Three-dimensional Precipitation Data Measured by Phased Array Weather Radar Every 30 Seconds

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Remote Sensing Laboratory,
Applied Electromagnetic Research Institute,
National Institute of Information and Communications Technology (NICT), Koganei, Tokyo

Self-introduction

Who am I?

1990-1995 Graduate student and JSPS fellowship
in Inst. of Low Temp. Sci, Hokkaido Univ.

1995-1998 Communications Research Lab.(CRL)
- Dev of airborne multiparameter radar (CAMPR)
- TRMM PR data analysis system

1998-2000 Visiting res. scientist, Univ. Oklahoma
- Bistatic Doppler radar network

2000-2002 CRL
- Dev of CRL Okinawa Bistatic Radar (COBRA)
- TRMM PR latent heating algorithm (PI)

2002-2004 NASDA/EORC & JAXA/GPMDPR team
- Dev of GPM/DPR

2004-(current) NICT
> 2005-2007 Director of NICT Okinawa Center
> 2011-2012 AER planning office
> 2016- Research Manager

- COBRA, WPR/RASS (2004-2008)
- Dev of Phased Array Weather Radar (2008-2012)
- Introduction of PANDA in Kobe & Okinawa (2014)

Dr. Shinsuke Satoh

(National Institute of Information and Communications Technology)

Shinsuke Satoh received the Doctor of Science degree from Hokkaido University in 1994. He joined National Institute of Information and Communications Technology (NICT) in 1995. He was a visiting research scientist with School of Meteorology, University of Oklahoma from 1998 to 2000. He worked in Japan Aerospace Exploration Agency (JAXA) from 2002 to 2004. He was a director of NICT Okinawa Subtropical Environment Remote-Sensing Center from 2005 to 2007. He is currently a research manager in Remote Sensing Laboratory, NICT. His research specialties are weather radar remote sensing and radar meteorology. He was involved in system development for bistatic Doppler radar (COBRA), space-borne precipitation radar (GPM/DPR), and phased array weather radar (PAWR).

COBRA

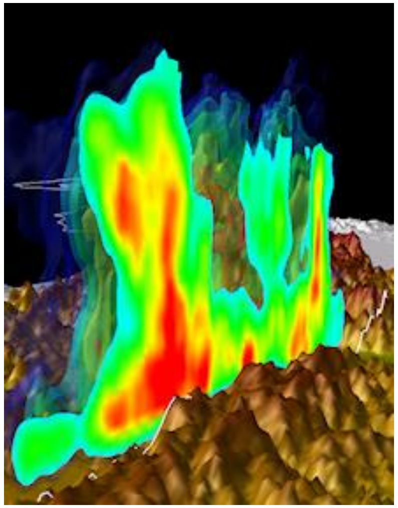
CRL 航空機搭載マルチ
パラメータレーダ (CAMPR)

400 MHz WPR/RASS

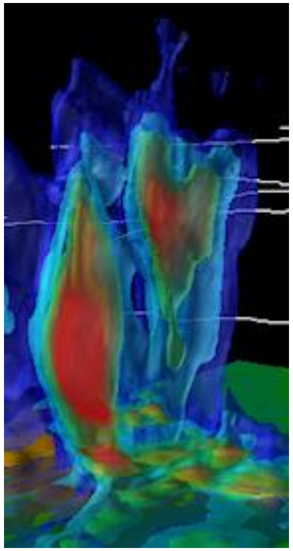
GPM core satellite

Contents

1. Introduction
   - What is the Phased Array Weather Radar (PAWR)?
   - Comparison of conventional radar and PAWR



2. Three-dimentional structure of precip
   - 3D visualization of localized heavy rainfalls from a cumulonimbus cloud and a rain band
3. Growth of precip and vertical motion
   - 3D TREC and dual-Doppler analysis
4. Real-time application of PAWR data
   - Expectation for Big Data Assimilation (BDA)
   - 3D nowcasting and smartphone application



5. Real-time data quality control (QC)
   - QC flags in some cases

Introduction

- In recent years, severe weather disasters caused by localized heavy rainfalls or tornadoes have occurred frequently in various parts of Japan.
- We developed a X-band Phased Array Weather Radar (PAWR) to watch and predict the severe weather. The PAWR measures 3-dimentional fine structure of rainfall with 100 m range resolution and 100 elevation angles every 30 seconds.
- The first PAWR was installed at Osaka University, Suita in 2012. The second and third PAWRs were install at NICT Kobe and NICT Okinawa in 2014, respectively.

Flash flood at Toga River in Kobe city (28 July 2008)

Tsukuba Tornado (6 May 2012)

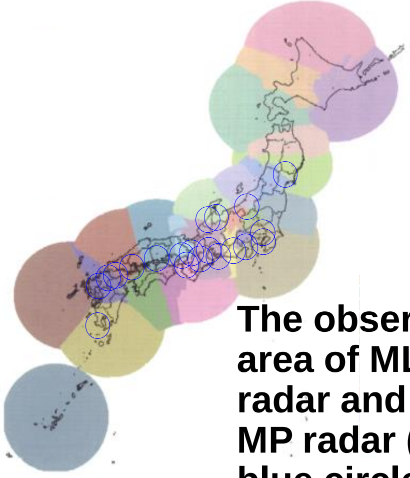
Suita in 2012

Kobe in 2014

Okinawa in 2014

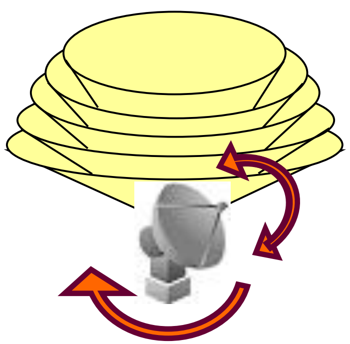
MRI@ Tsukuba in 2015

MP-PAWR Saitama in 2017



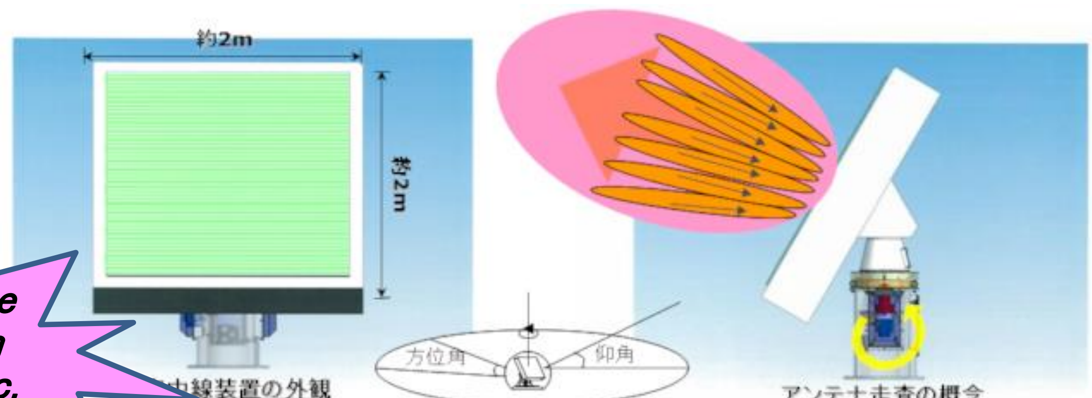
The observation area of MLIT C-band radar and X-band MP radar (small blue circles).

Phased Array Weather Radar (PAWR)



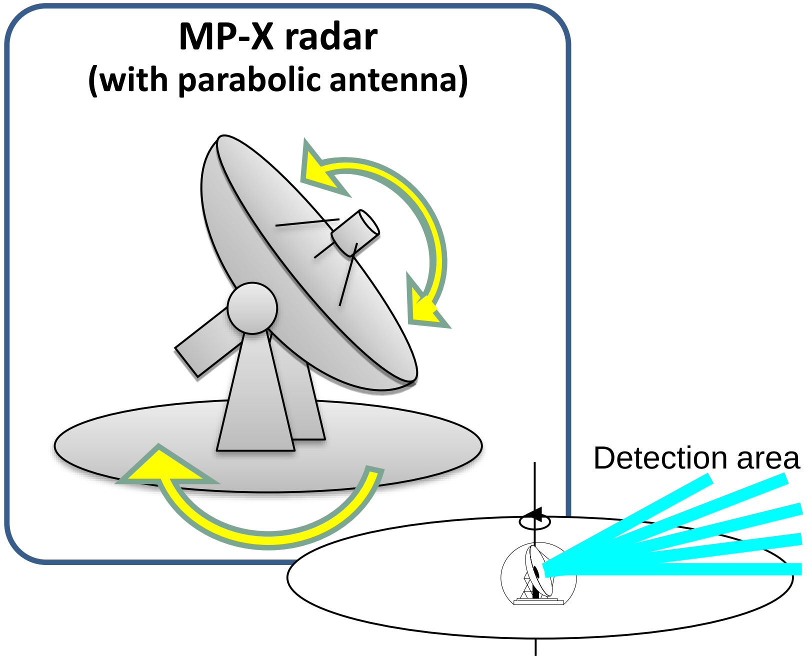
3-dim measurement using a parabolic antenna (150 m, 15 EL angles in 5 min)

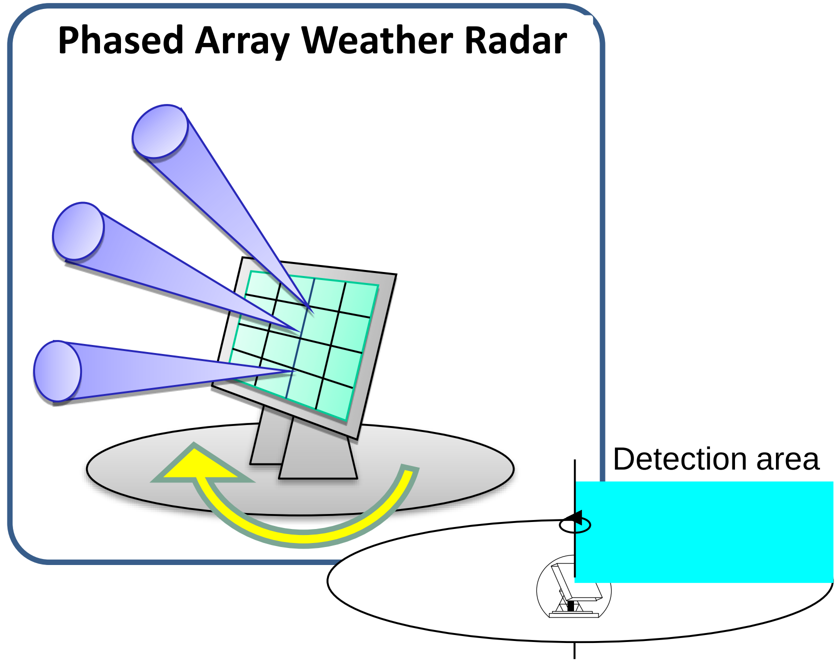
3-dim. dense observation every 30 sec.



3-dim measurement using 128 slot-array antennas with fan-beam transmitting and DBF receiving. (100 m, 100 EL angles in 30 sec)

Comparison of MP-X and PAWR

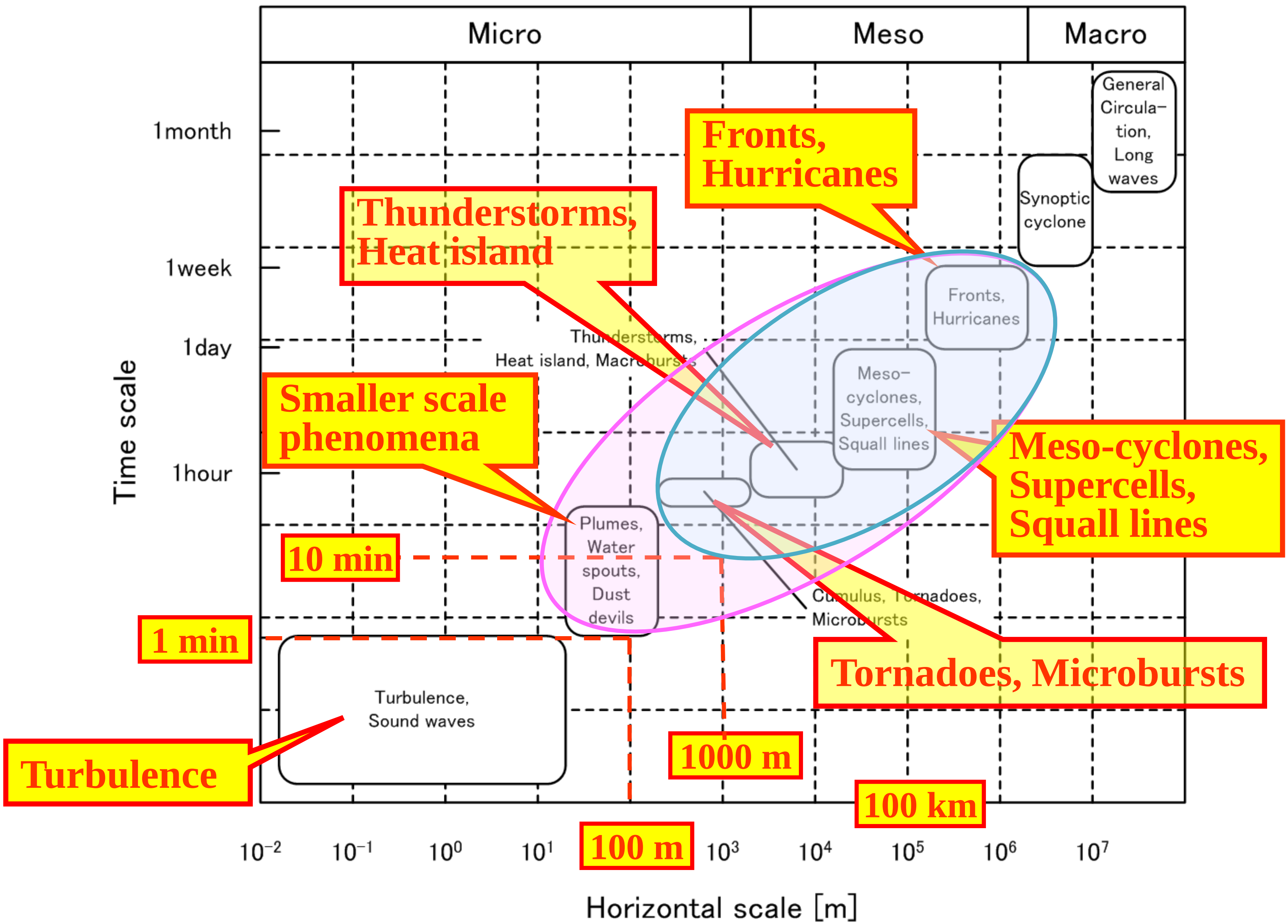




XRAIN (39 radars in Japan)		PAWR (4 radars in Japan)
Parabolic dish antenna (2 m diameter) with mechanical EL and AZ scanning	Antenna	Flat antenna (128 elements slot array) with electronic EL scanning and mechanical AZ scanning
5 minutes for 3D scan (15 EL angles) 1 minutes for a rain map (3 EL angles)	Observation cycle	30 seconds for 3D scan (100 EL angles)
80 km in radius	Observation range	60 km in radius
Reflectivity (Ze), Doppler velocity (Vr), velocity width (W), and polarization parameters (Zdr, ϕdp, ρHV)	Observation parameters	Reflectivity (Zh), Doppler velocity (Vr), and velocity width (W)

