Early detection of baby rain cell aloft in a severe storm and its risk projection using vertical vorticity detected by Doppler radars for urban flash flood

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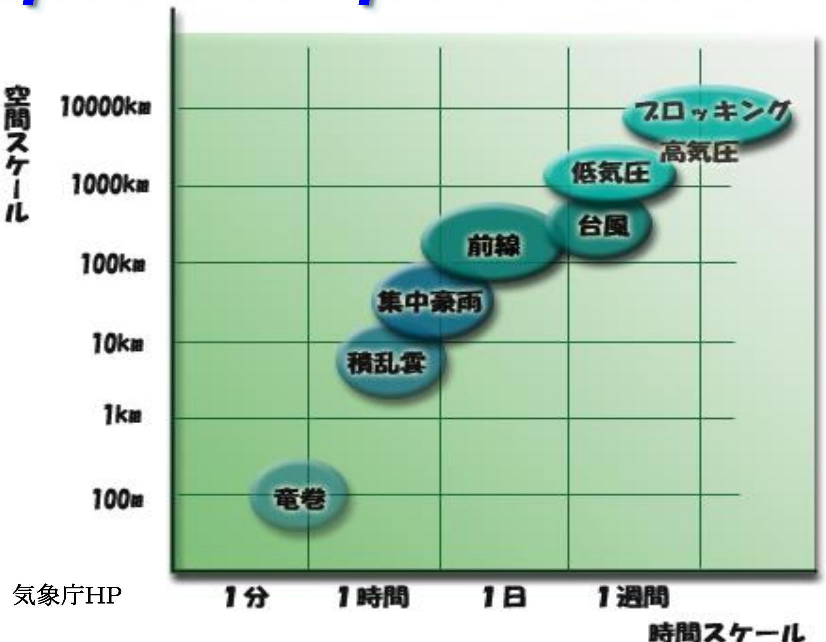
Since 2007

Contents

- Tragic flash floods disaster caused by localized heavy rainfall
- Ten to twenty minutes earlier detection of risky storm by its first echo (baby cell) aloft
- Prediction of risk at the stage of the first echo, using vertical vorticity as an index
- Operational early warning systems based on radar echo and vorticity aloft
- Analysis on vortex tube in early and developing stages of single sever storm using
  - X-band weather radar
  - Ka-band cloud radar
  - X-band phased array weather radar
- Conclusion

Spatio-temporal Scale

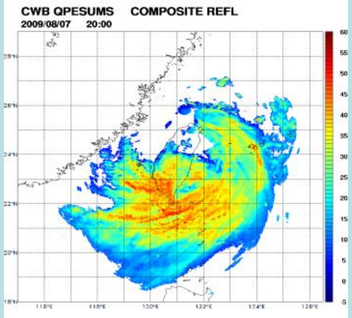


気象庁HP

Typhoon

Range: 1000km
Duration: 1day to a few days

大河川での洪水、大規模水害、土砂災害
2009/08/08 in 台湾

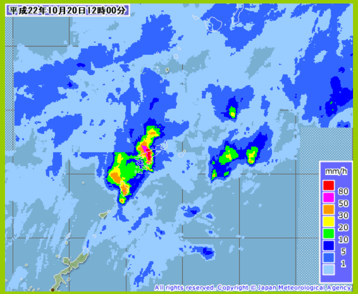


台湾中央気象局、台湾国家災害防救科技中心

Localized heavy rainfall (Baiu season)

Range: 100km
Duration: 6 hours to half a day

中・小河川での洪水、内水氾濫、土砂災害
2010/10/20 in奄美



南日本新聞 OFFICIAL SITE

Shower or Torrential rainfall

Range: 10km
Duration: about half an hour

小河川や下水道内での鉄砲水、都市内水氾濫
2008/07/28 at 都賀川　2008/08/05 at 雑司ヶ谷

都賀川モニタリング映像

共同通信

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Background (Urban Flash Flood)

Disasters caused by torrential rainfall in July, 2008

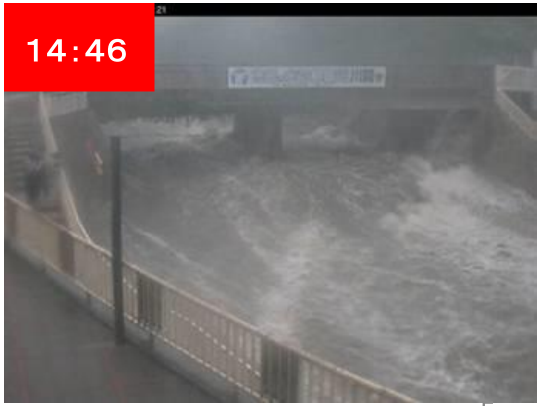
On July 28　(Toga River, Kobe)

About 50 people were washed away by the flash flood in Toga River, Kobe, Japan, without any overpass from embankment. Five people were died.

In this case, many people were enjoying in the river side park. This is the place where public people enjoy the water front. The local people and Kobe government have been making any efforts to develop such the water front.

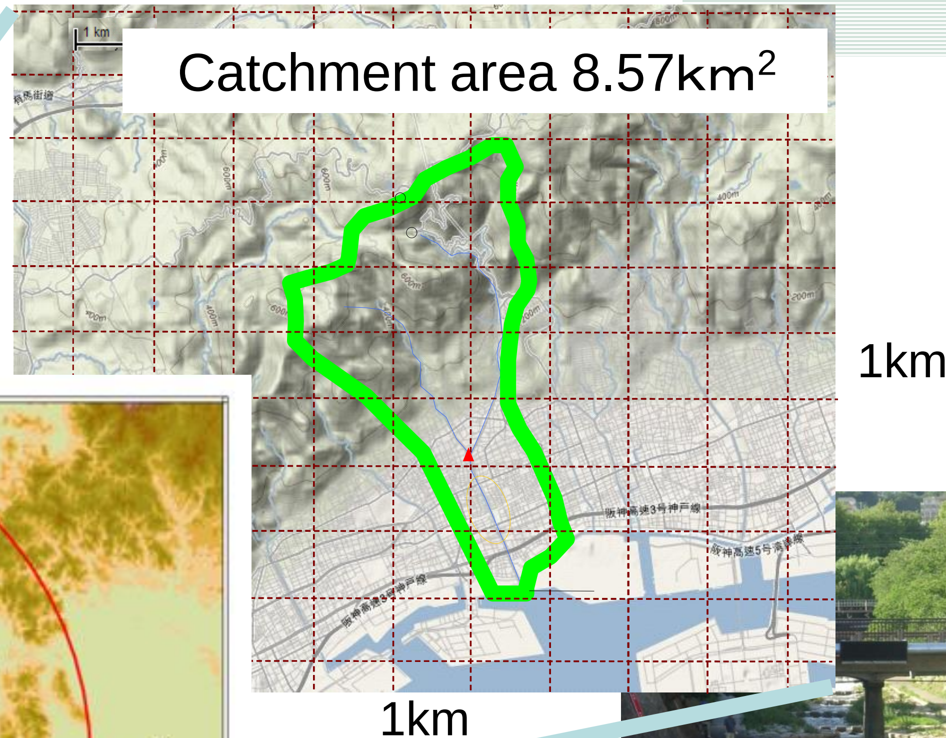
There is a risk that same kind of disaster could occur in small river basin in any urban area.

