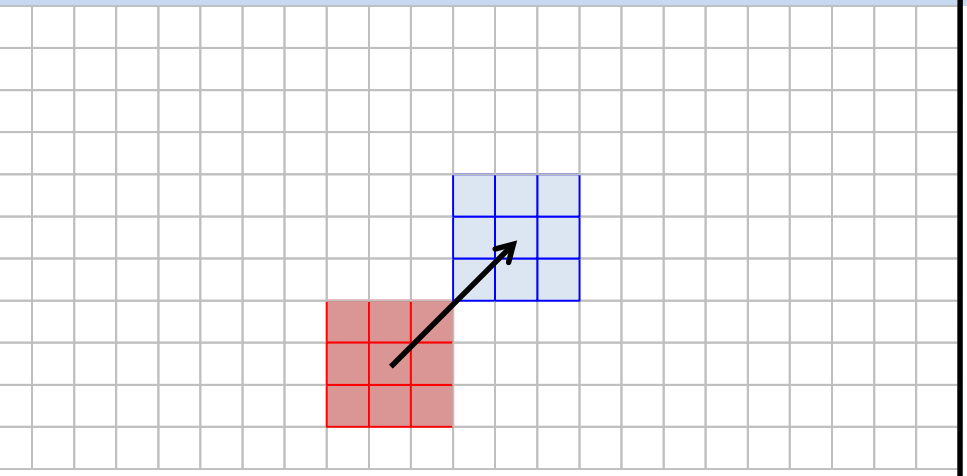
$t = t_0 - 1$





$t = t_0$

TREC



- Determine motion vector based on spatial similarity (correlation and so on).

- Vector components become integer (not smooth)

COTREC

- Smoothing method
- Outcome must
  - be close to original vectors.
  - satisfy continuity equation.

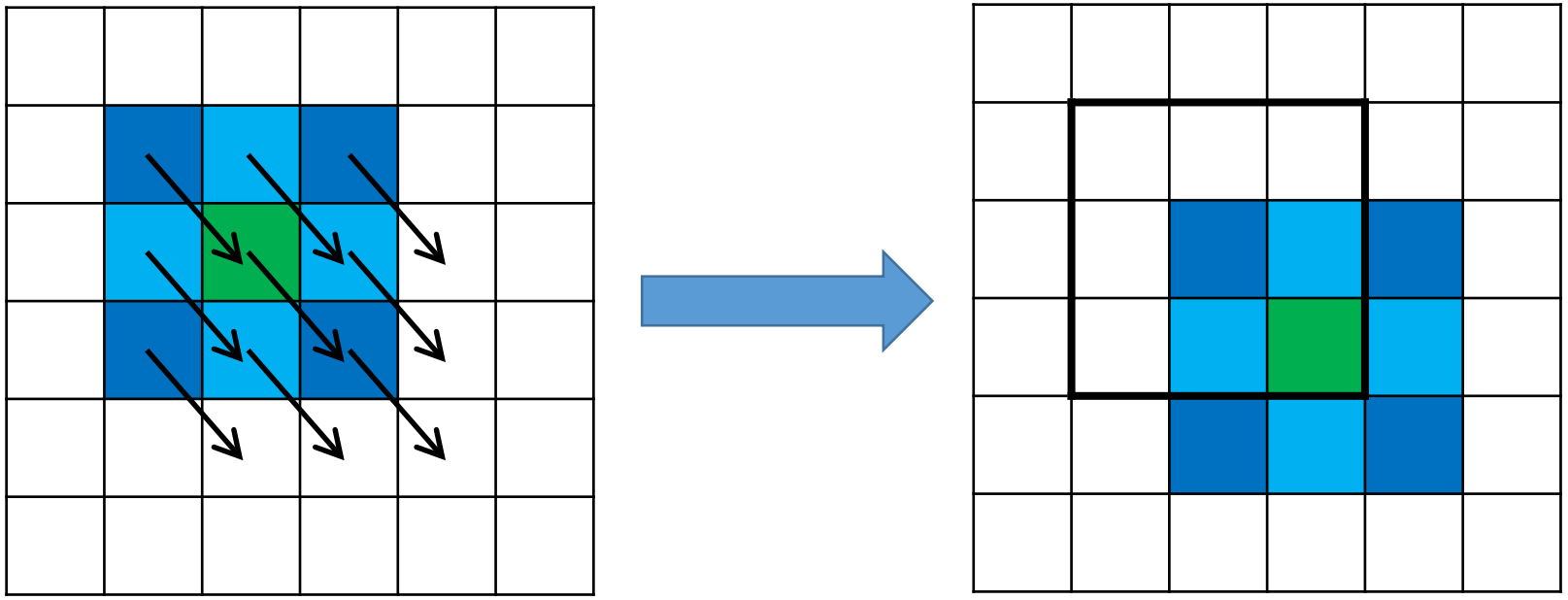
- calculate λ to minimize equation

$$\int \left[(u-u_0)^2 + (v-v_0)^2 + \lambda\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial x}\right) \right] dxdy$$

Where (u_0, v_0) are inputs and (u, v) are outputs.