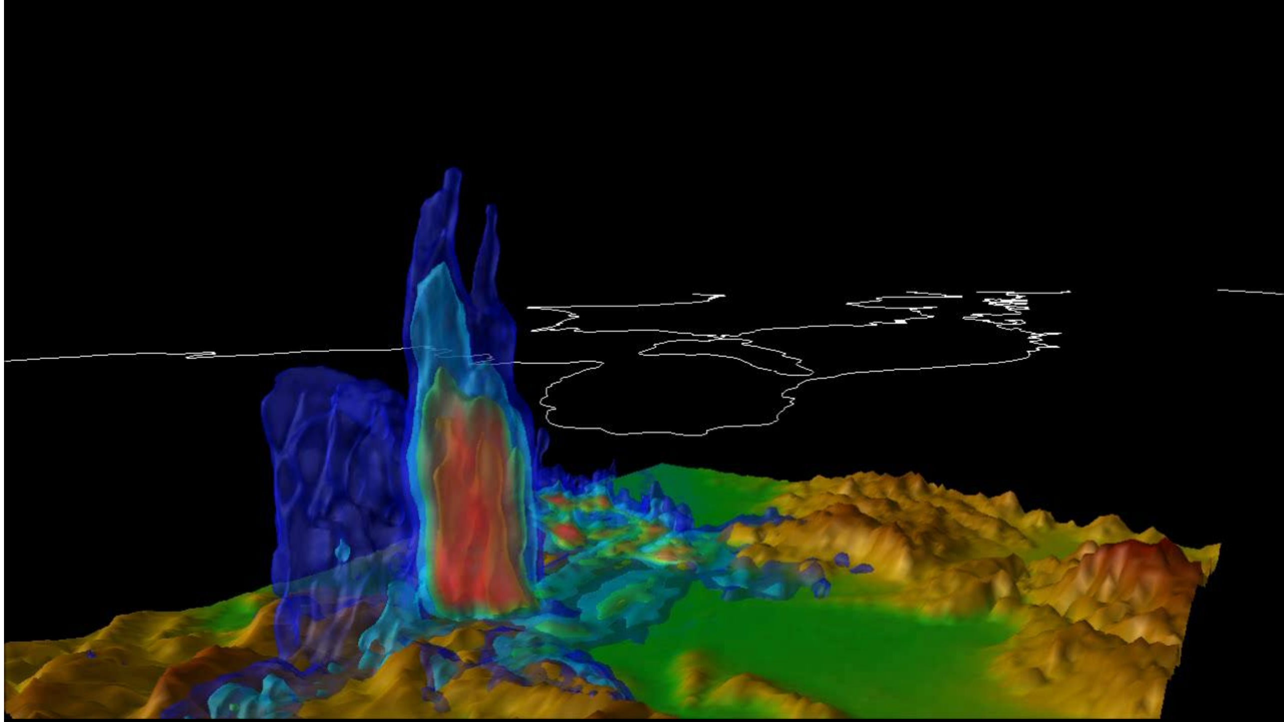
* XRAIN (X-band MP-X radar network) is operated by Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

Time and Space Scales of Atmospheric Motion

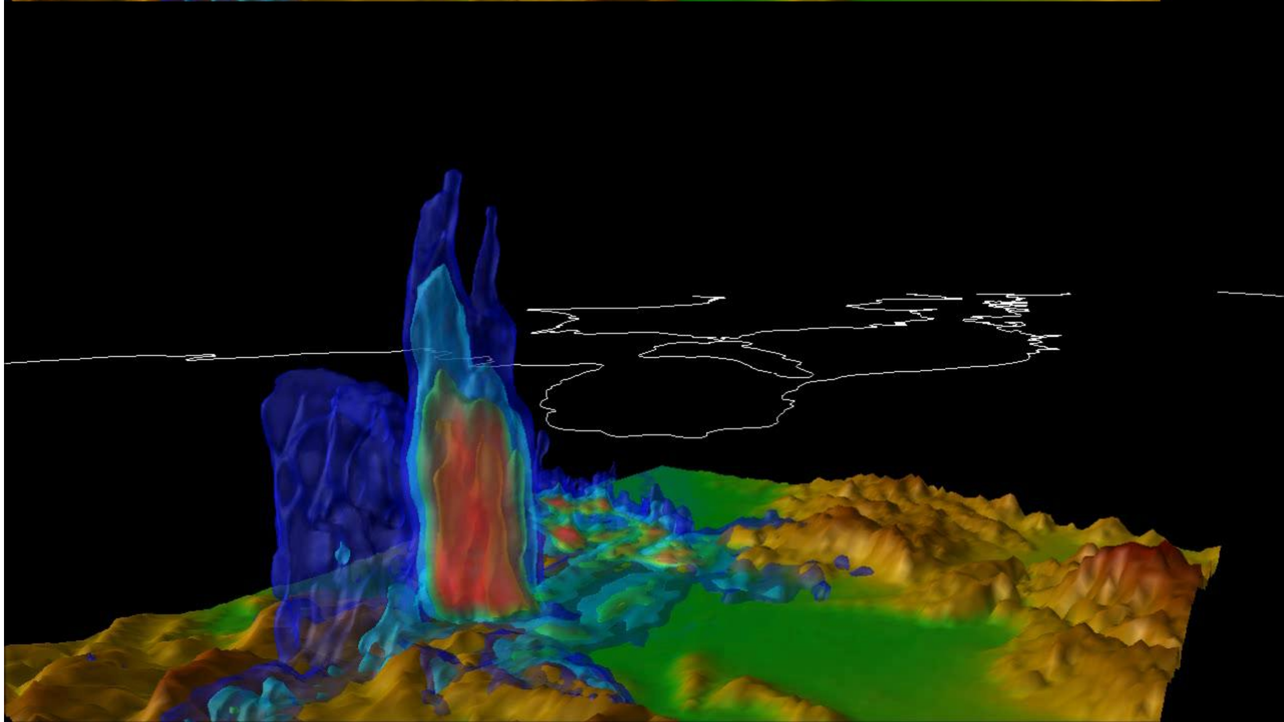


From 17:20:16 to 18:10:46, 26 July 2012

every 5 min.
(Conventional radar)

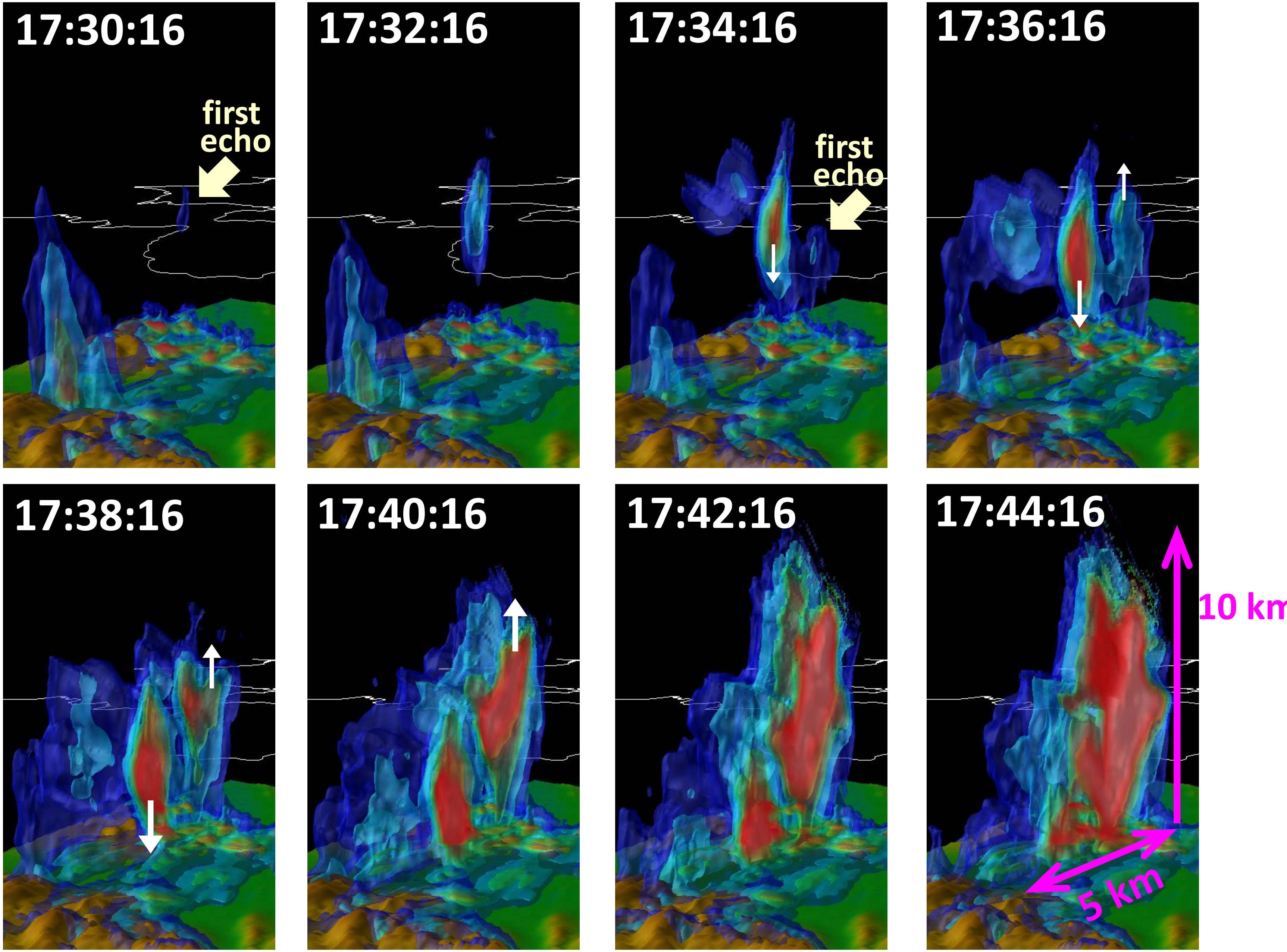


every 30 sec.
(PAWR)

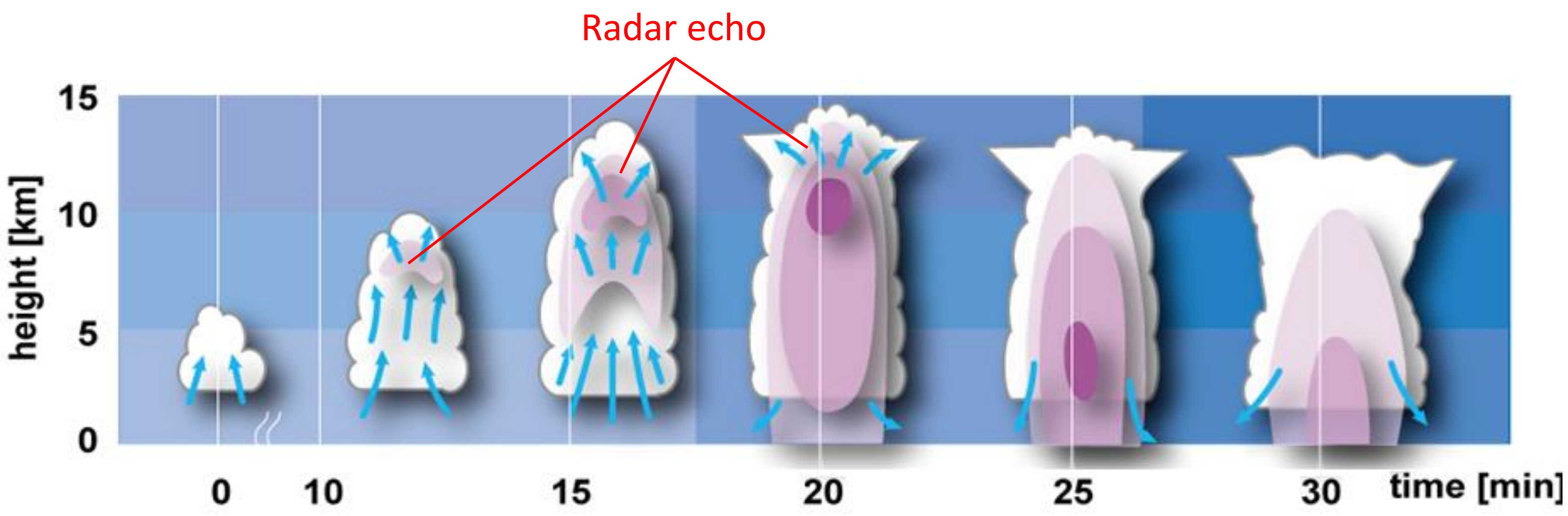


- 3D View of localized heavy rainfall from the North-East dir.
- The grid size is 100 x 100 x 100m
- Red color shows heavy rainfall

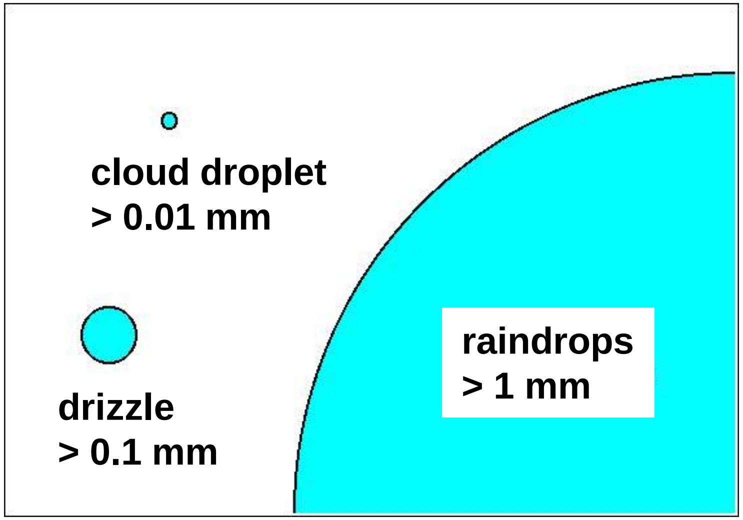
First echo and its evolution



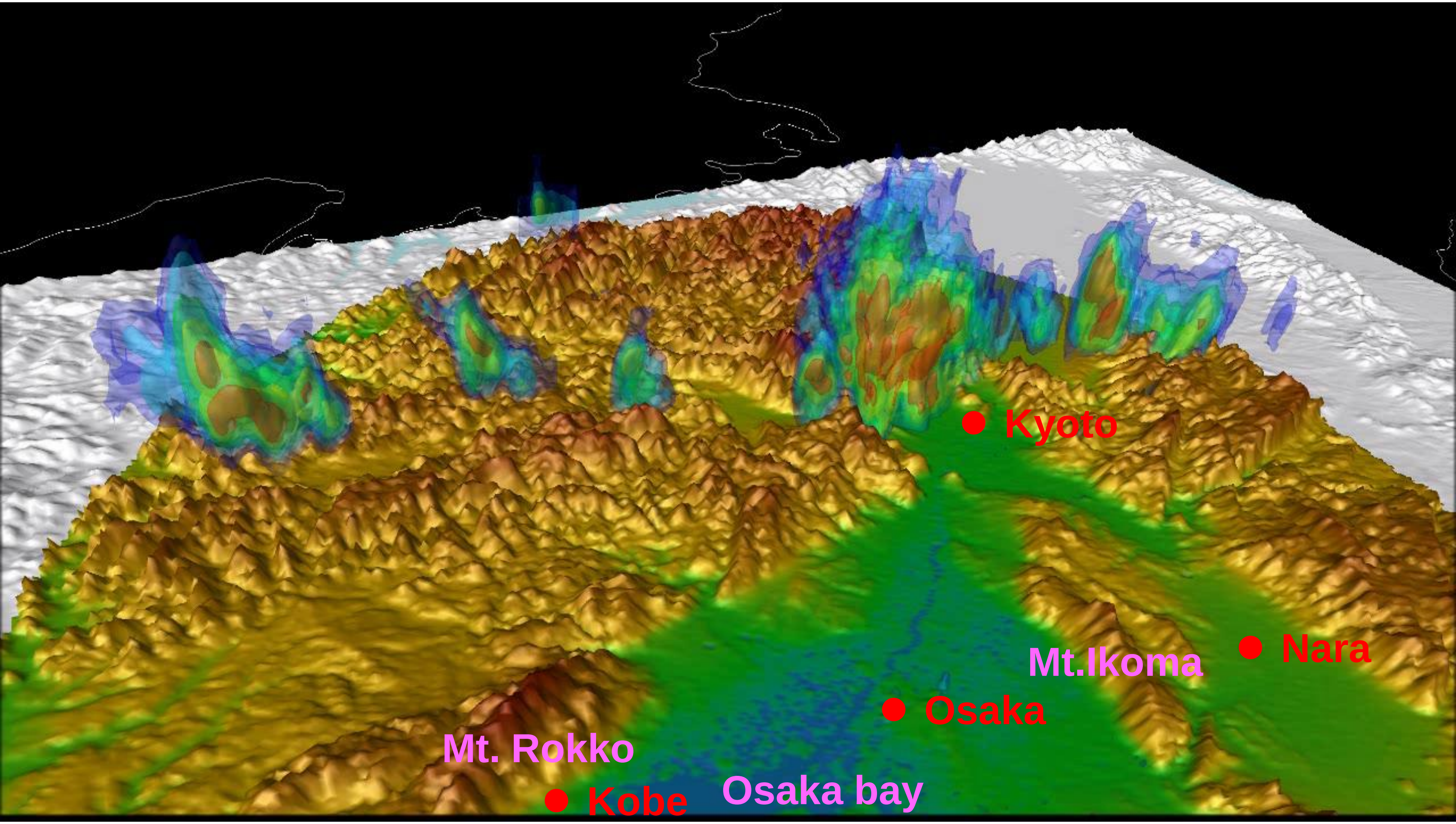
Dev of precipitation in a cumulonimbus cloud



(1) growth of cloud droplets in cumulus updrafts
(2) increase of droplet size in upper levels
(3) large droplets detected by radar (first echo)
(4) raindrops falls to the ground at a rate of
4-5 km in 10 min.
(5) The life time of a cumulus cloud is 30-60 min.