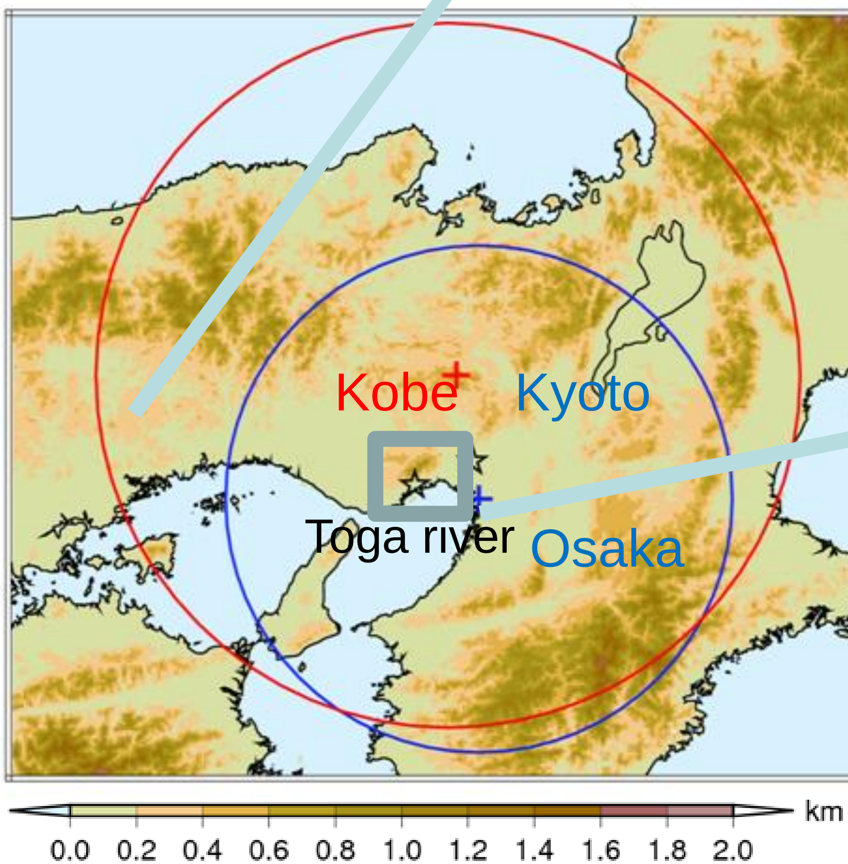
10 min later

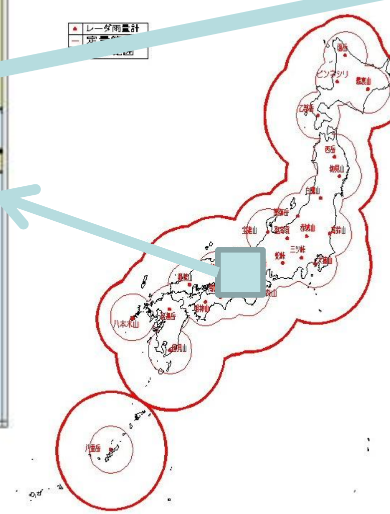


Toga River Basin

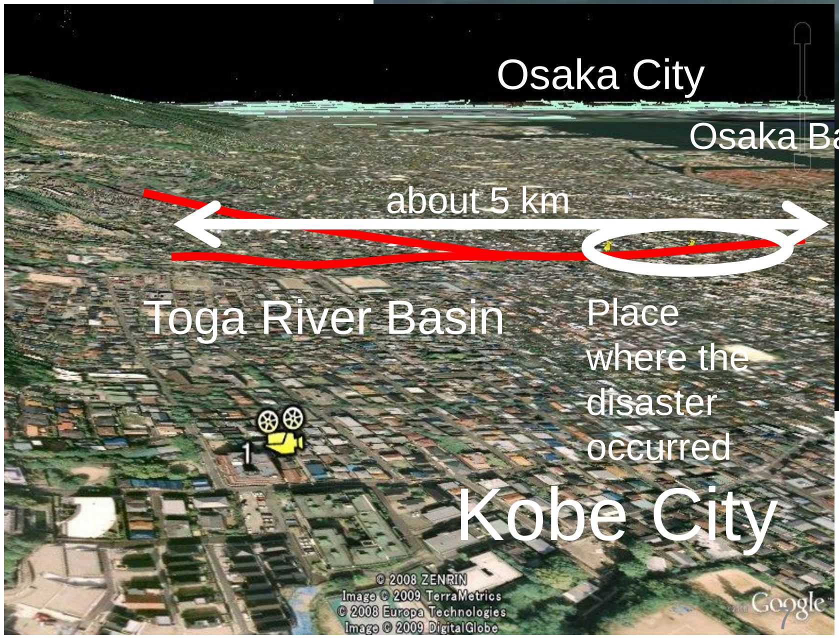
As you can see the size of river basin is very small.