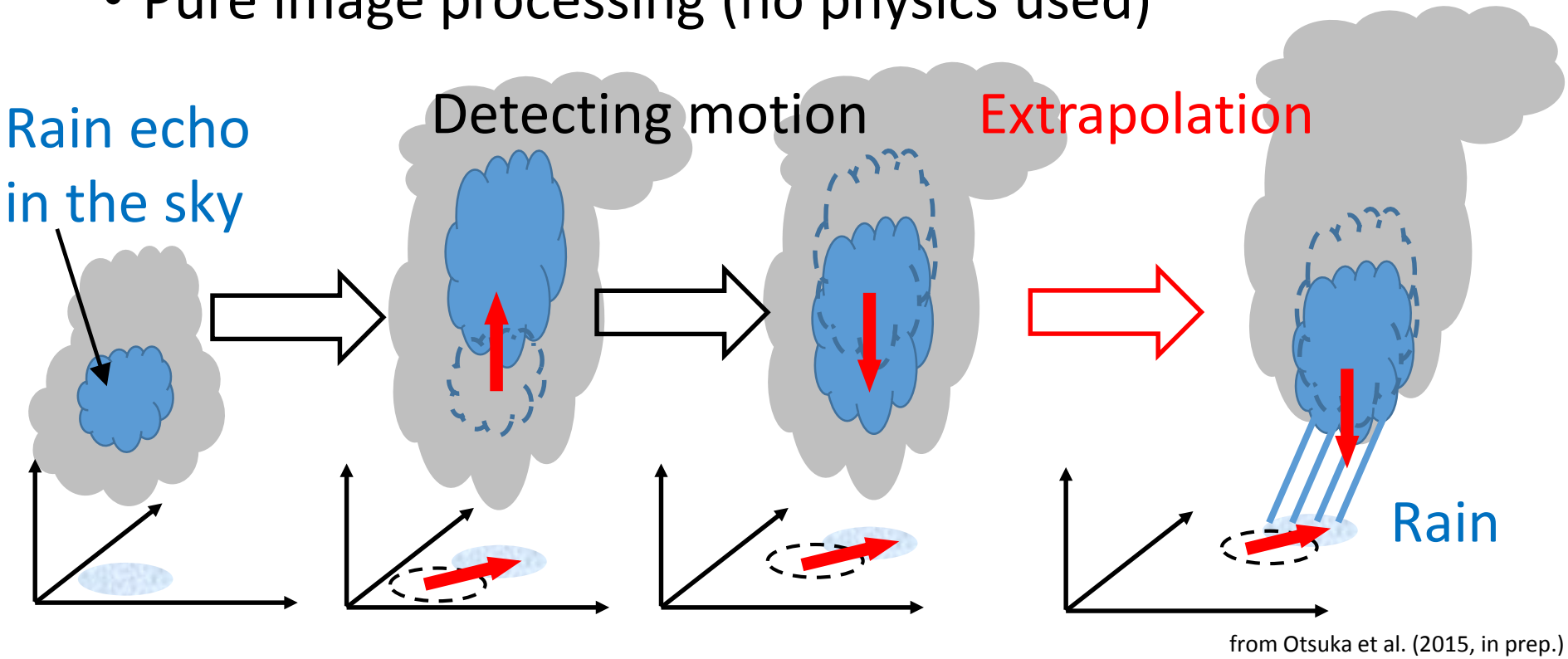
Advection

- Rain distribution is moved by the motion vector
  - Weighted Essentially Non-Oscillatory scheme (WENO)
  - 2nd order Adams-Bashforth
- Motion vector field is also advected