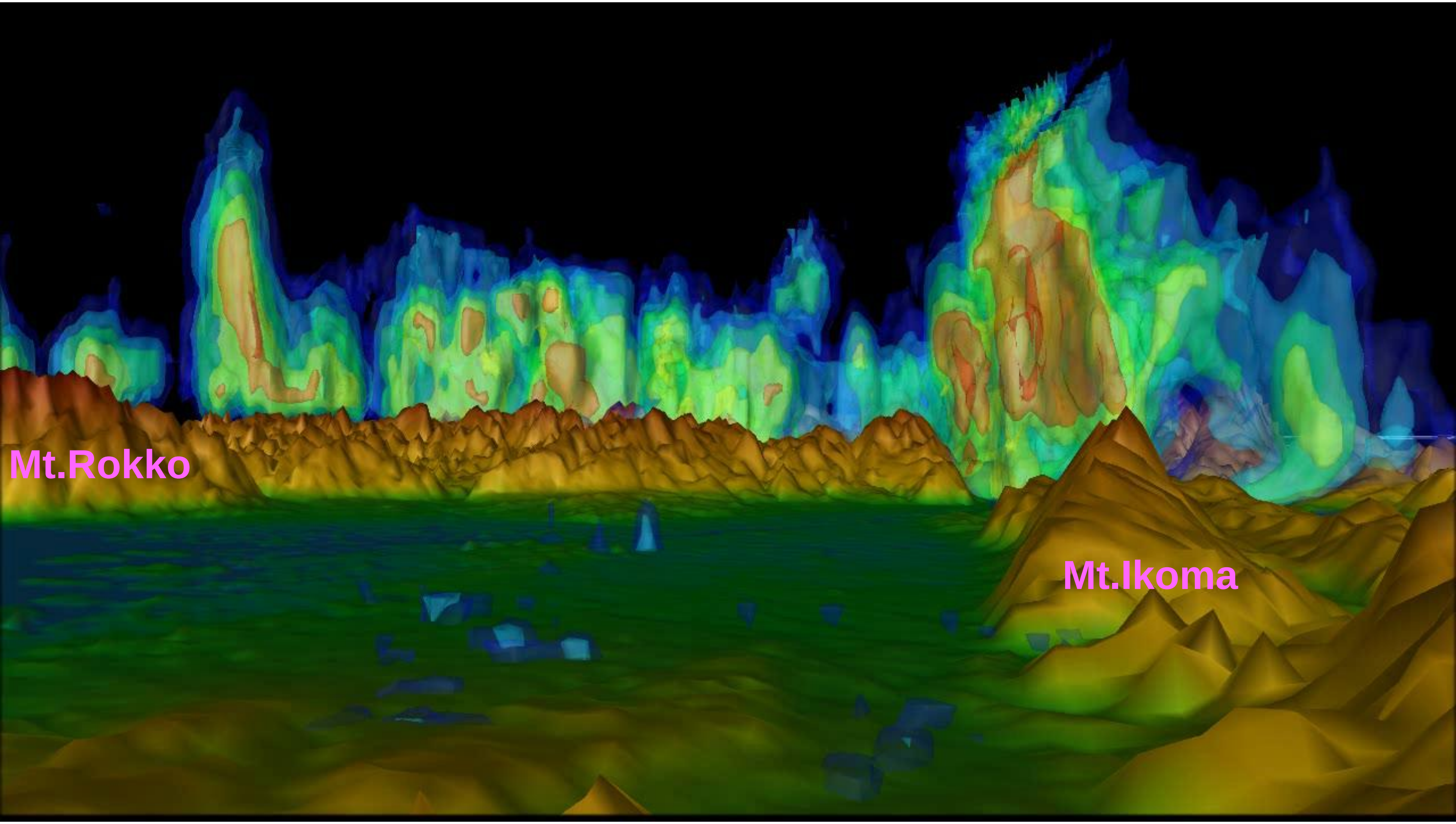
3D structure of linear rain band



3D precipitation distribution of the linear rain band from the sky over Osaka-bay (14:00-16:20JST, 13 July 2013)

10fps → 300x speed

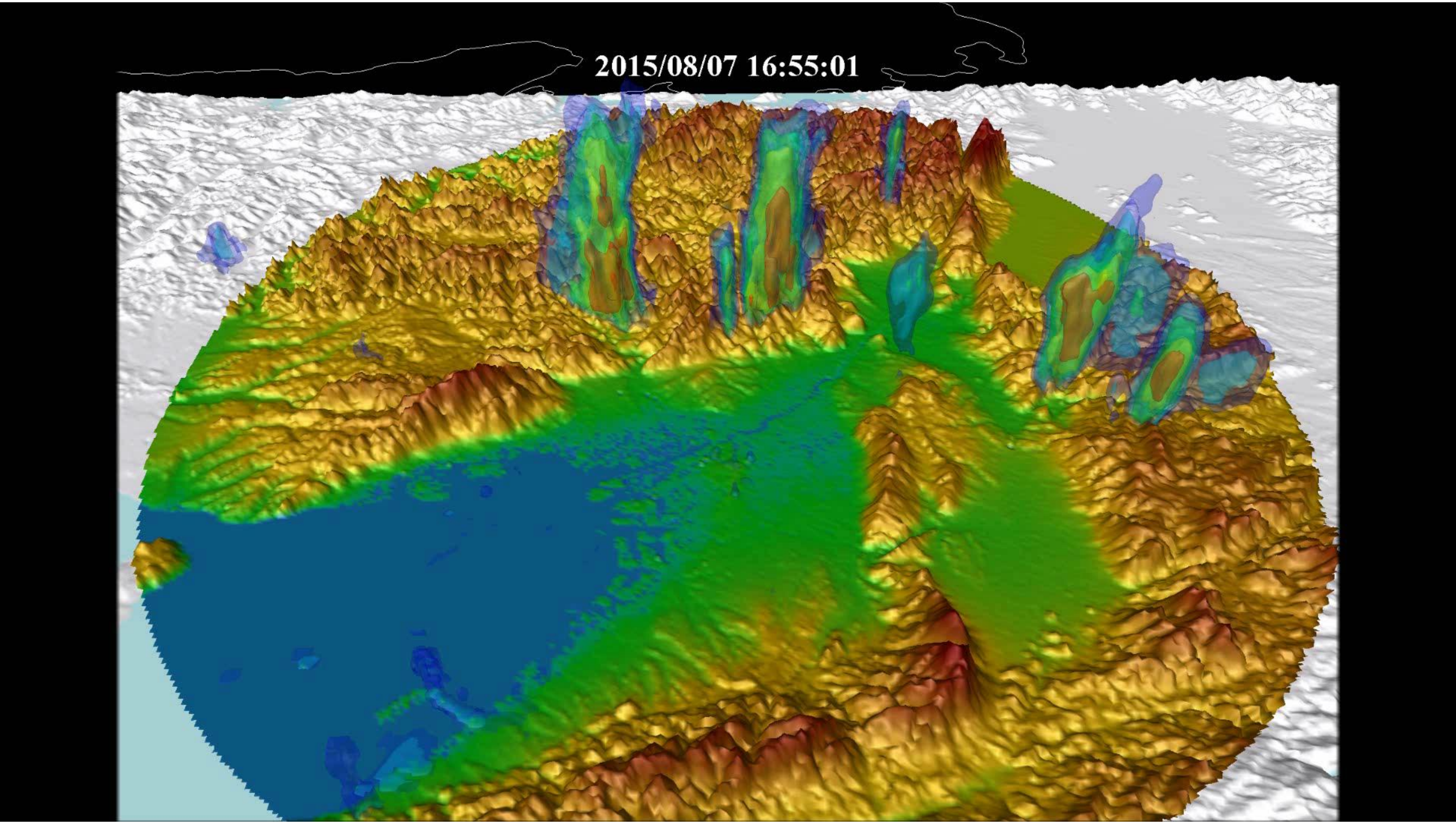
3D structure of linear rain band



3D precipitation distribution of the linear rain band viewed from the southern part of the Osaka plain (15:20-16:20JST, 13 July 2013)

10fps → 300x speed

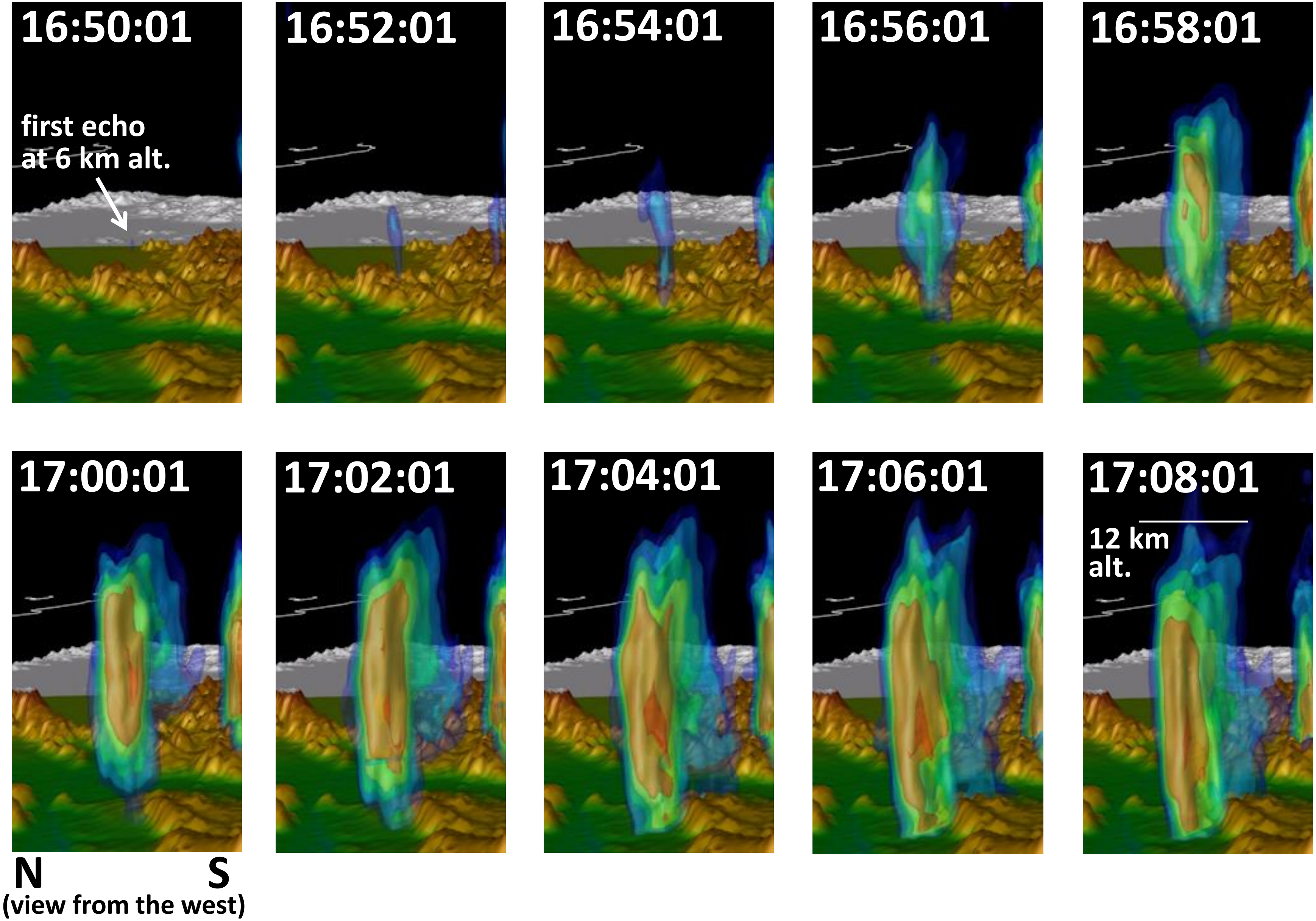
3D visualization of localized rainfalls



3D structure and evolution of localized heavy rainfalls observed by Suita PAWR in 07 Aug. 2015. 3D animation every 30 second showed for about 1 hour (16:55 to 17:59 JST) in the 60 km in radius, 250 m grid size.

Precipitation growth from a first echo

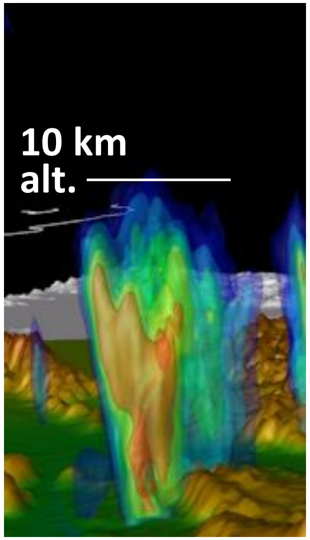
(07Aug2015)



Precipitation growth again

(07Aug2015)

17:21:01



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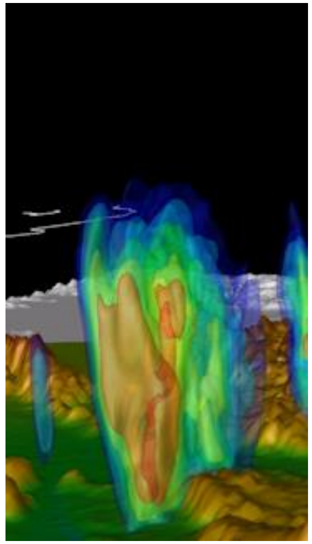
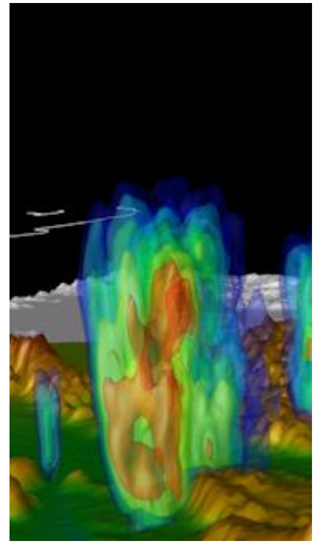


17:25:01



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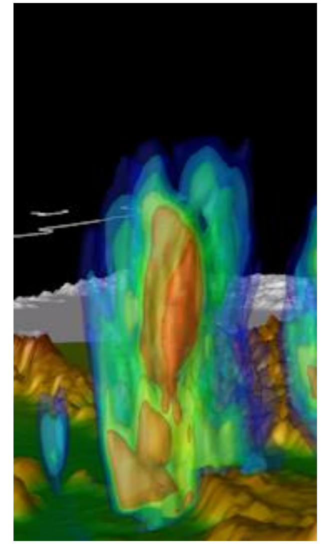
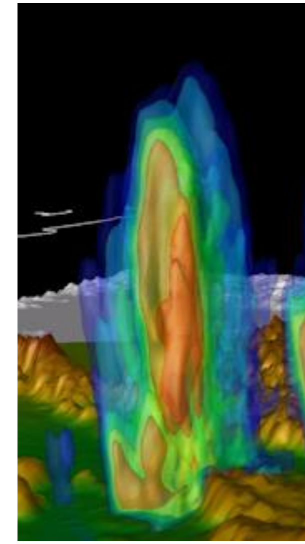
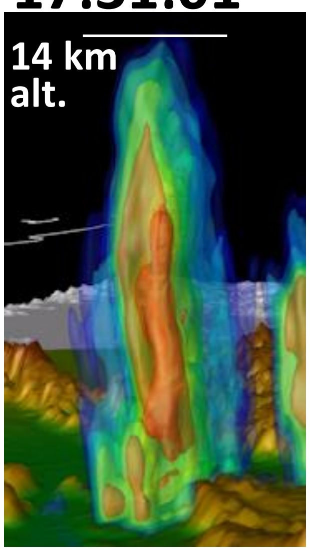