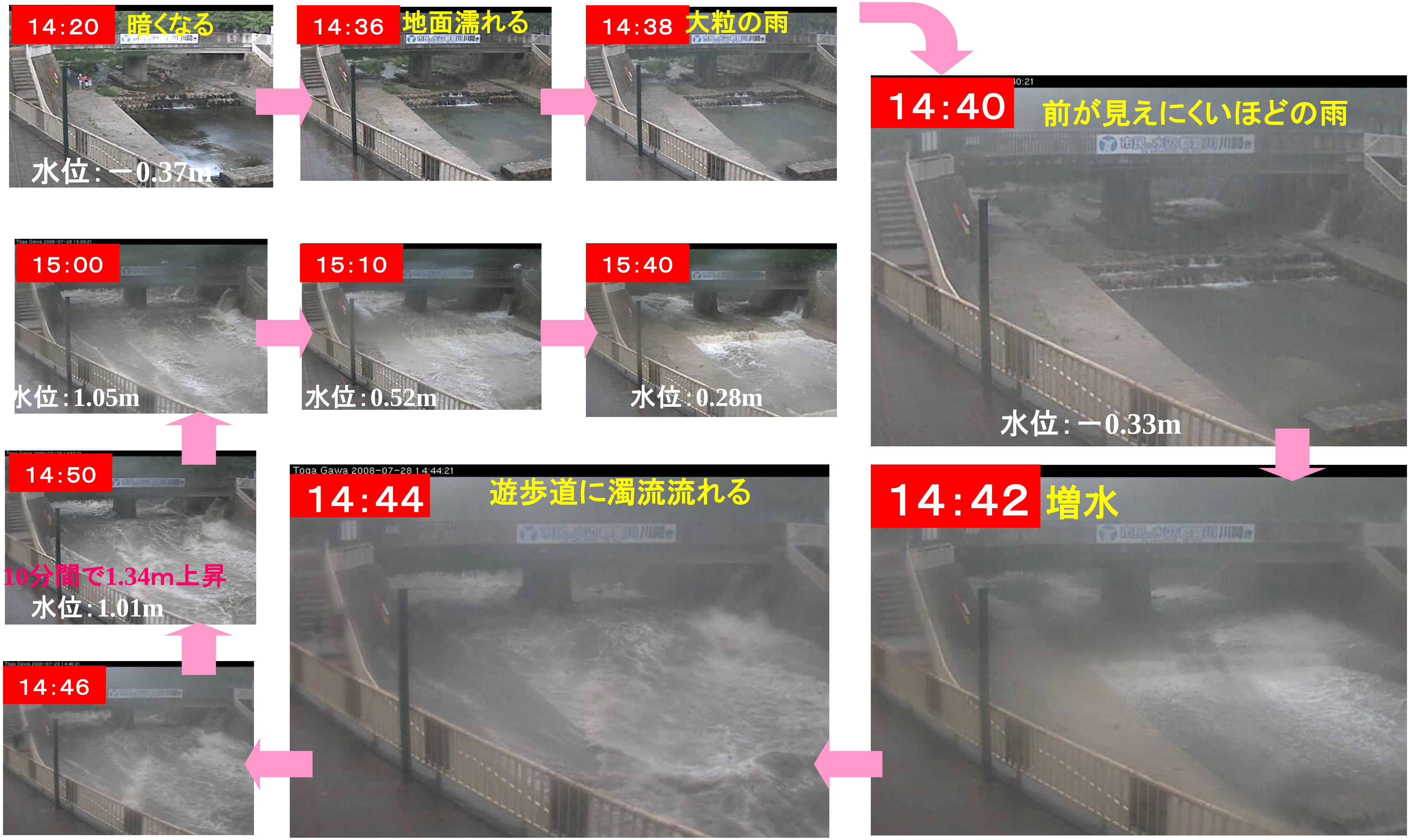




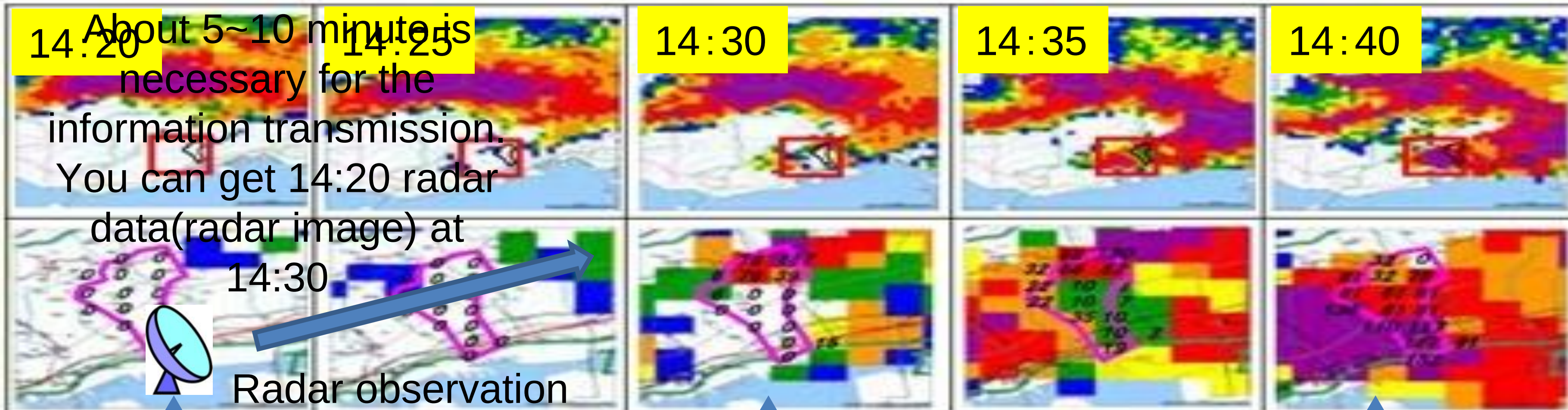
View around Toga River Basin 20 min. before flash flood




Toga Gawa 2008-07-28 14:22:21
川開き


14:20 暗くなる
水位：－0.37m
14:36 地面濡れる
14:38 大粒の雨
14:40 前が見えにくいほどの雨
水位：－0.33m
14:42 増水
Toga Gawa 2008-07-28 14:44:21
14:44 遊歩道に濁流流れる
14:46
14:50
10分間で1.34m上昇
水位：1.01m
15:00
水位：1.05m
15:10
水位：0.52m
15:40
水位：0.28m

Operationally distributed radar image



14:42

Time

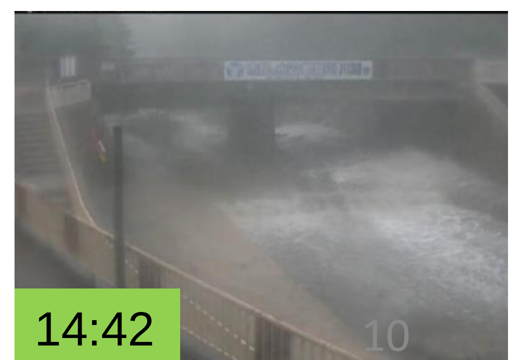
14:20

14:30

14:40

flood

- ✓The rain area covered all the small river at 14:35:
- ✓Flash flood occurred at 14:42.
- ✓Runoff concentration time is very short.
- ✓In this case, you may think that this 7 minutes is enough for people to escape . However you should not forget that we need time for making and transmitting radar image.
- ✓People can verify the radar image which showed us that the rain area covered all the small river base is after flash occurred.