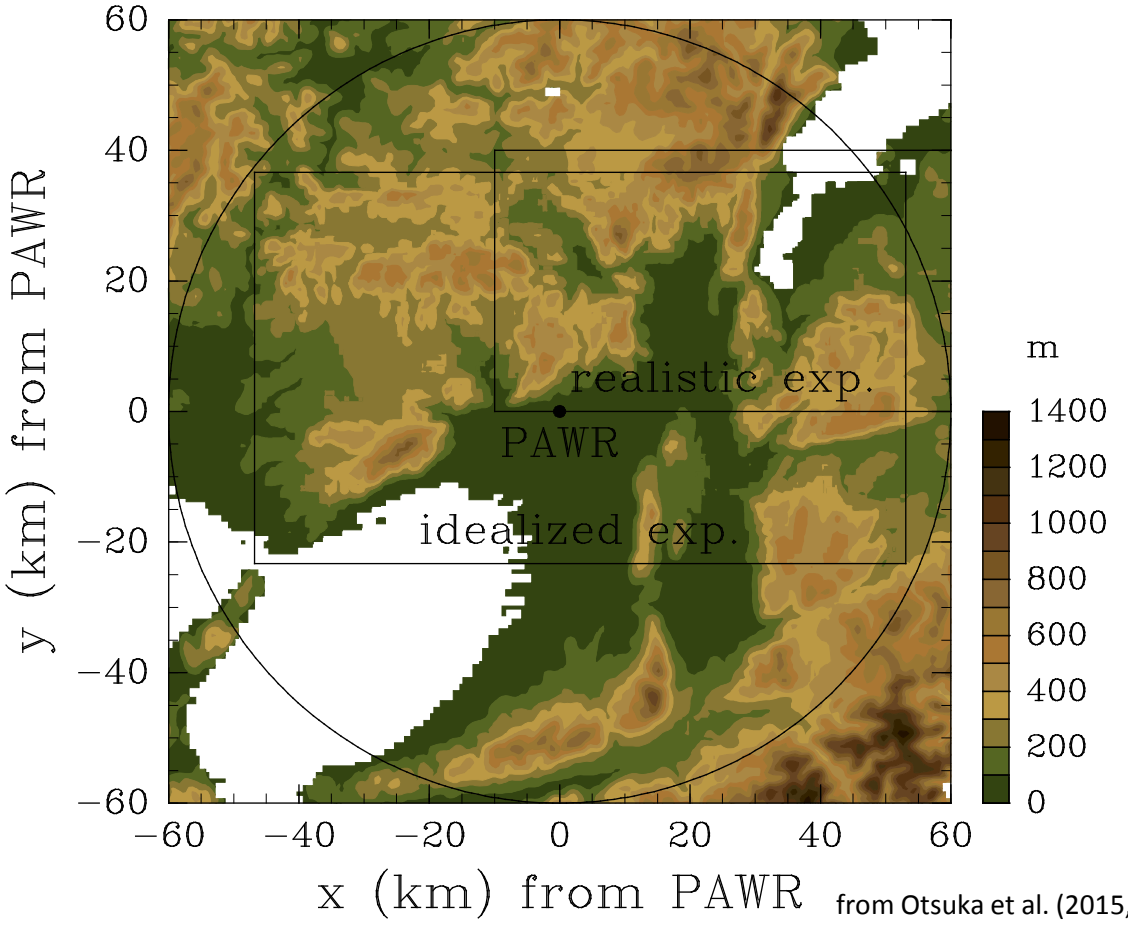


2D vs. 3D

- 3D motion extrapolation (assuming persistence)
- Pure image processing (no physics used)