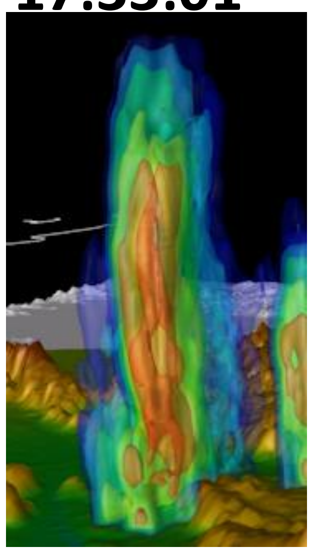
17:29:01



17:31:01



17:33:01



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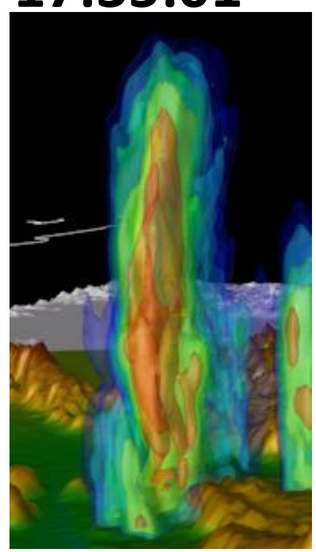

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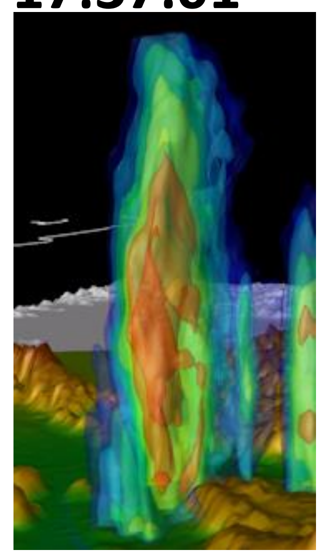
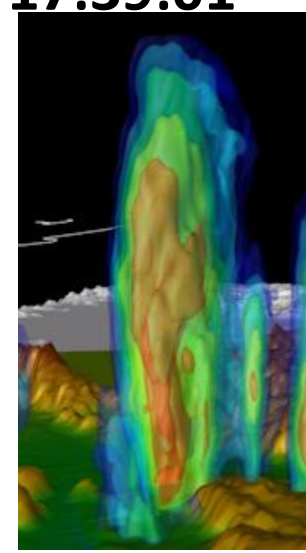


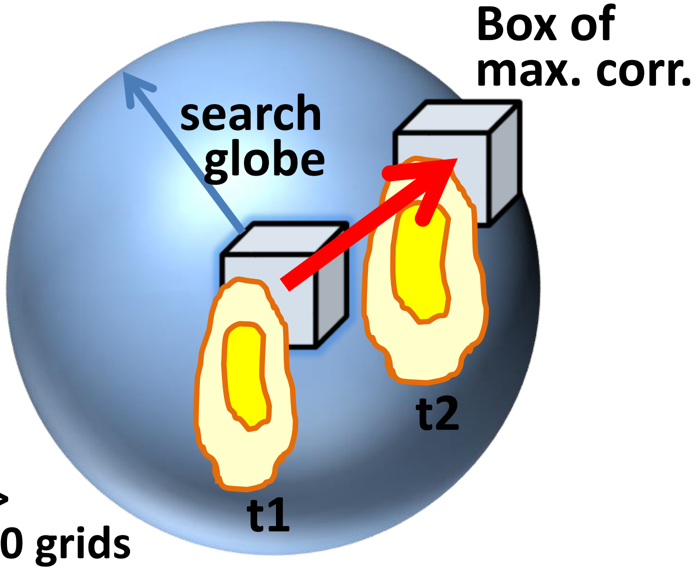
17:39:01



3D TREC analysis

TREC (by Rinehart and Garvey, 1978)
- Tracking Radar Echoes by Correlation
- to get horizontal (2D) motion vectors

COTREC (by Li et al., 1995) --- not use in this study
- Continuity of TREC
- Practical nowcasting



<default param.>
search radius = 10 grids
comparison box = 5x5x5 grids

Resolution of motion vector (grid size vs temporal diff.)

grid size	30sec	60sec	120sec (2 min)	240sec (4 min)
62.5 m	2.1 m/s	1.05 m/s	0.52 m/s	0.26 m/s
125 m	4.2 m/s	2.1 m/s	1.05 m/s	0.52 m/s
250 m	8.3 m/s	4.2 m/s	2.1 m/s	1.05 m/s

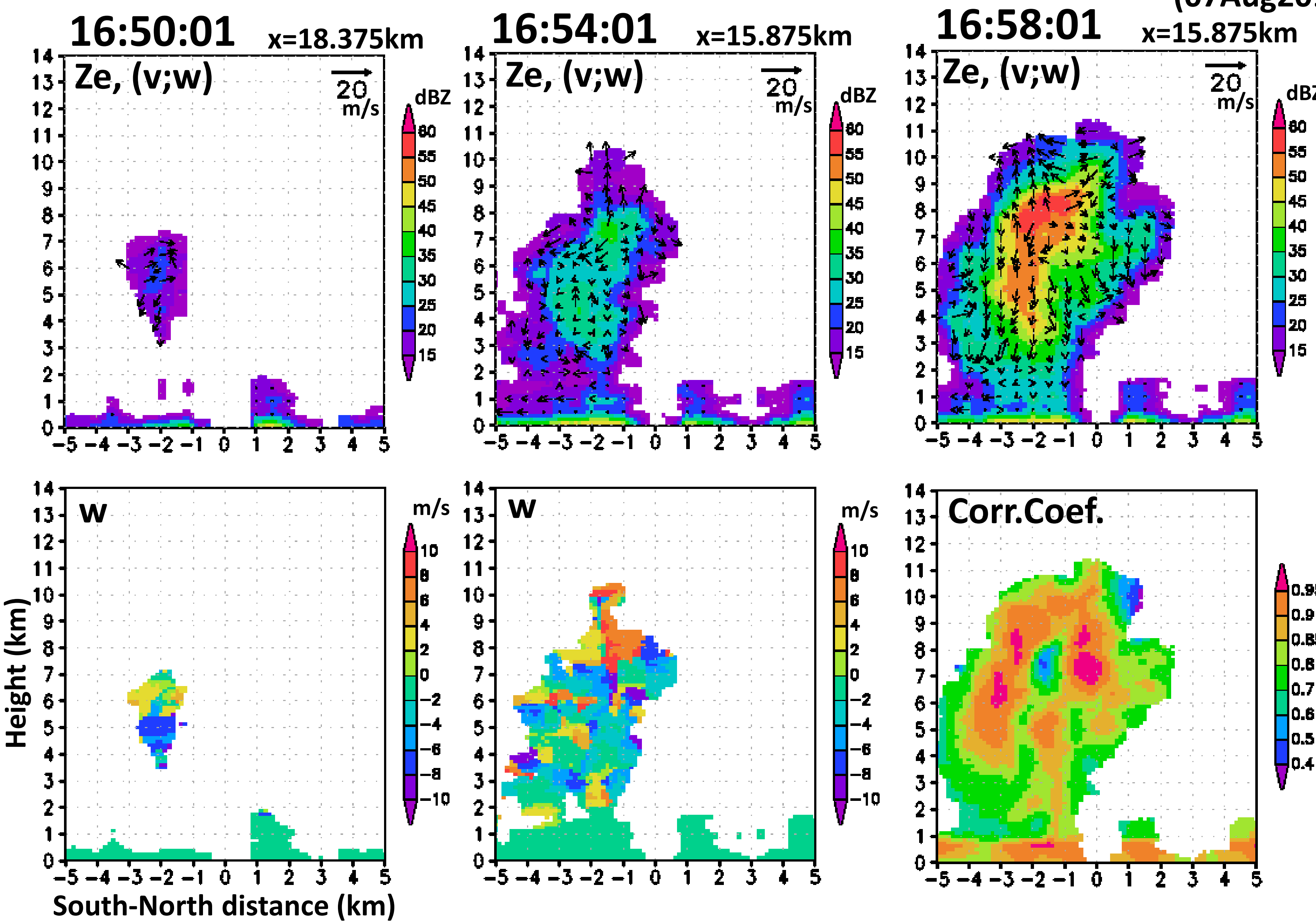
useful for accurate calculation of TREC

applied in this study

general 2D-TREC for conventional radar

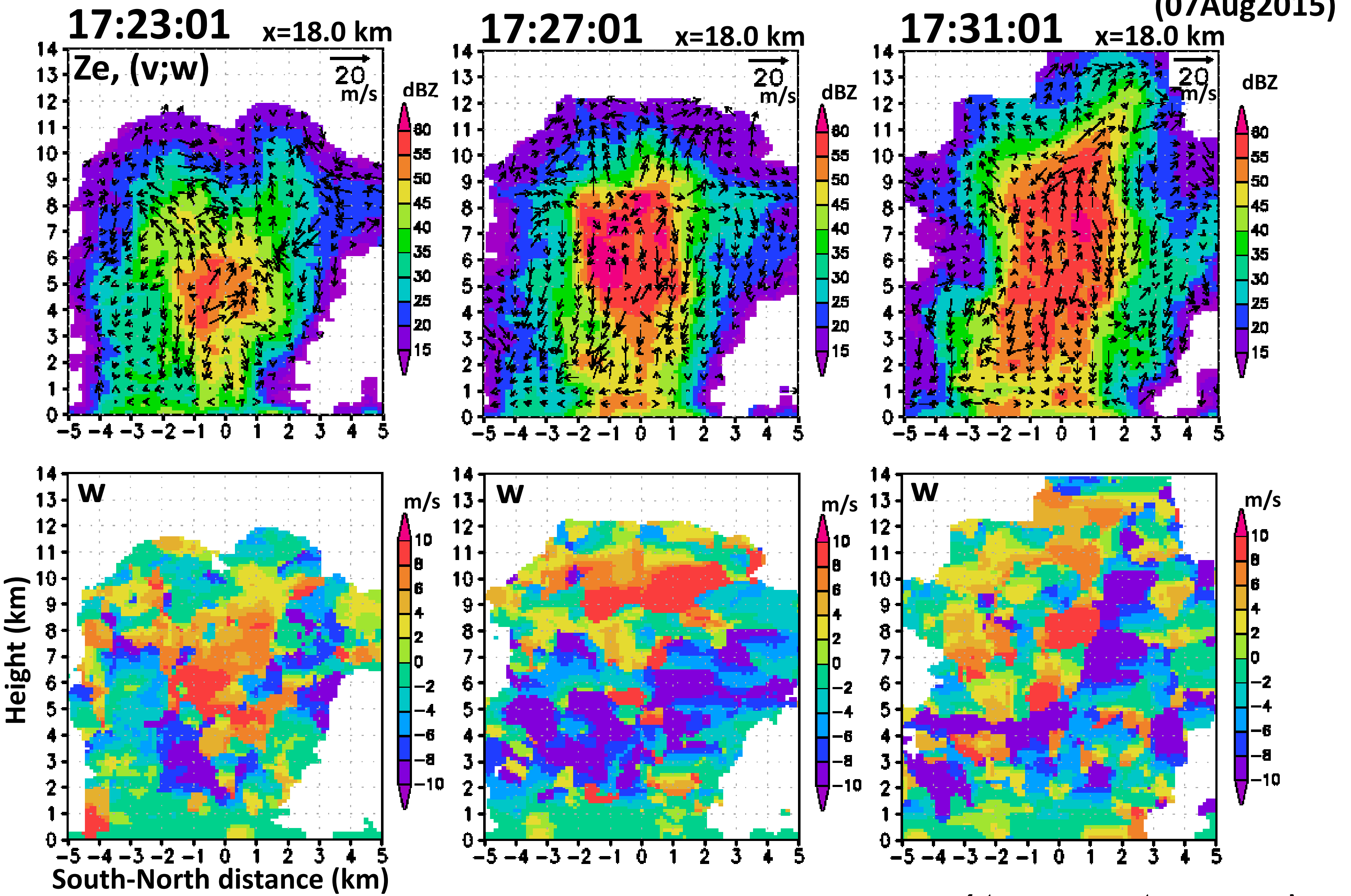
Results of 3D TREC (Δ z=125m, Δ t=120sec)

(07Aug2015)



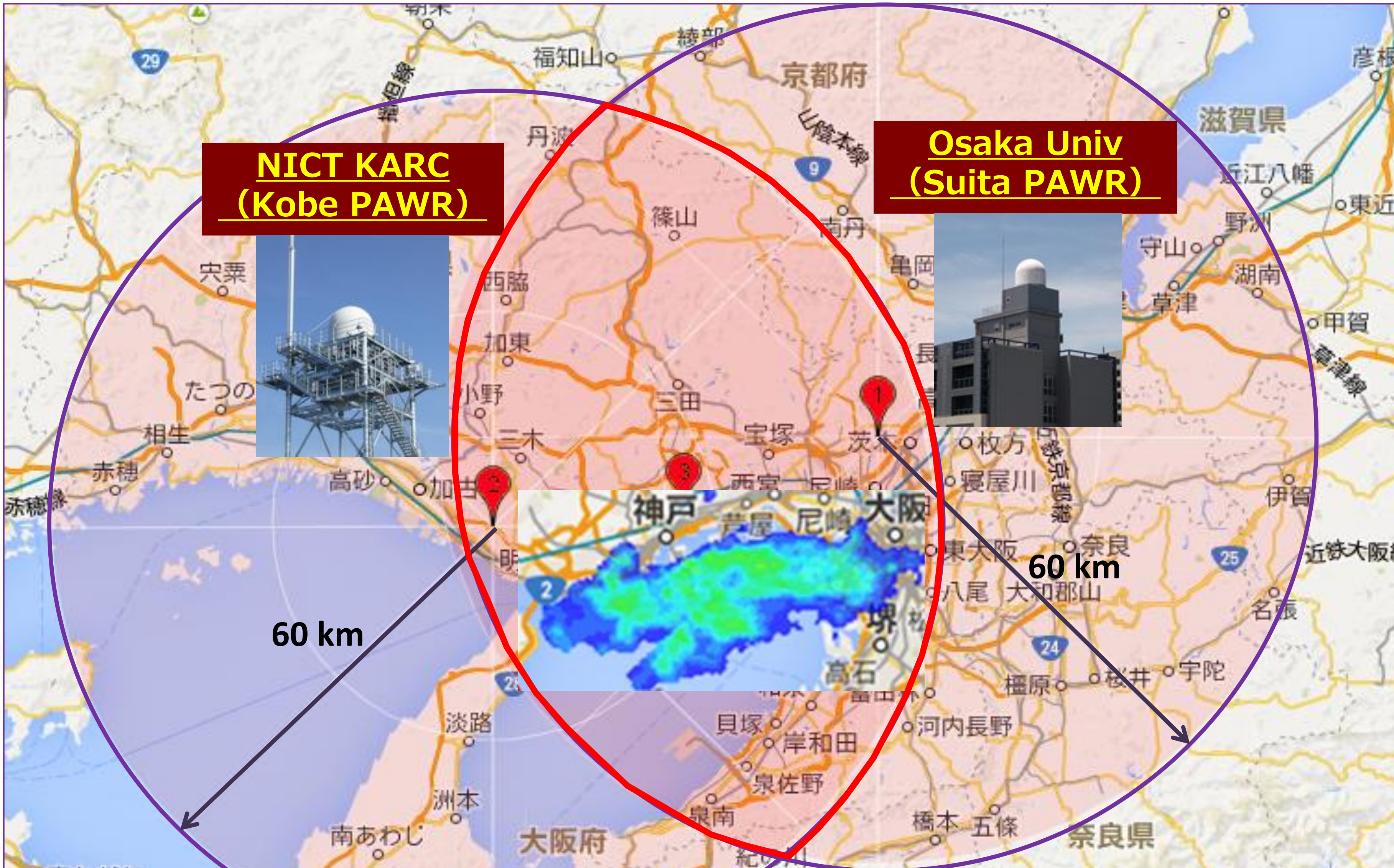
Results of 3D TREC (growth again)

(07Aug2015)