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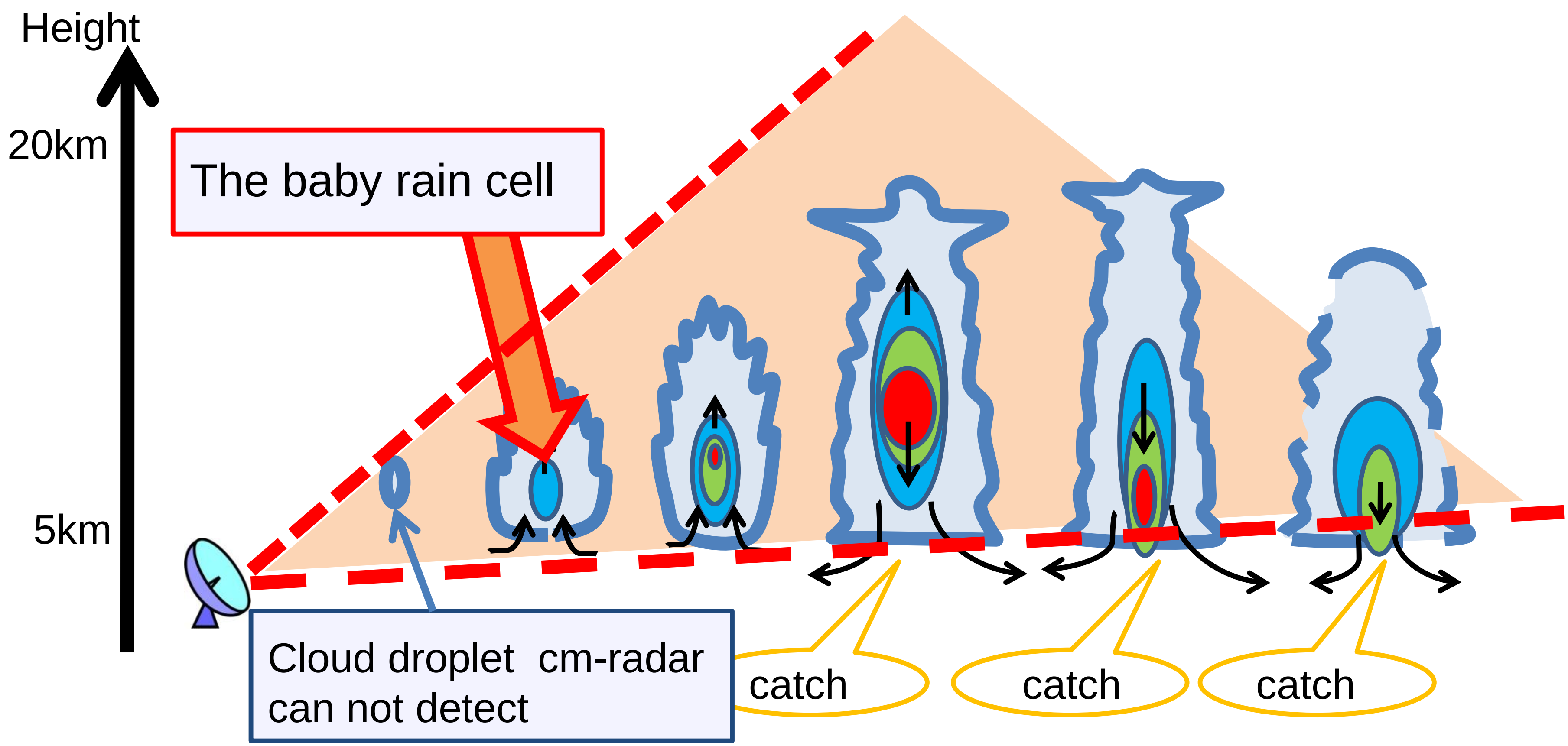
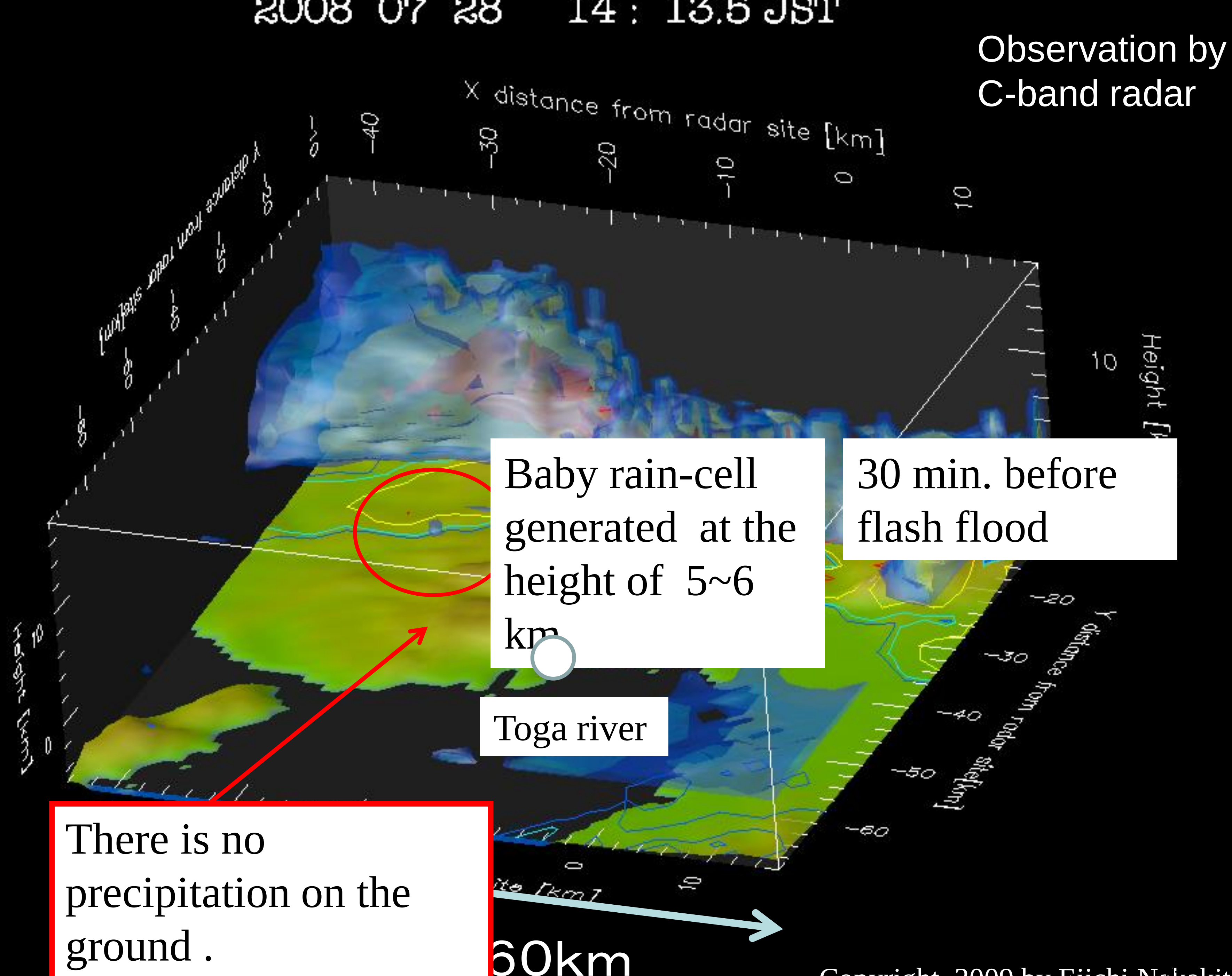
Earlier detection of baby cell for warning