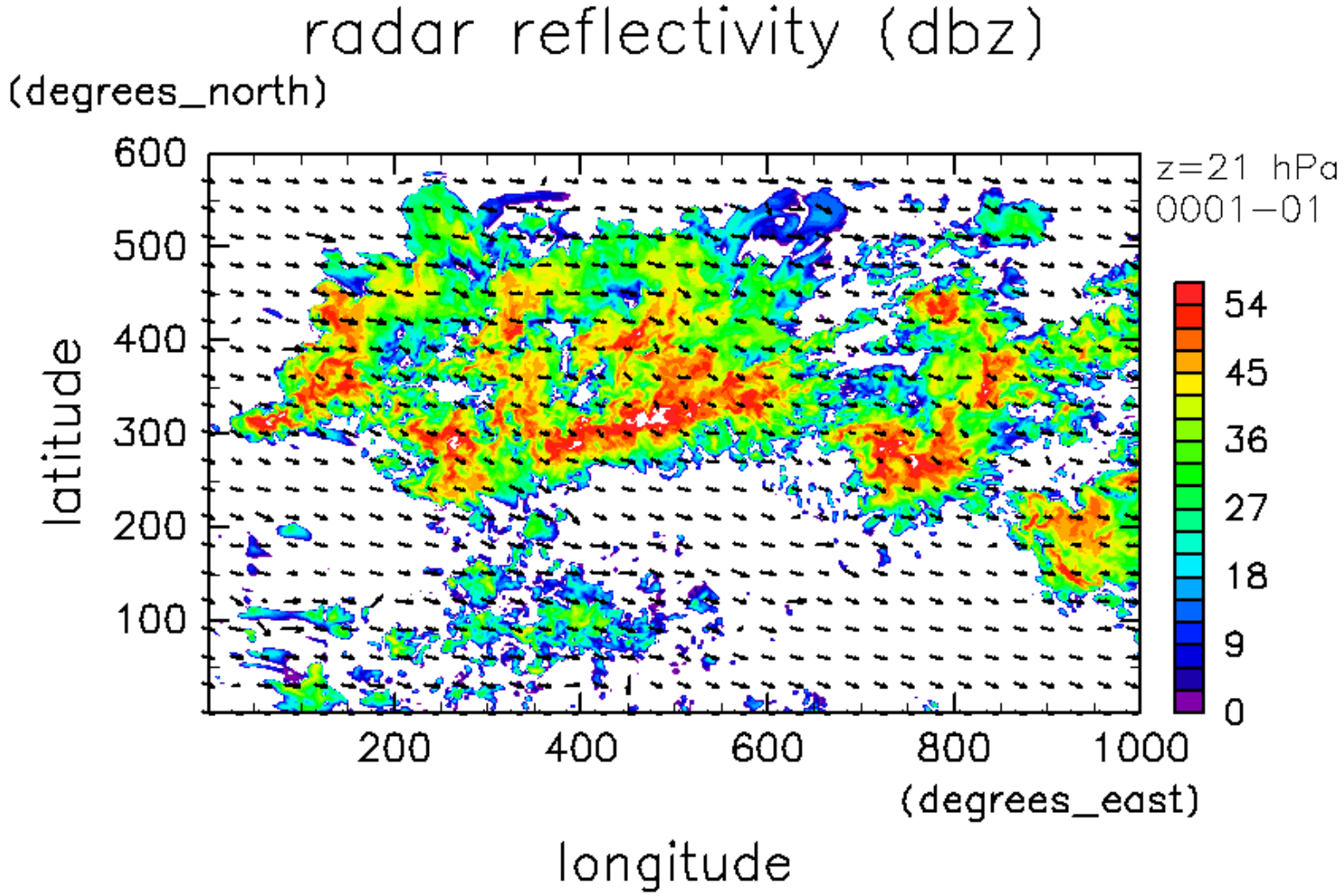
Computational domains of realistic and idealized experiments