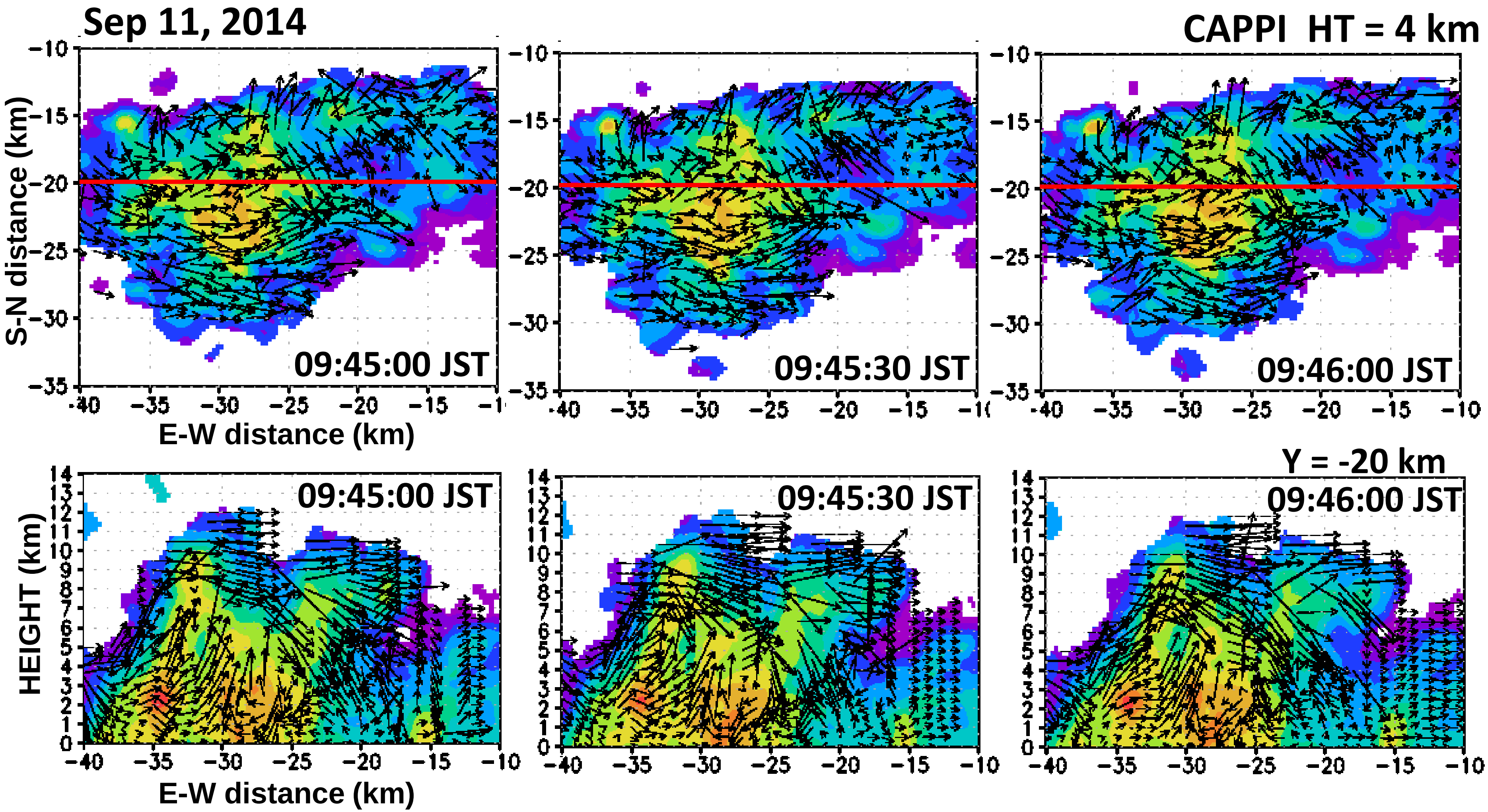
(Δz=125m, Δt=120sec)

Observation range of Kobe & Suita PAWR



- Dual-Doppler analysis to estimate 3-dim. wind vectors
- Rain-attenuation correction using two radar data

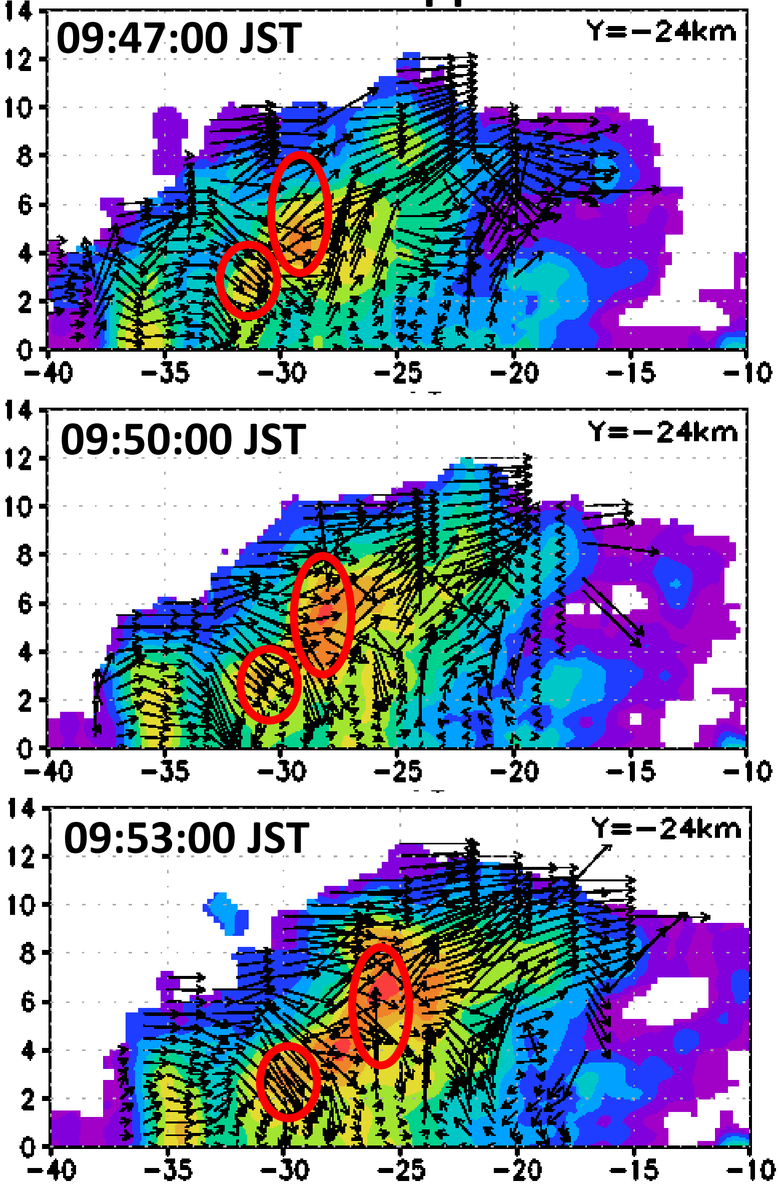
Dual-Doppler analysis every 30 seconds



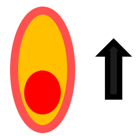
- Distribution of the horizontal wind vectors (u;v) changes little in appearance in a few minutes, but, the precipitation core is growing around x=−30, Y=−24km.
- There is also little change in the vertical circulation (u+v).

Vertical motion and growth of precip.

dual-Doppler



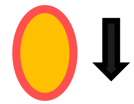
In strong updrafts (> 6 m/s), the precipitation moves upward with growth



vertical motion:

w + Vt > 0

In downdrafts (or weak updrafts), the precipitation falls to the ground



vertical motion:

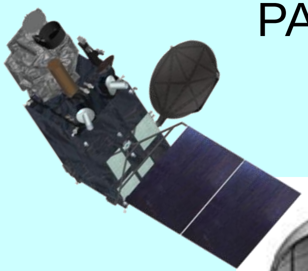
w + Vt < 0

where,
w: vertical winds (derived from dual-Doppler),
Vt: terminal fall velocity of precipitation (from Ze),
and the vertical motion of the precipitation should be determined using 3D TREC (Tracking Radar Echoes by Correlation) algorithm.

Big Data Assimilation

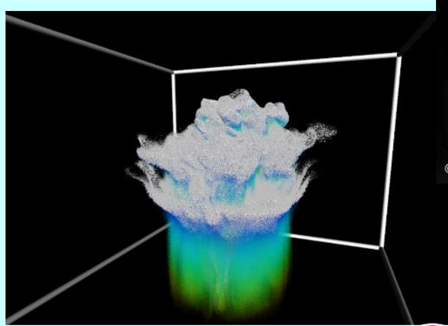
"Big Data Assimilation" Revolutionizing Severe Weather Prediction (PI: T. Miyoshi@RIKEN)

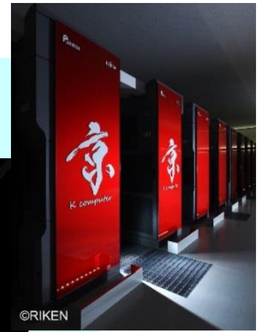
Himawari-8
PAWR



LETKF
Data Assimilation

（Local Ensemble Transform Kalman Filter ）

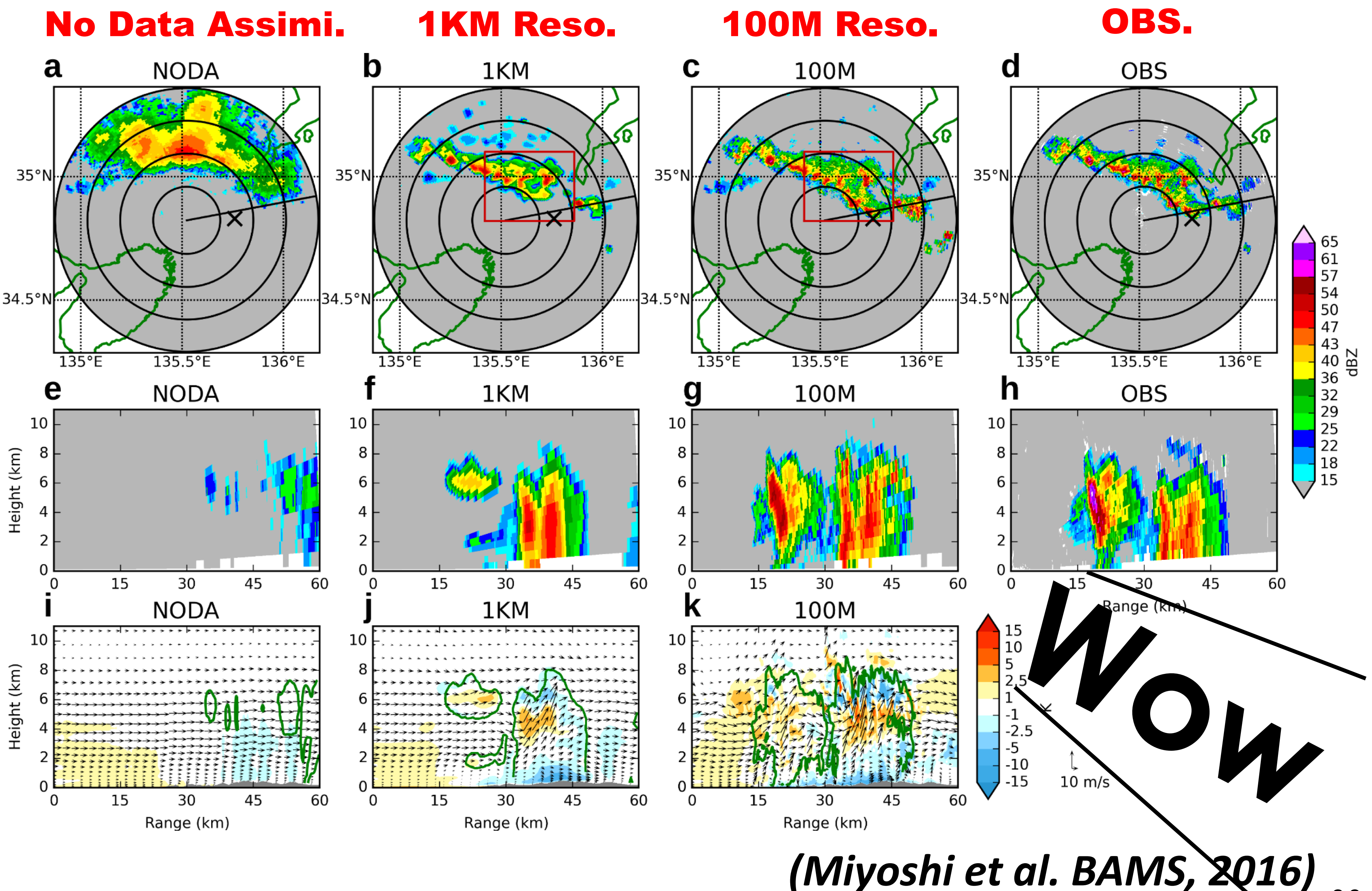




NHM SCALE

Pinpoint (< 100-m resol.) forecast of severe local weather by updating 30 min forecast every 30 sec!

Results of the data assimilation



(Miyoshi et al. BAMS, 2016)

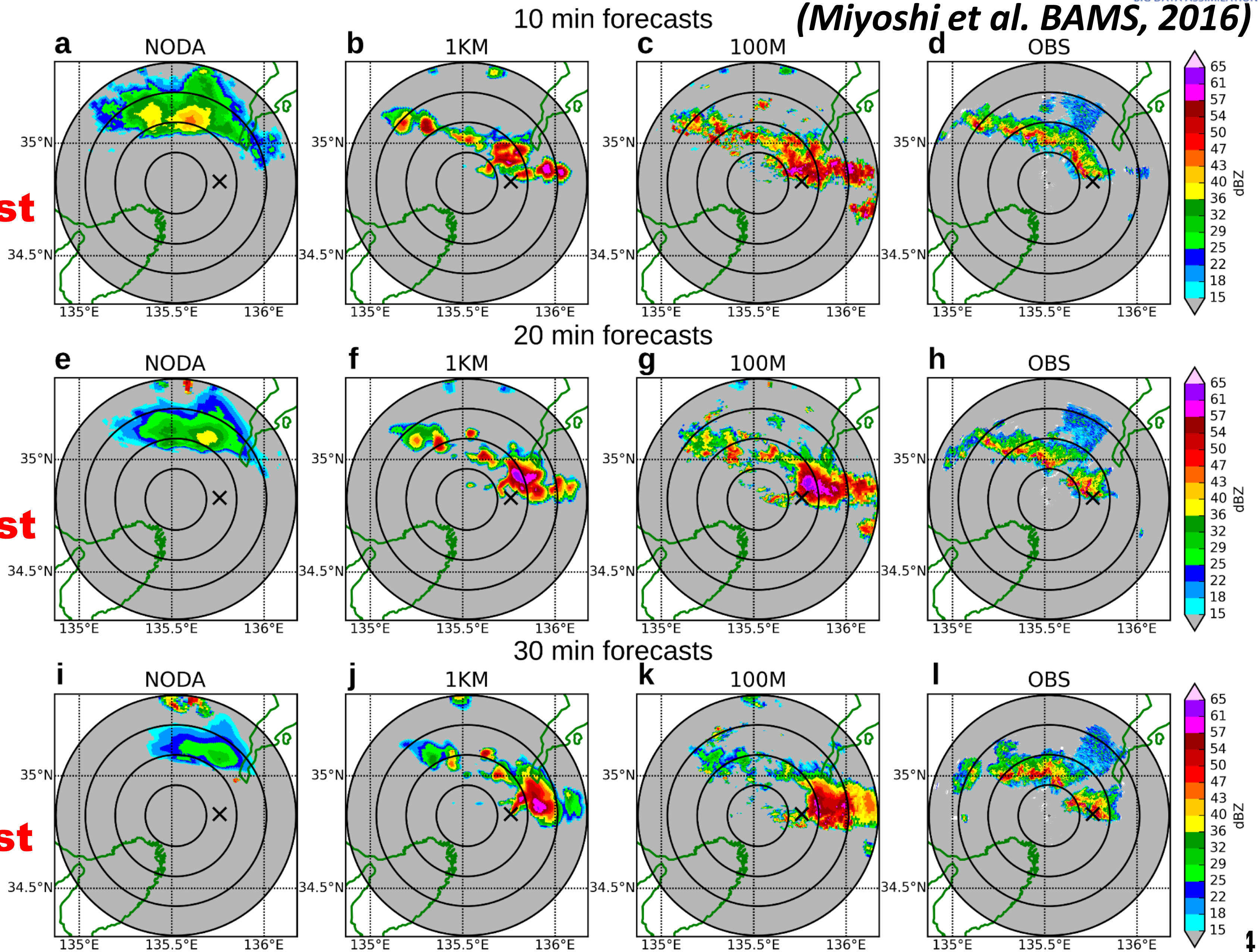
Results of the forecast

(Miyoshi et al. BAMS, 2016)