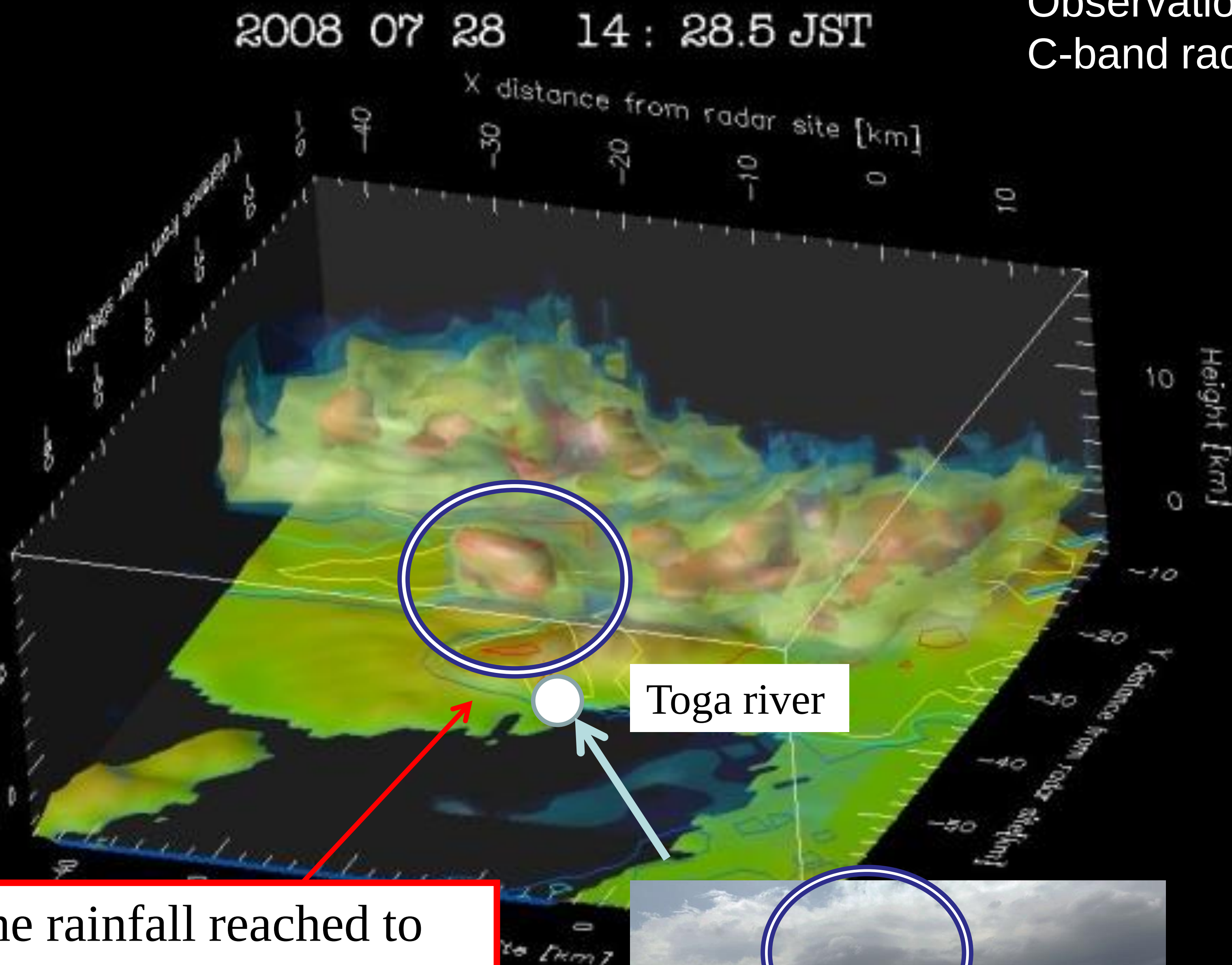
✓ Even **single convective system** brings the regional localized short-tem torrential rain within 30 minutes from its generation.

✓This torrential rain brings flash flood in **small sized urban** river channel which is utilized as **waterside park**.

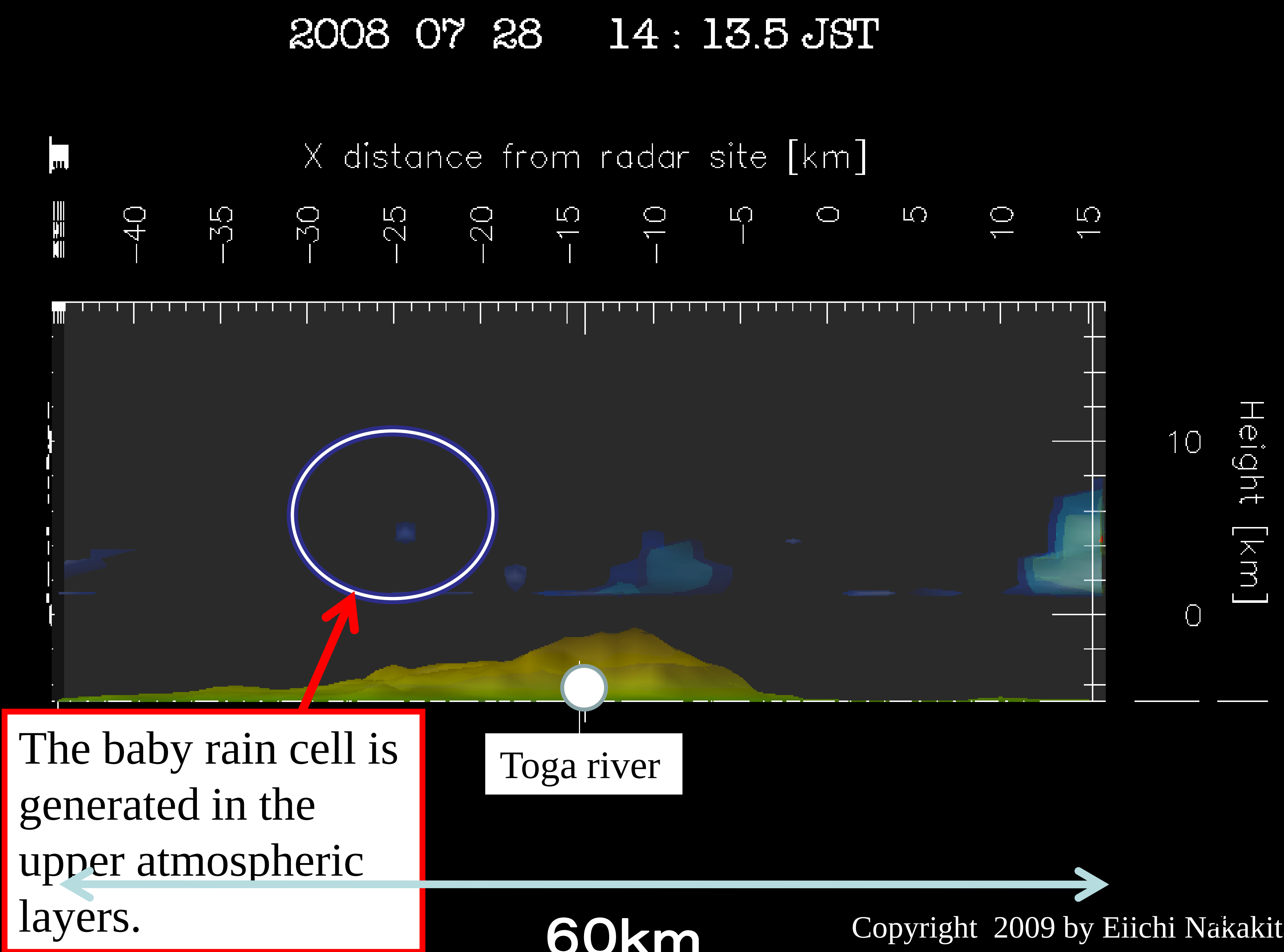
✓Even it's 5 to10 minutes, **earlier detection of baby cell aloft** is quite crucial for disaster prevention.