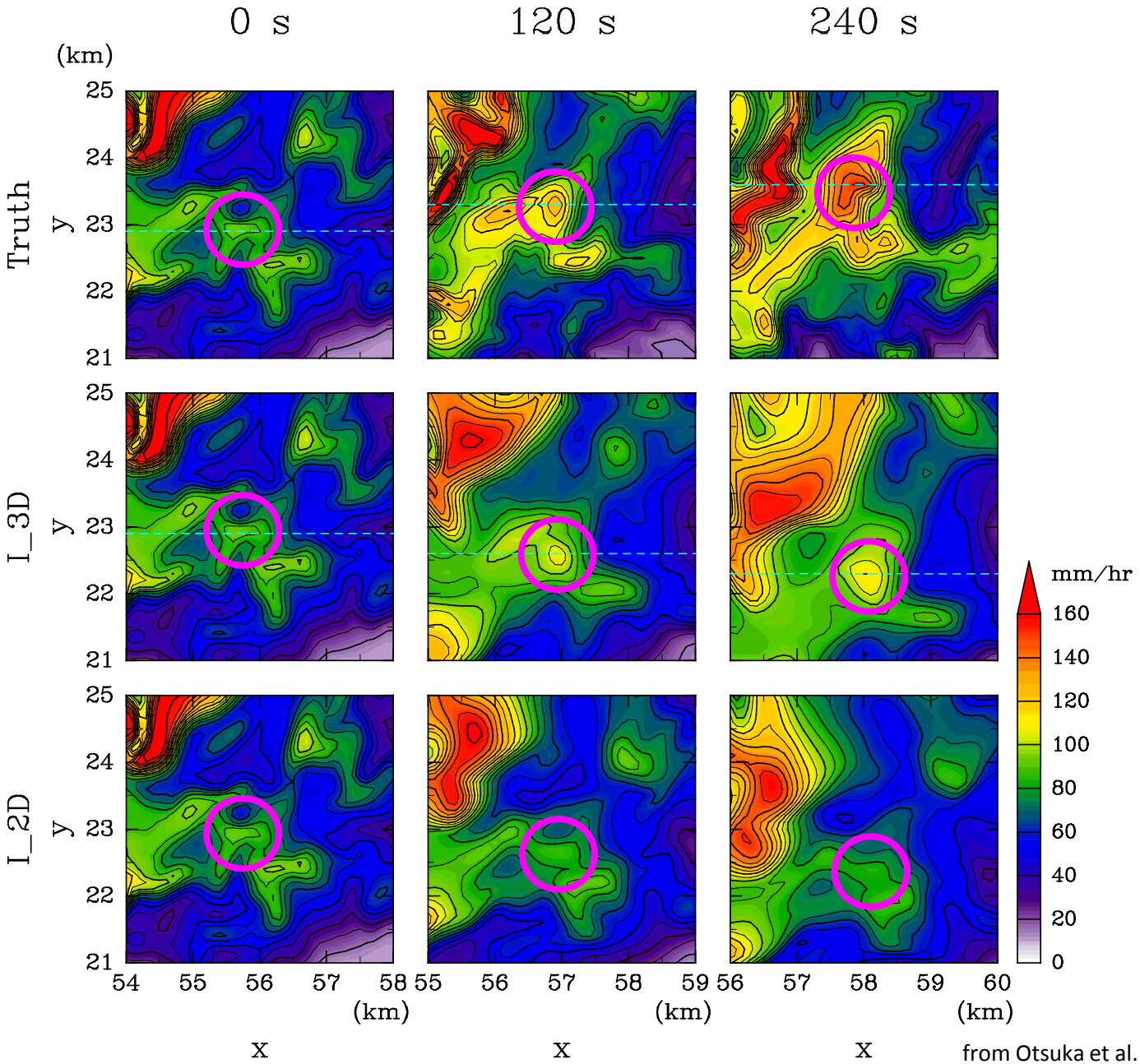
from Otsuka et al. (2015, in prep.)

Results of
2D & 3D extrapolation

Result of idealized experiments (3D extrapolation)