10 min forecast

20 min forecast

30 min forecast

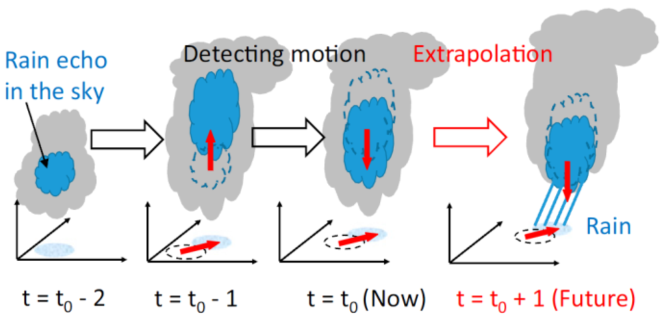


RIKEN real-time weather forecast

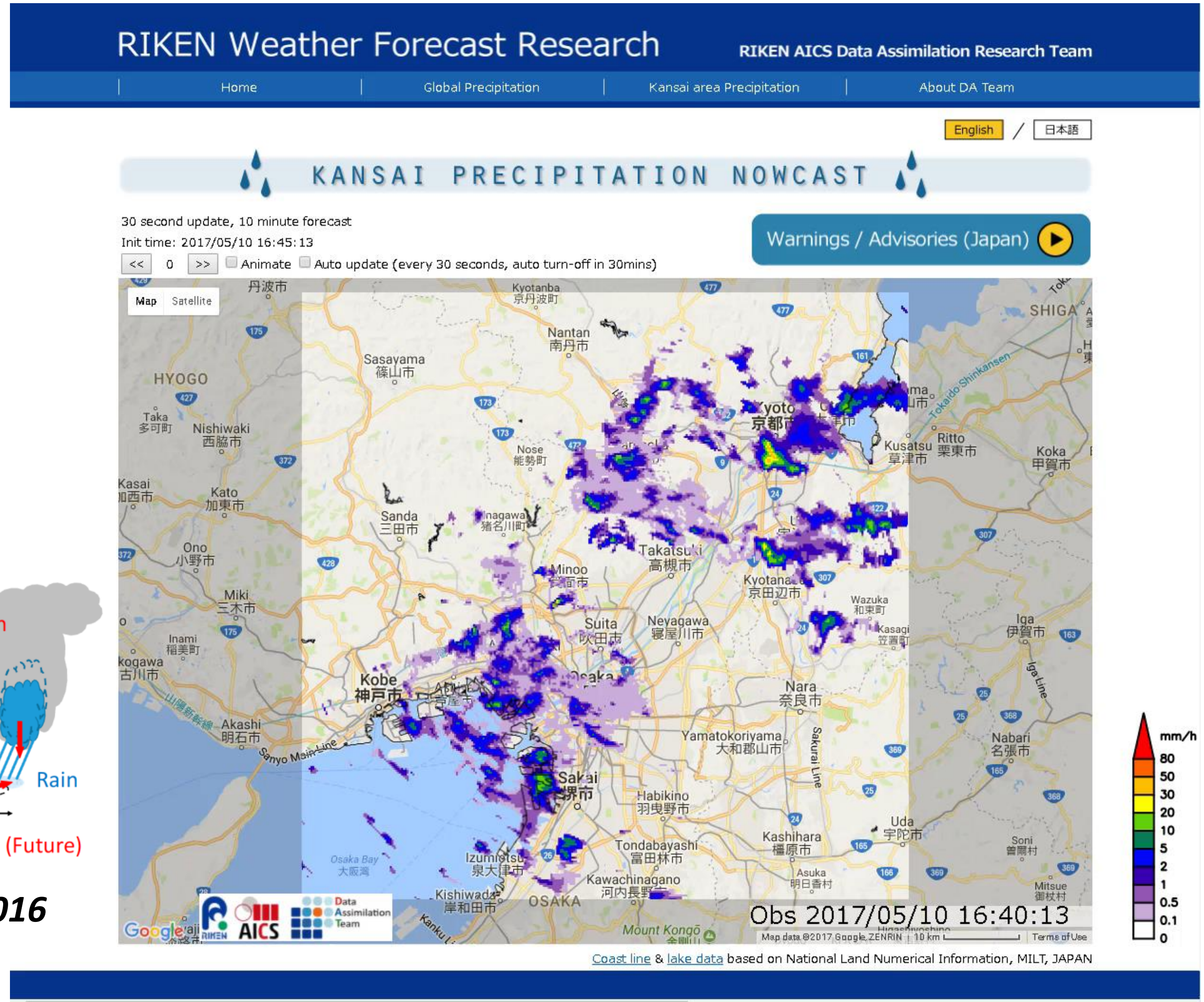
Real-time demonstration of
3D nowcasting

http://weather.riken.jp

30-second update nowcasting for 10 minutes started on July 3, 2017.



Otsuka et al. Wea. Forecast, 2016

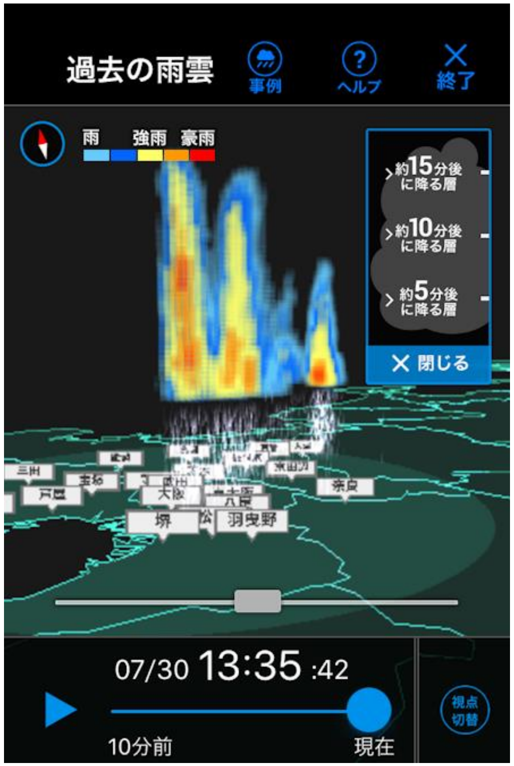


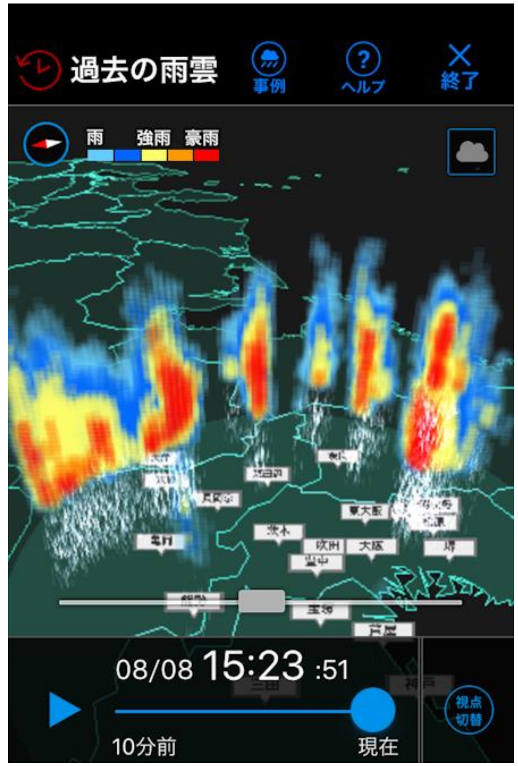
PAWR smartphone application

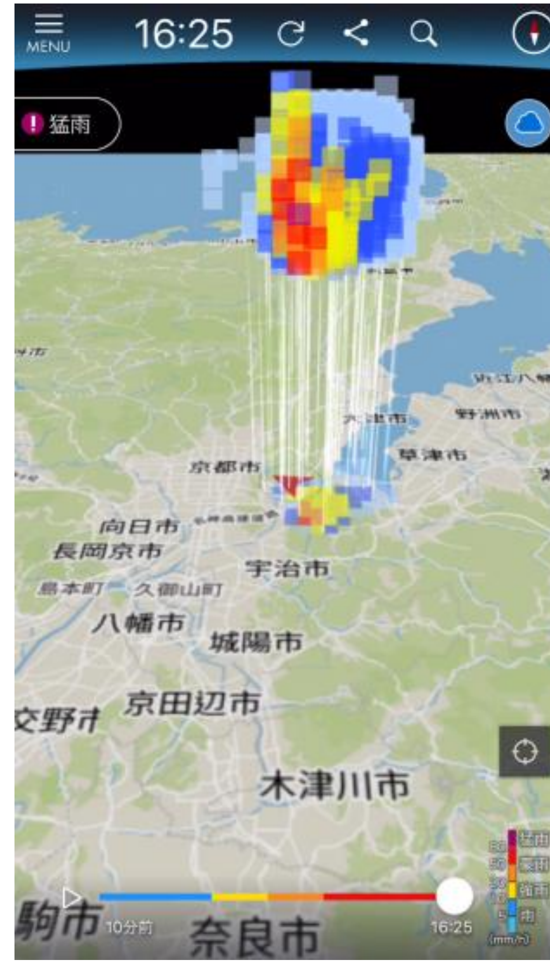
MTI Ltd.

3D雨雲ウォッチ
～フェーズドアレイレーダ～

Free app. for Android and iPhone







3D rainfall display (2nd year ver.)

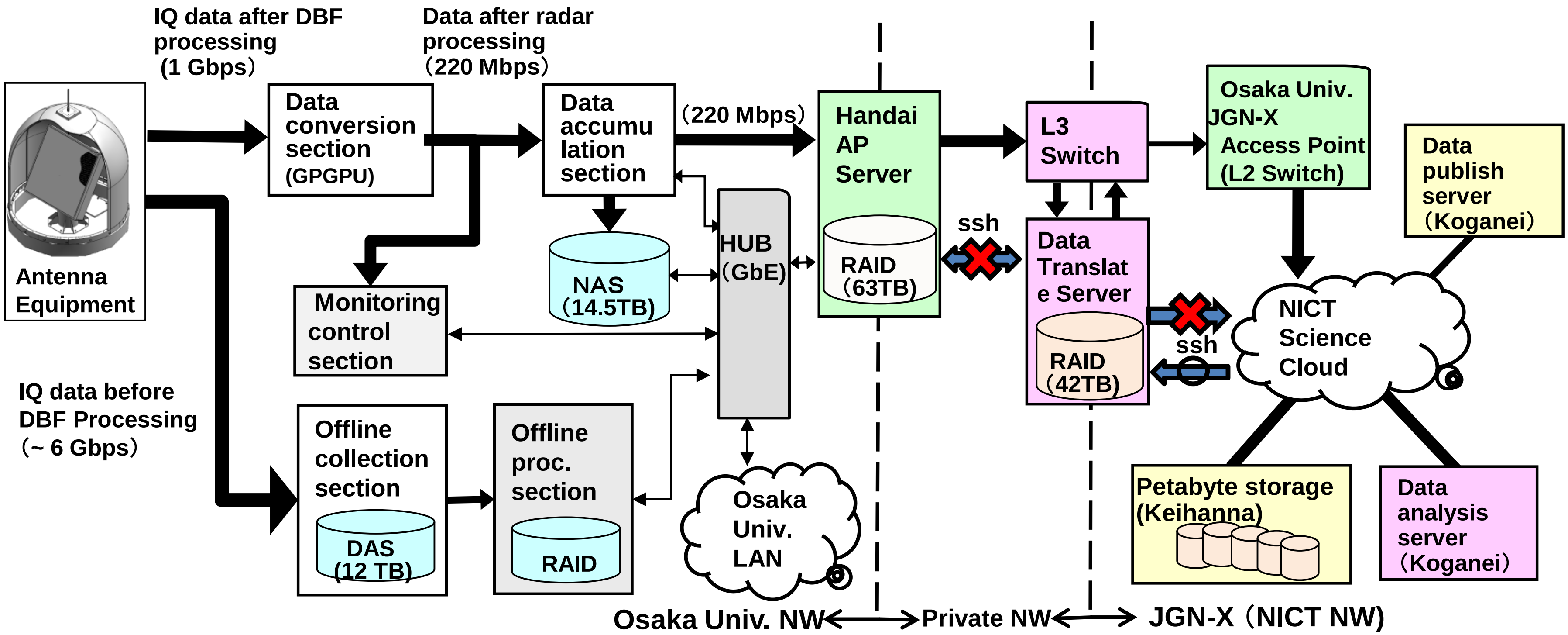
- Real-time 3D rainfall display every 30 sec.
- Heavy rainfall forecast by push notification

(3rd year ver.)

NICT 国立研究開発法人 情報通信研究機構 × ライフレンジャー

http://pawr.life-ranger.jp

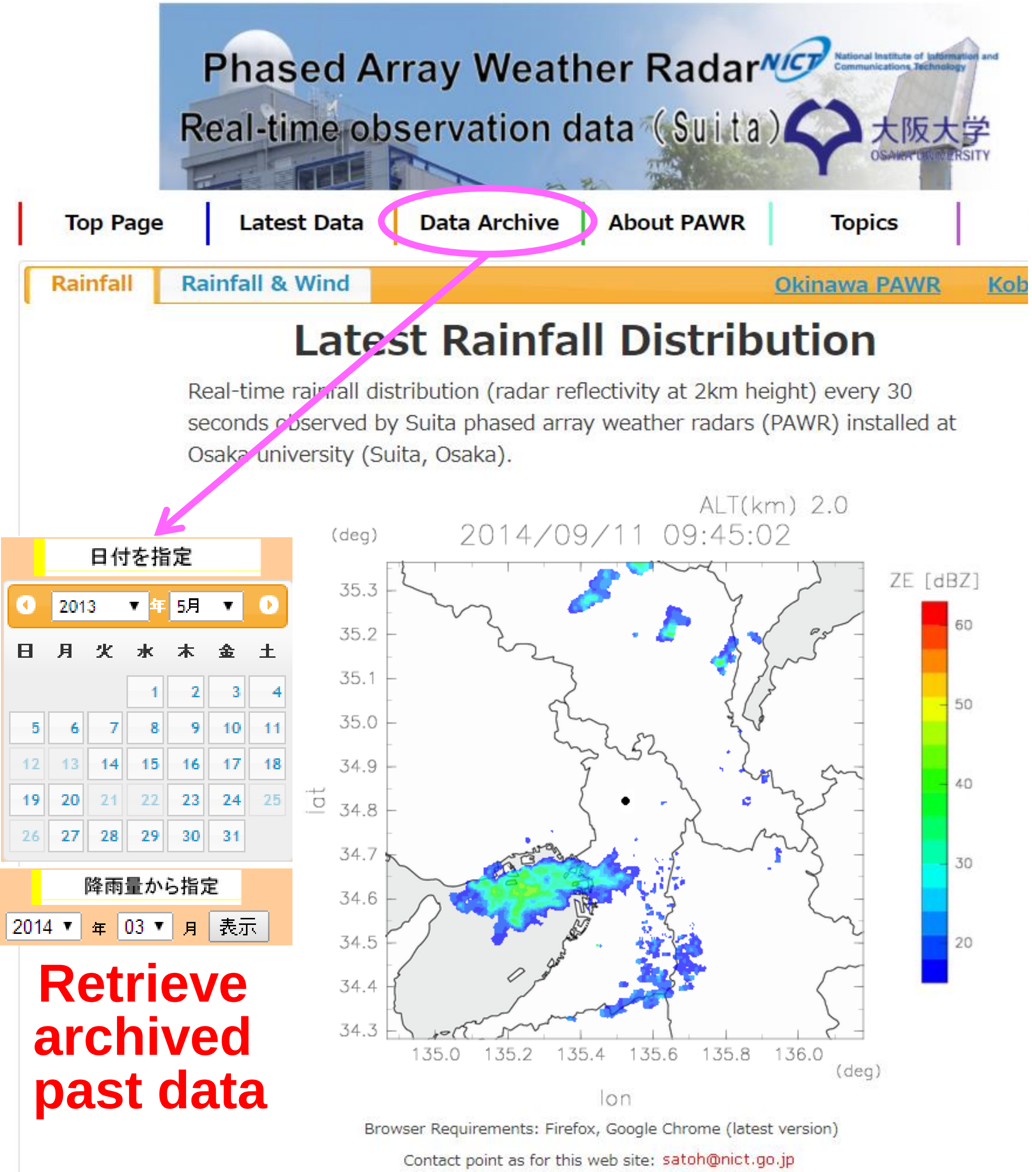
Suita PAWR data processing system



Observation mode and data rate

Detailed (10 sec.)	300 range × 320 sector (AZ) × 110 angle (EL) × 2 byte = 20.3 MB / file Total size (13 files): 275 MB / 10sec (∼2.4TB/day) ⇒ 220 Mbps
Normal (30sec.)	600 range × 300 sector (AZ) × 110 angle (EL) × 2 byte = 37.8 MB / file Total size (13 files): 493 MB / 30sec (∼1.4TB/day) ⇒ 131 Mbps