2008 07 28 14: 13.5 JST
Observation by C-band radar
X distance from radar site [km]
-40
-30
-20
-10
0
10
Height
10
Baby rain-cell generated at the height of 5~6 km
30 min. before flash flood
-20
-30
-40
-50
-60
Y distance from radar site[km]
Toga river
Height [km]
10
0
There is no precipitation on the ground .
60km
0
10

Observation by
C-band radar

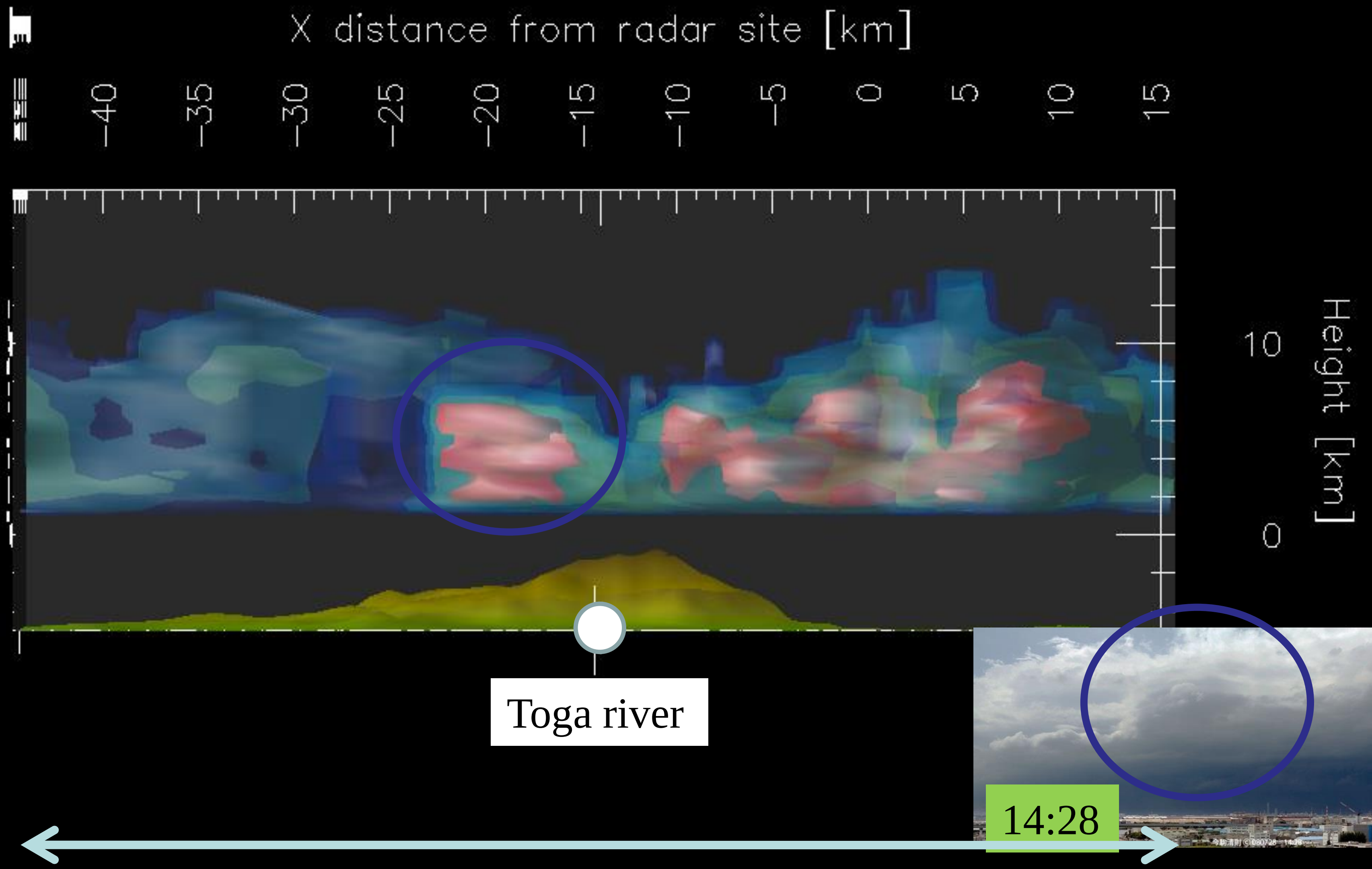


The rainfall reached to the ground surface.



The baby rain cell is generated in the upper atmospheric layers.

2008 07 28 14 : 28.5 JST



Baby rain cell detected aloft by a C-band radar raingauge in the case of the Toga river disaster