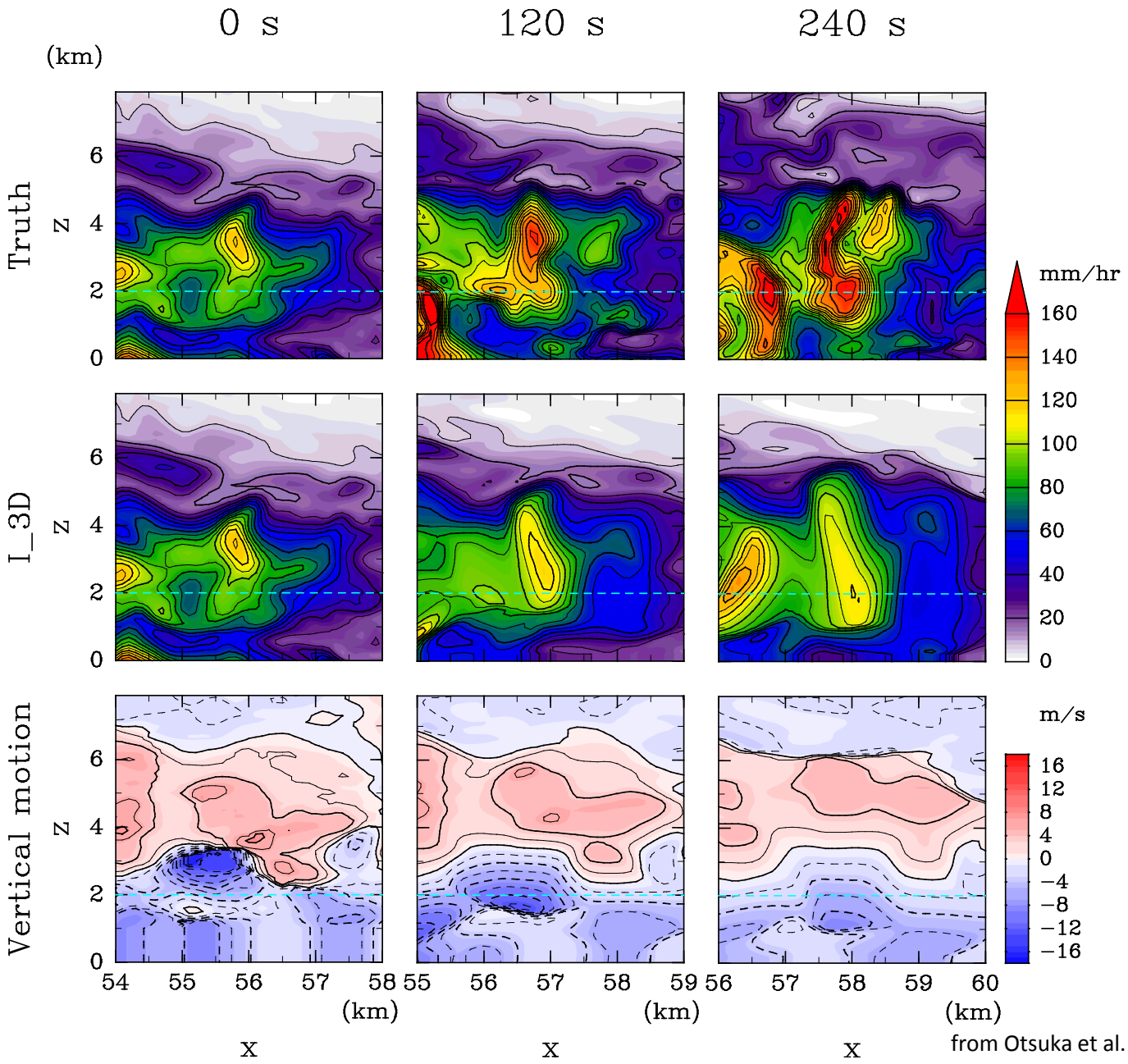


Horizontal maps of rain rate at z = 2 km



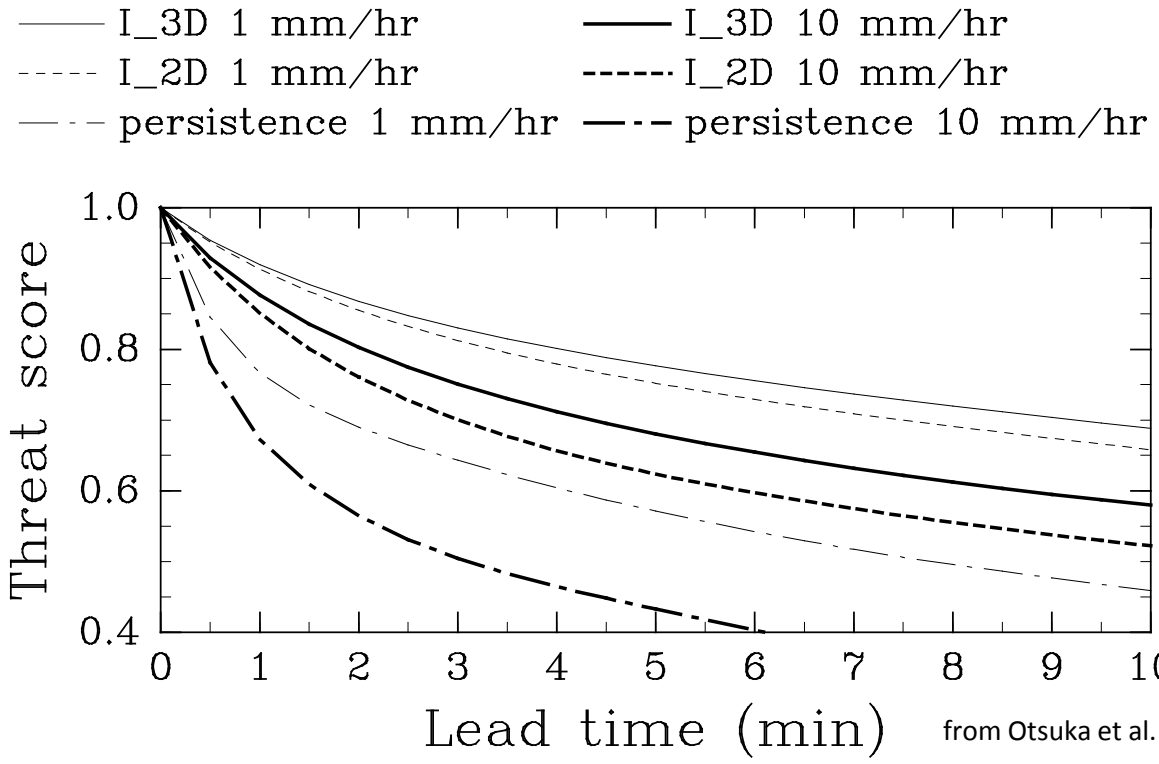
from Otsuka et al. (2015, in prep.)