PAWR web page（http://pawr.nict.go.jp/）

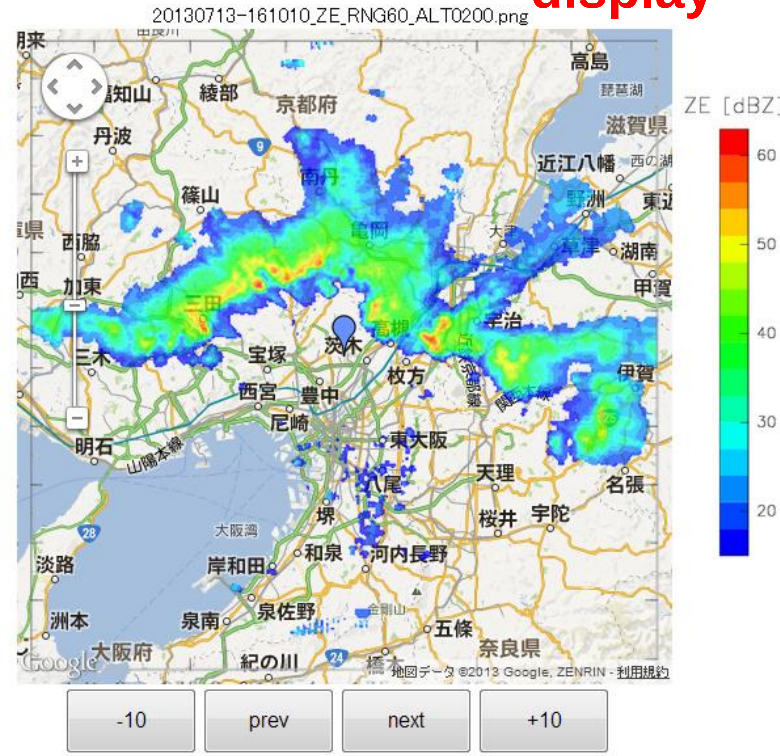


Retrieve archived past data

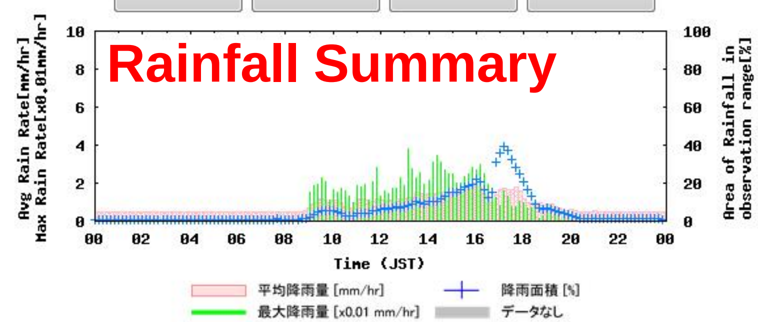
Real time display（within 1 min of obs）

2013/07/13
16:10:10

Google maps display



Rainfall Summary



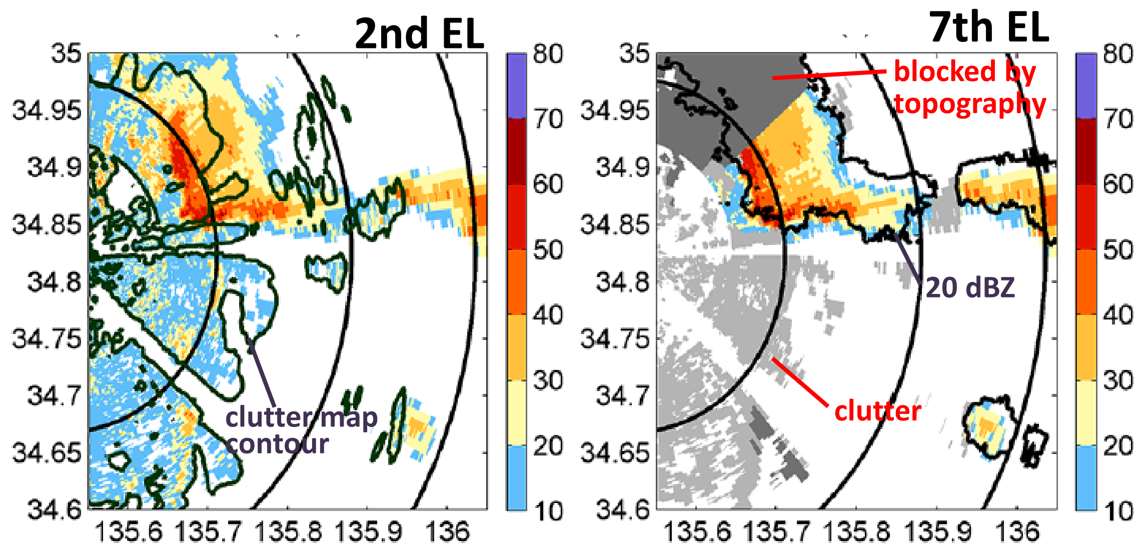
降雨サマリー(グラフ)をクリックすると、その時刻の降雨分布を表示します。

Request for faster QC algorithm

Data quality control (QC) such as clutter removal is essential in order to use PAWR observation data for data assimilation and nowcast.

The Ruiz 's QC algorithm (SOLA, 2015) used for the BDA experiment requires calculation time of 40 seconds. However, it is necessary to develop a faster and general-purpose QC algorithm to perform real-time processing on the various observation data.

Perform QC calculation and data transfer within 10 seconds for 3D nowcast



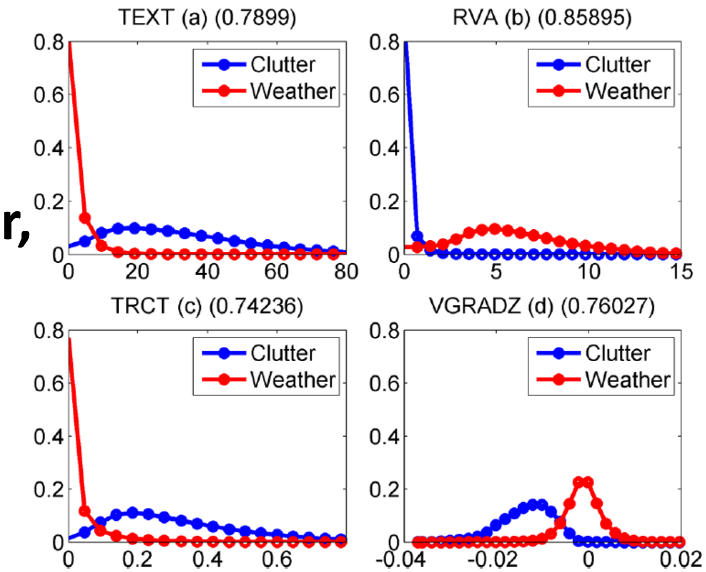
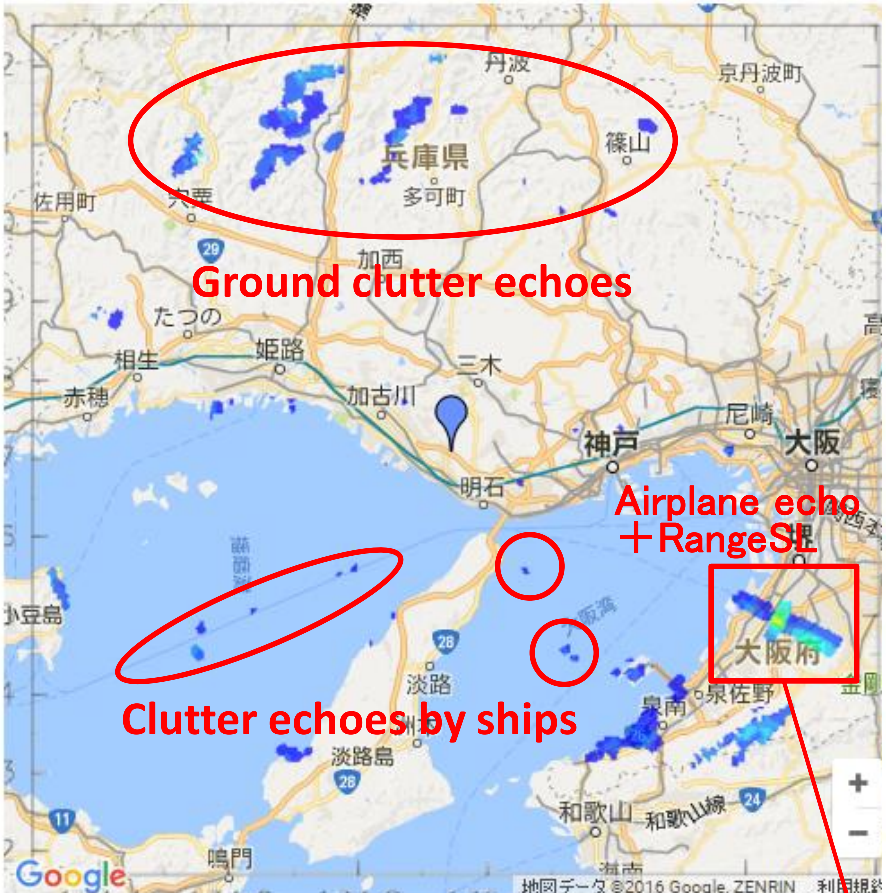


Fig. 2. Conditional histogram for the parameters (a) TEXT, (b) RVA, (c) TRCT, and (d) VGRADZ. The parenthetical numbers on top of each panel indicate the discrimination index values.

Ruiz et al. SOLA, 2015

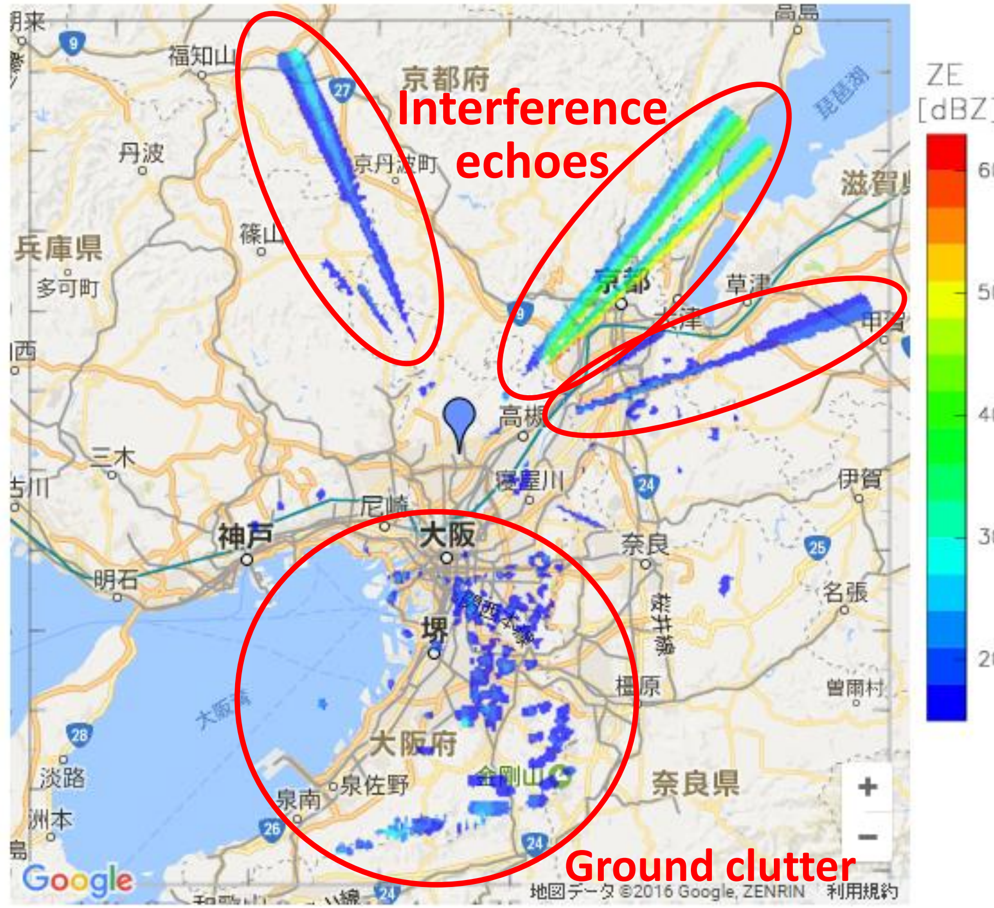
Surface clutter and interference echoes

2016/12/01 10:10:30



Kobe PAWR (fine weather)

2015/12/18 10:40:34



Suita PAWR (fine weather)

Add another data at
2016/12/01, 10:03:30

Contents and overview of QC flag file

QC flag < 8 bit >

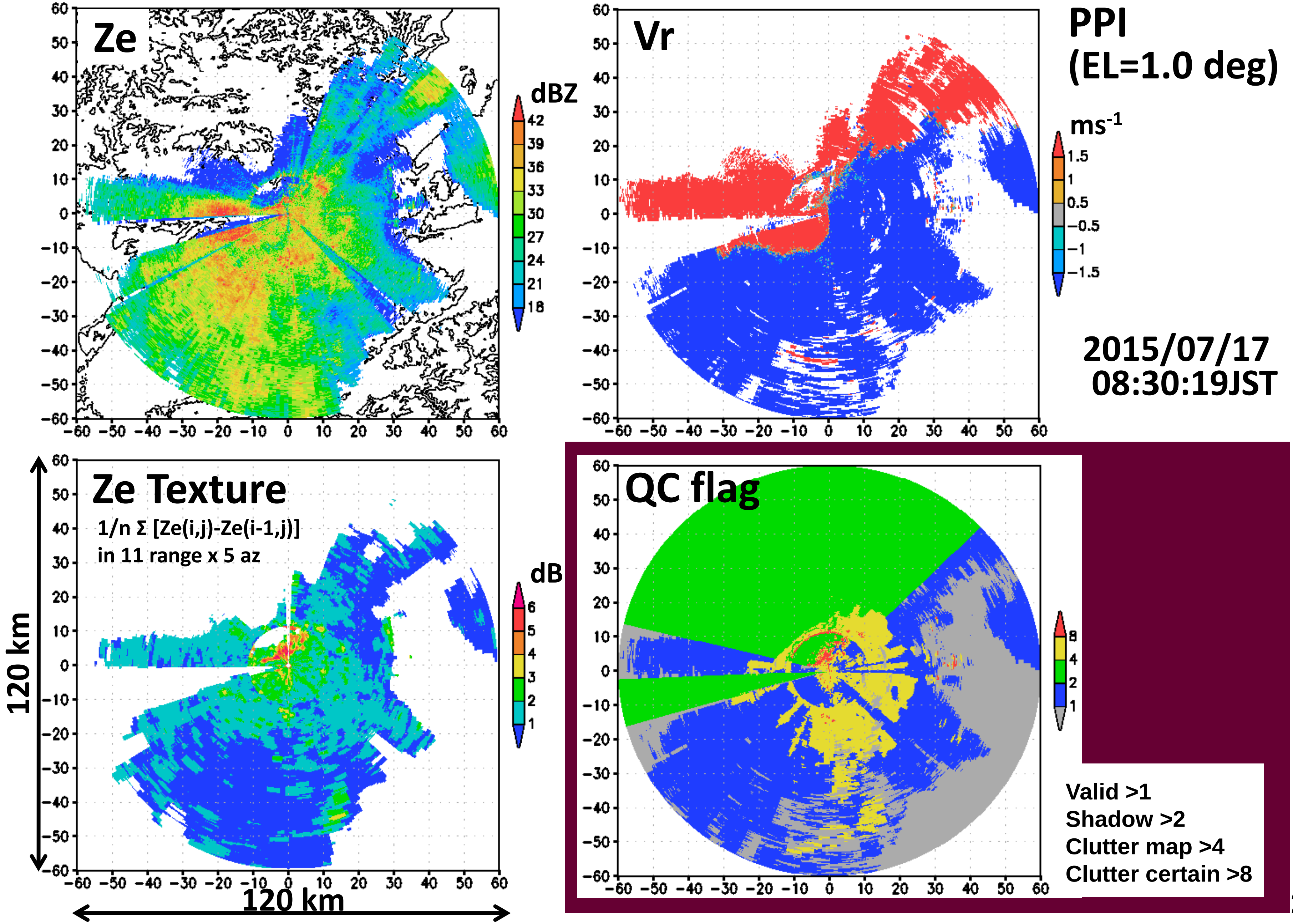
[0]Valid data, [1]Shadow, [2]Clutter possible, [3]Clutter certain,
[4]Noise, [5]RainAttn., [6]RangeSL, [7](Reserve)

- A new file of 1-byte QC flag data is provided in the same format of the same polar-coordinates as Ze and Vr data.
  (e.g. 20150808-160021.all**_pawr_qcf.dat,** kobe_20150808160000_A08**_pawr_qcf.dat**)
- The QC flag file will be created in NICT Koganei in real-time (within 10 sec.)