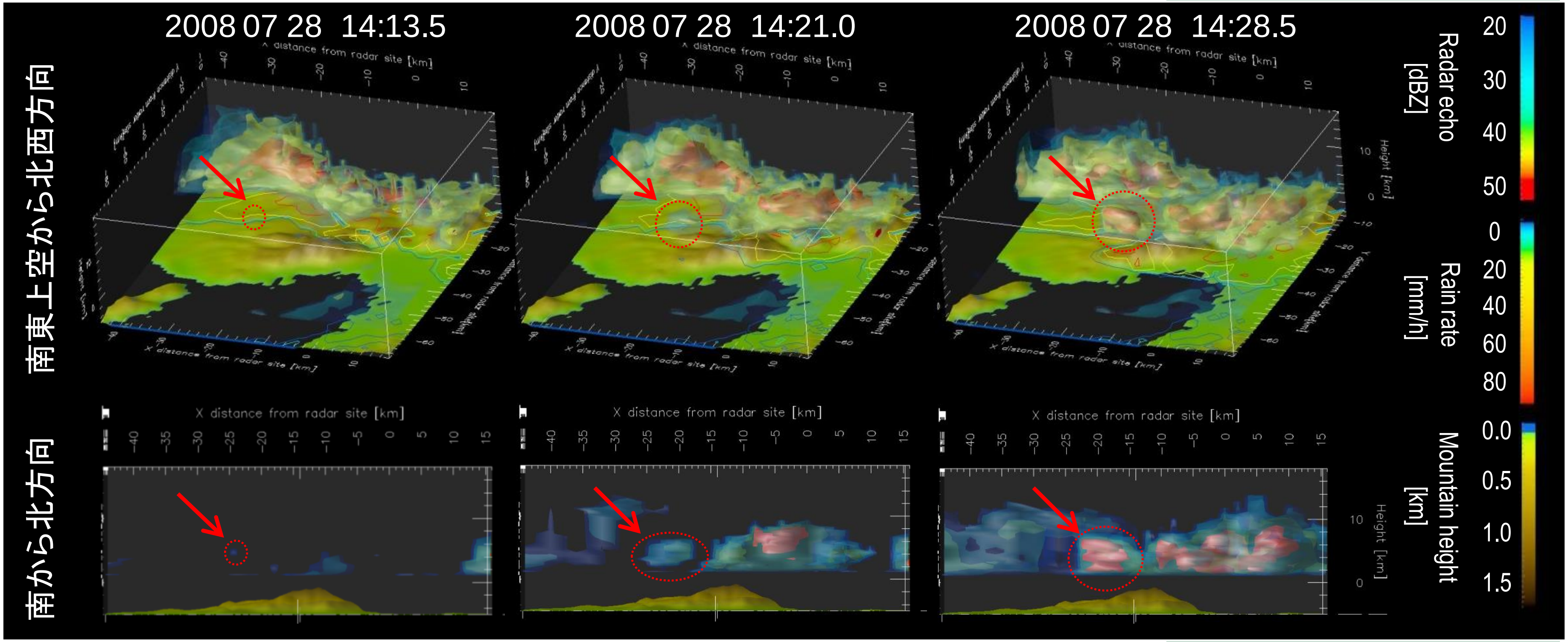
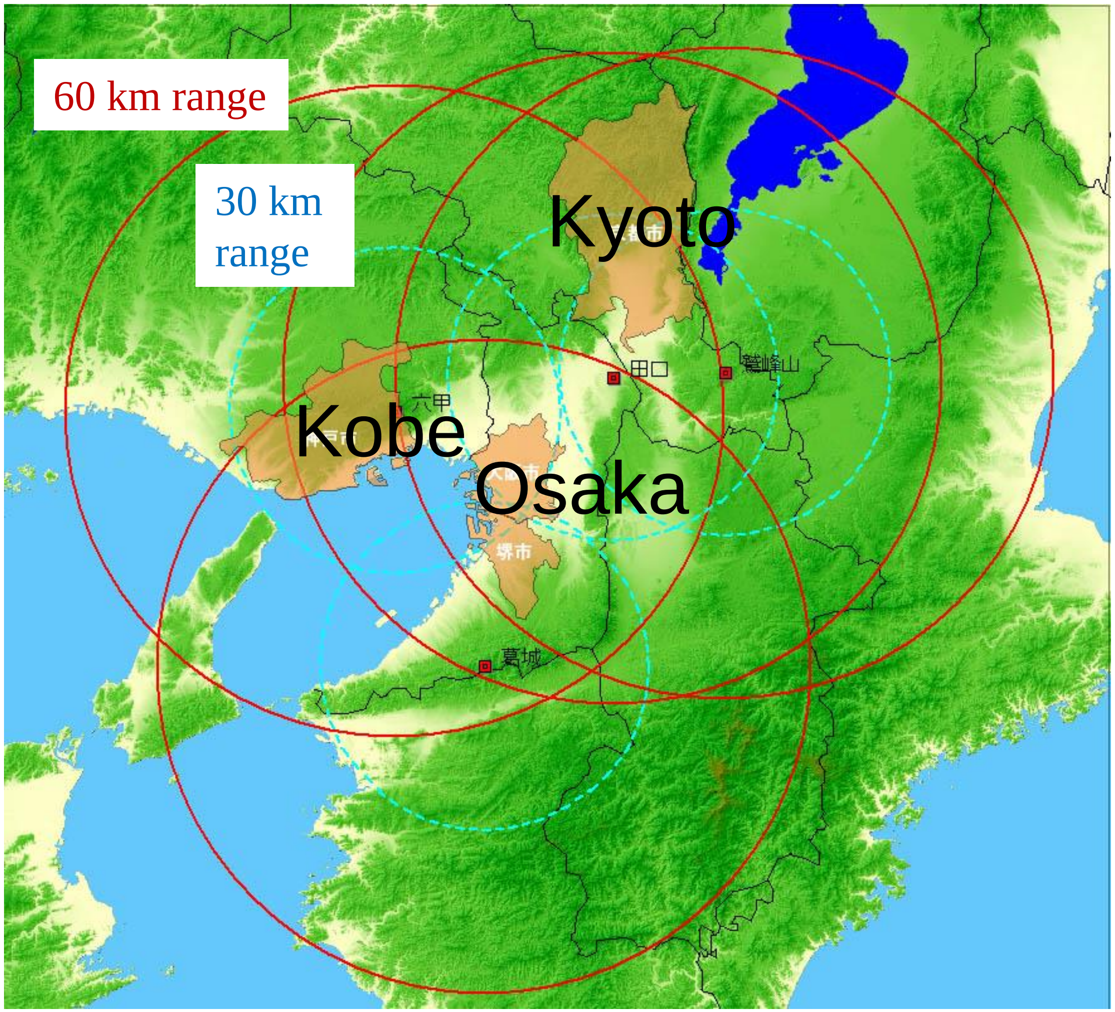


図2　ゲリラ豪雨のタマゴを捉えていた、都賀川豪雨時の深山レーダー立体観測画像[3)]

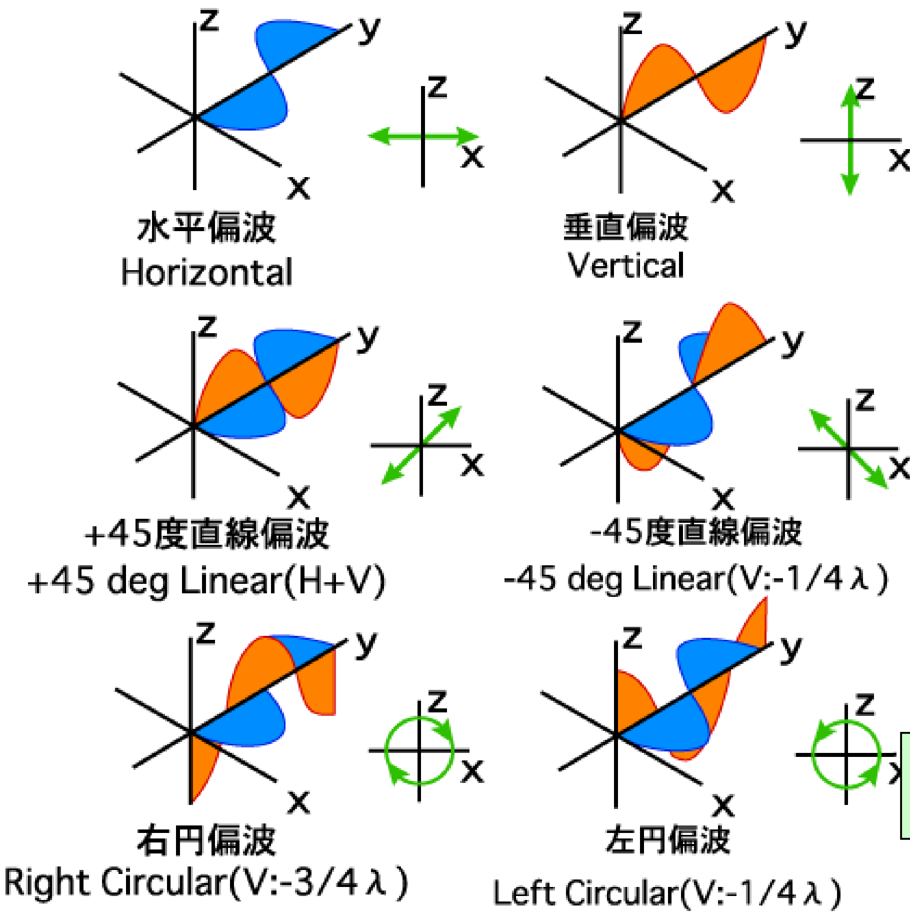
Nakakita, Yamabe and Yamagchi（2010)