Vertical cross sections



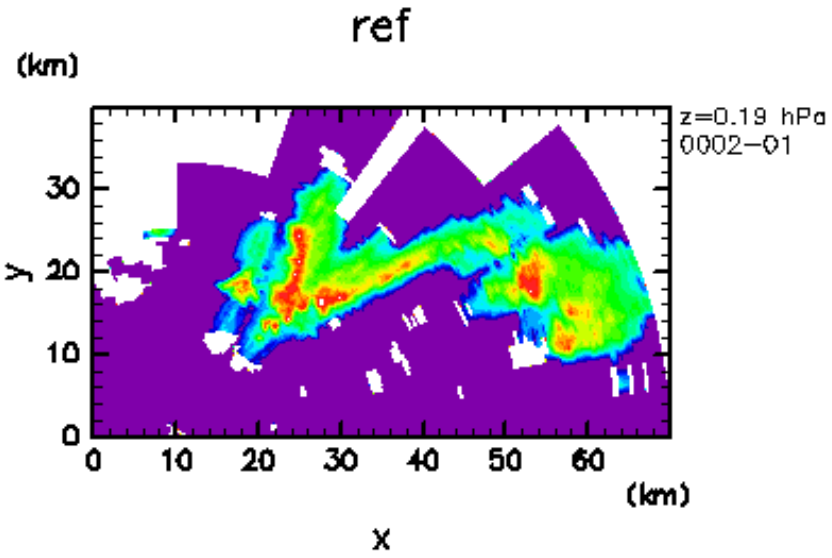
from Otsuka et al. (2015, in prep.)