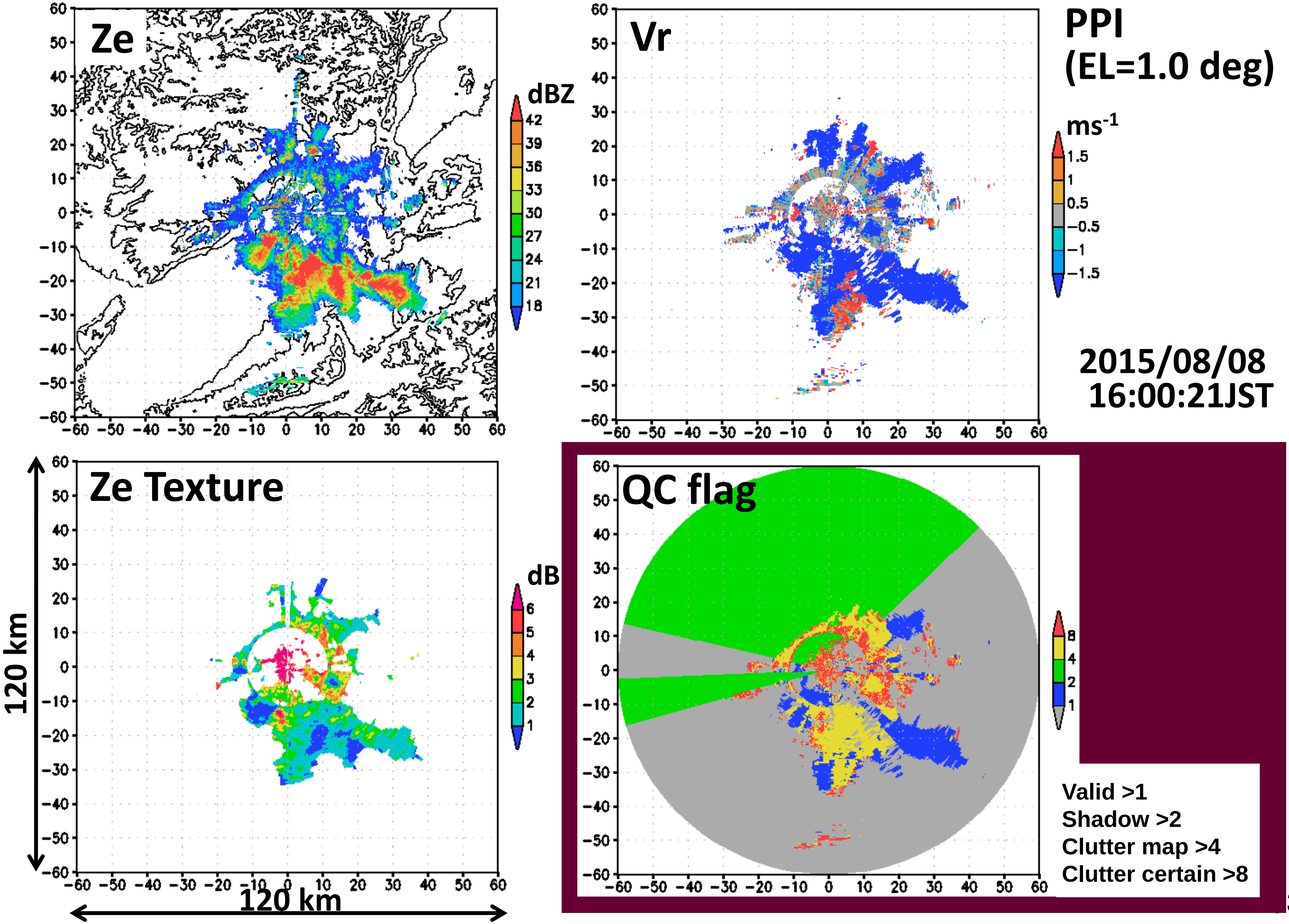
< CONTENTS >

[0] Valid data : if (Ze > -327.68 & Vr > -327.68) then (1)
[1] Shadow : if (ASL(Dem) > beamHT using 4/3 equiv. earth radius) then (1)
[2] Clutter possible (clutter map) : if (statistical Ze_PD > 20%) then (1)
[3] Clutter certain : if (Ze_PD>20% & -1.5<Vr<1.5ms^{-1} & ZeText > 3.0) then (1)
[4] Noise (Interference) : if (rng_num > 500 & Ze_std/Ze_avg < 0.5) then (1)
[5] Rain attenuation : if (Ze_inetg > 50 dBZ & delta_Ze < -2 dB/km) then (1)
[6] Range Side Lobe : if (Ze > 40 dBZ & ZeText < 1.5 & ZrTextAz < 0.8) then (1)
[7] (Reserve): future use (e.g. abnormal Vr., uncorrected aliased velocity)

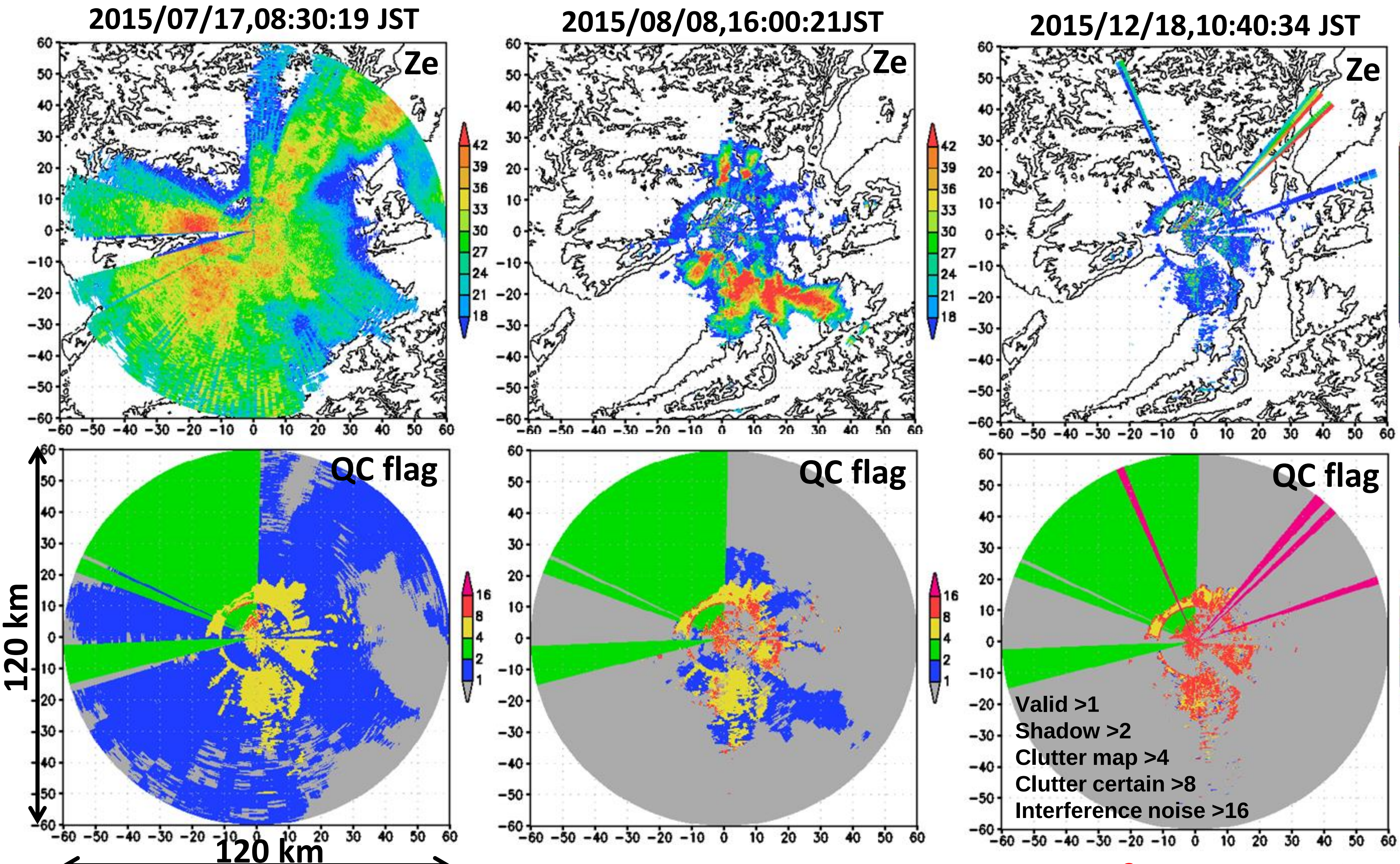
QC flag of stratiform rain echo



QC flag of convective rain echo



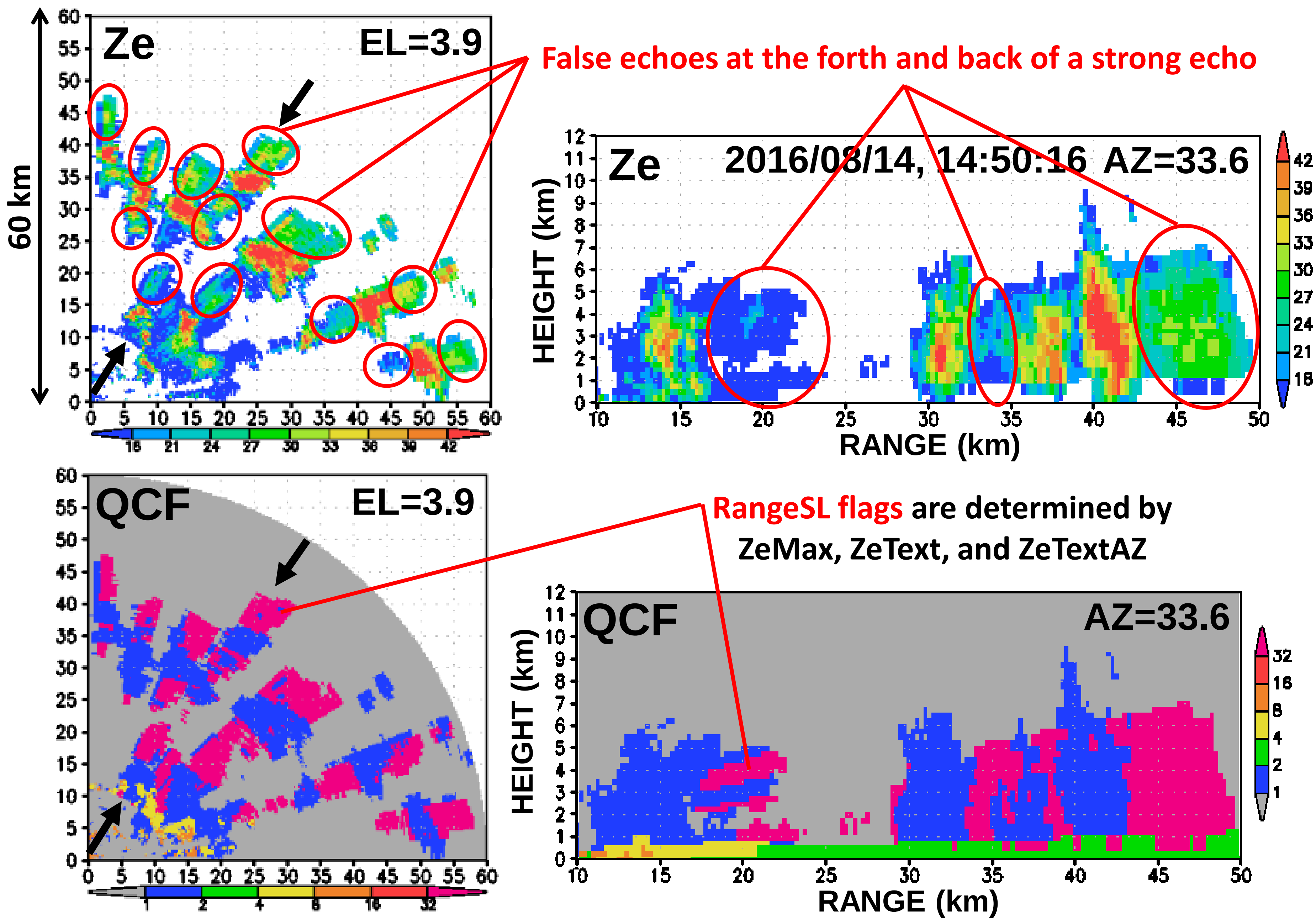
Ze and QC flag in PPIs (EL=2.0 deg)



Stratiform Rain | **Convective Rain** | **Interference Noise (fine weather)**

determined by ZeStd/ZeAvg < 0.5

Range side-lobe contamination



Computation time for creating QC flag

<< original without Interference Noise and Rng SL >>
Input file: 20150717-083019.all.
10000000.dat, and .20000000.dat
Total make qc flag **real time = 7.000** proc time = 7.890
Input data read: real time = 0.000 proc time = 0.550
Calc Ze_ave, rinteg: real time = 1.000 proc time = 0.500
Calc Ze_texture: real time = 5.000 proc time = 5.250
Make QC flag: real time = 1.000 proc time = 1.570
Output QC flag: real time = 0.000 proc time = 0.020

Only clutter detection (v0.8) after 19 June

7 sec.
(single CORE)

<< Single core CPU >>
Input file: 2015-0717/20150717-083019.all.
10000000.dat, and .20000000.dat
Total create qc flag **real time = 34.000** proc time = 34.410
Input data read: real time = 0.000 proc time = 0.470
Calc Ze_ave, rinteg: **real time = 15.000 proc time = 14.820**
Calc Ze_texture: **real time = 17.000 proc time = 17.160**
Judgement of QCF: real time = 2.000 proc time = 1.930
Output QC flag: real time = 0.000 proc time = 0.030

Current operational ver (v1.1) after 15 Sep

34 sec.
(single CORE)

openMP (8 threads)

<< -O3 & -fopenmp & OMP_NUM_THREADS=8 >>
MOP_NUM_THREADS= 8
Input file: 2015-0717/20150717-083019.all.
10000000.dat, and .20000000.dat
Total create qc flag **real time = 9.000** proc time = 15.490
Input data read: real time = 1.000 proc time = 0.470
Calc Ze_ave, rinteg: **real time = 1.000 proc time = 7.270**
Calc Ze_texture: **real time = 5.000 proc time = 6.390**
Judgement of QCF: real time = 2.000 proc time = 1.330
Output QC flag: real time = 0.000 proc time = 0.030

9 sec.
(4 CORE)

Summary

- The PAWR was developed to detect and predict localized heavy rainfall using the 3D observed big data (100 m, 100 EL angles) every 30 seconds.
- The PAWR data shows 3D structure of precipitation. 3D TREC and dual-Doppler analysis are useful to investigate the growth of precip and vertical motion.
- Big Data Assimilation (BDA) is expected for future weather forecast, but some problems remain. Real-time 3D nowcasting and smartphone application are expected for current PAWR data usage.
- The real-time data QC to remove clutter and noise echoes is essential for BDA and nowcasting.