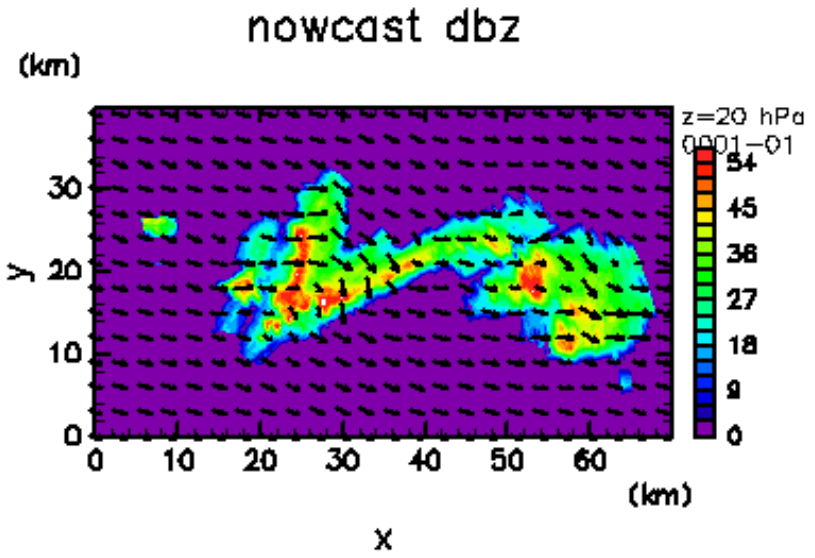
Threat scores



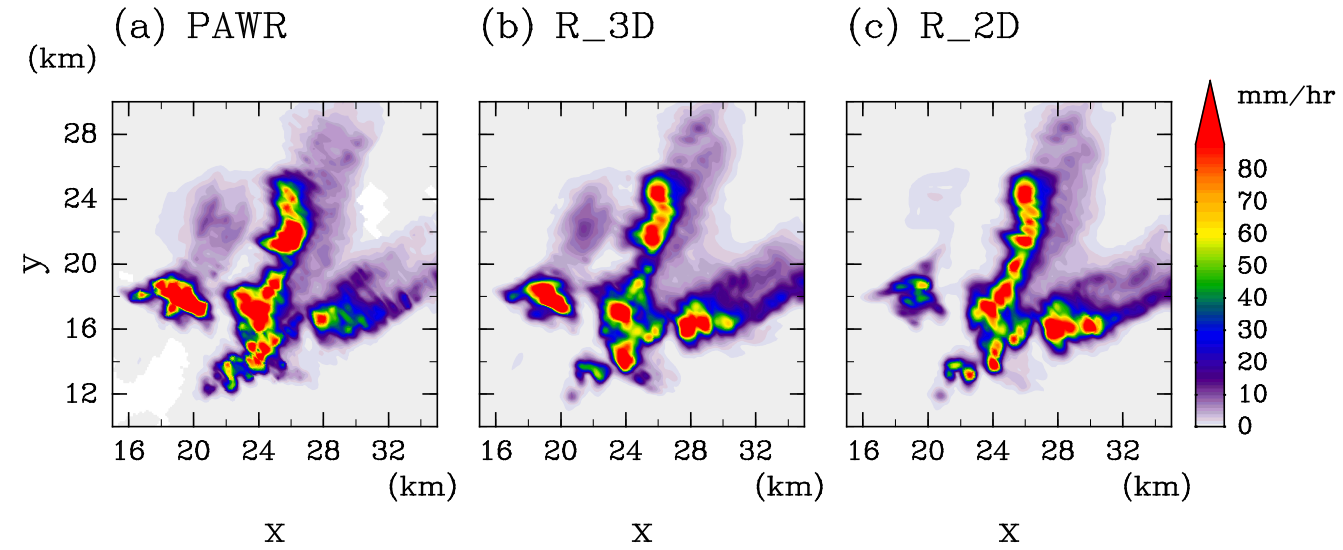
from Otsuka et al. (2015, in prep.)

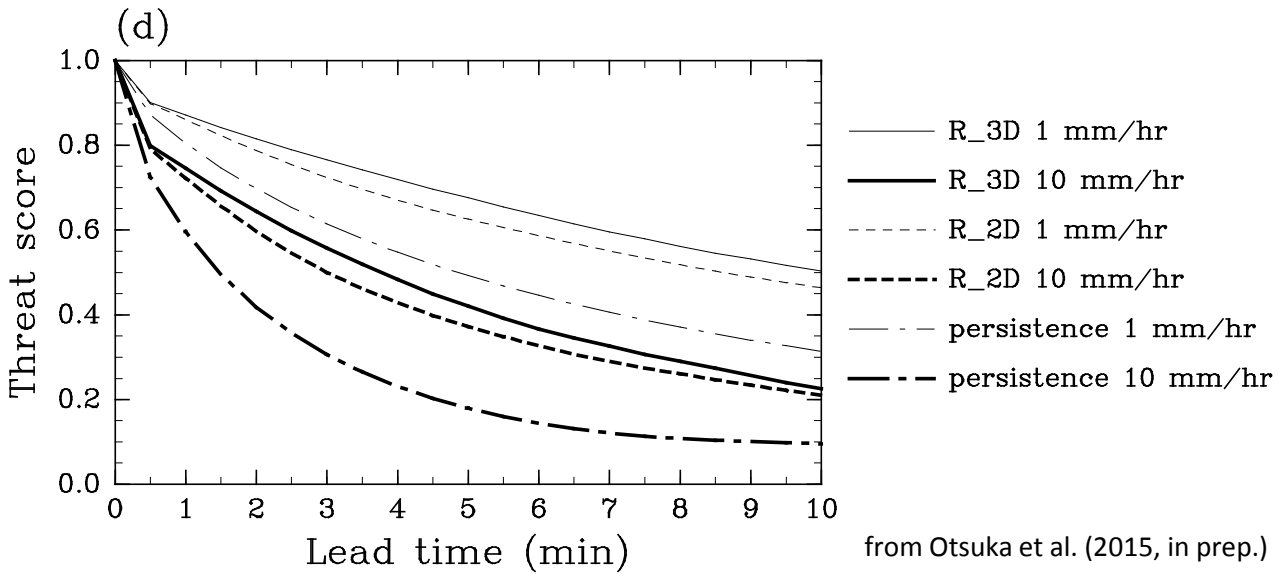
Result of realistic experiments (observation / 3D extrapolation)





Horizontal maps of rain rate / threat scores





from Otsuka et al. (2015, in prep.)

Summary of 3D nowcasting

- The super-rapid PAWR can perform 100-m resolution 3D volume scan every 30 seconds
- The intern students successfully developed a super-rapid 3D rain extrapolation system
- The system successfully captures precise 3D motion of rain and improved the forecasts with a few minutes lead