New operational network by X-RAIN in Kyoto, Osaka Kobe area



- **Higher sensitivity by :**
  X band radar
- **Higher spatial resolution by :**
  X band radar (250m)
  Dense network
- **Free from attenuation by :**
  Polarimetric function (K_{DP})
  Dense network together with C-band
- **Higher accuracy by :**
  Polarimetric function (Z_{DR}, K_{DP})
- **Shorter scan interval with low elevation :**
  1 minute
- **Shorter transmission time :**
  1 minute
- **Earlier detection of baby cell:**
  Volume scan (3D image)

What is the polarimetric radar？



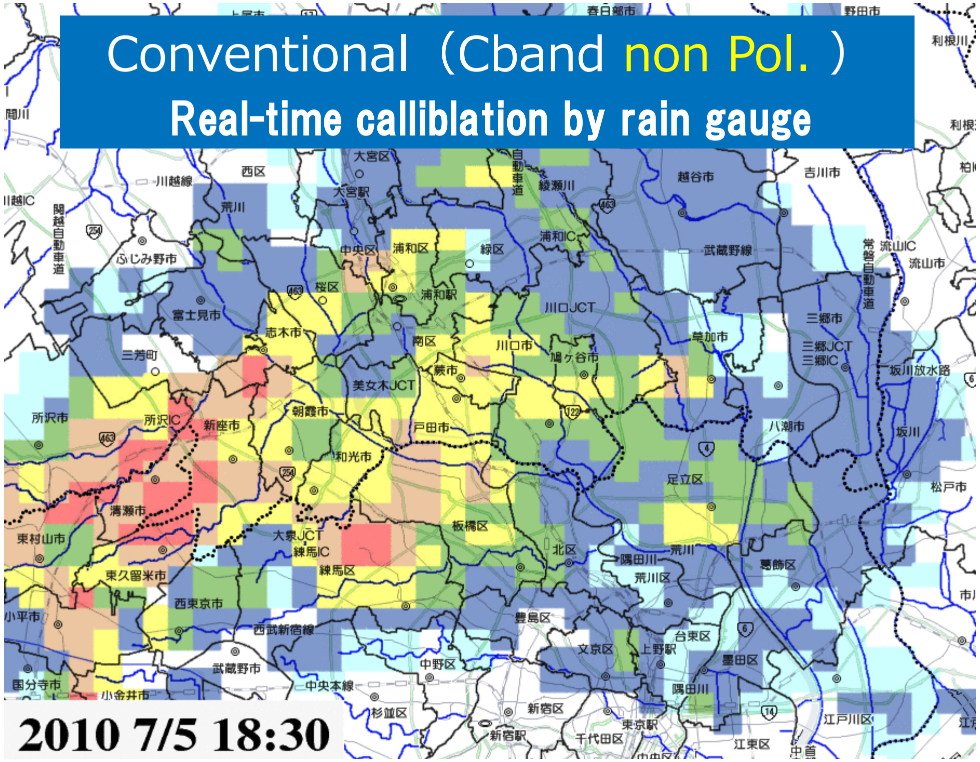
- Conventional radar uses only Horizontal wave
- Polarimetric radar can produce many kind of polarized wave
- The latest polarimetric radar can get difference of not only power but also phase shift between polarizations.

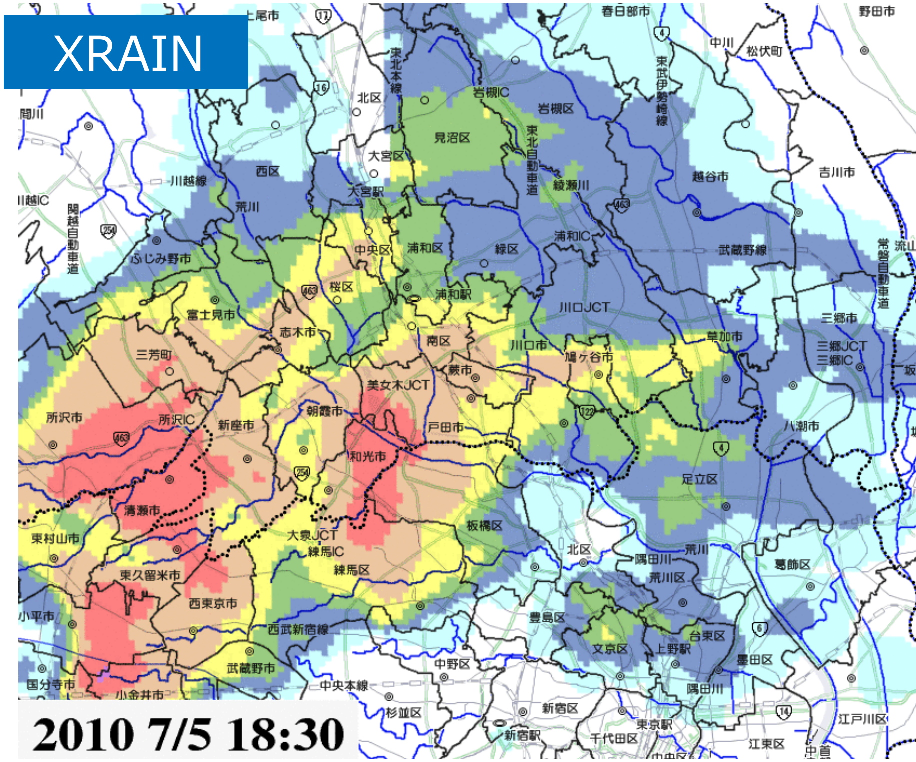
Shape and size of hydrometeors

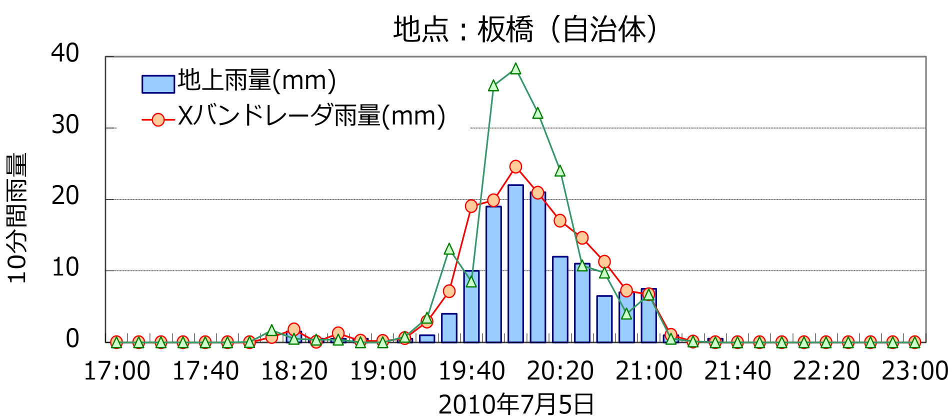
Type of hydrometeors | **Drop Size Distribution**

Improvements of
Quantitative precipitation estimation (QPE)
Quantitative precipitation Forecast (QPF)
=> Flash flood forecast

Advantage of XRAIN

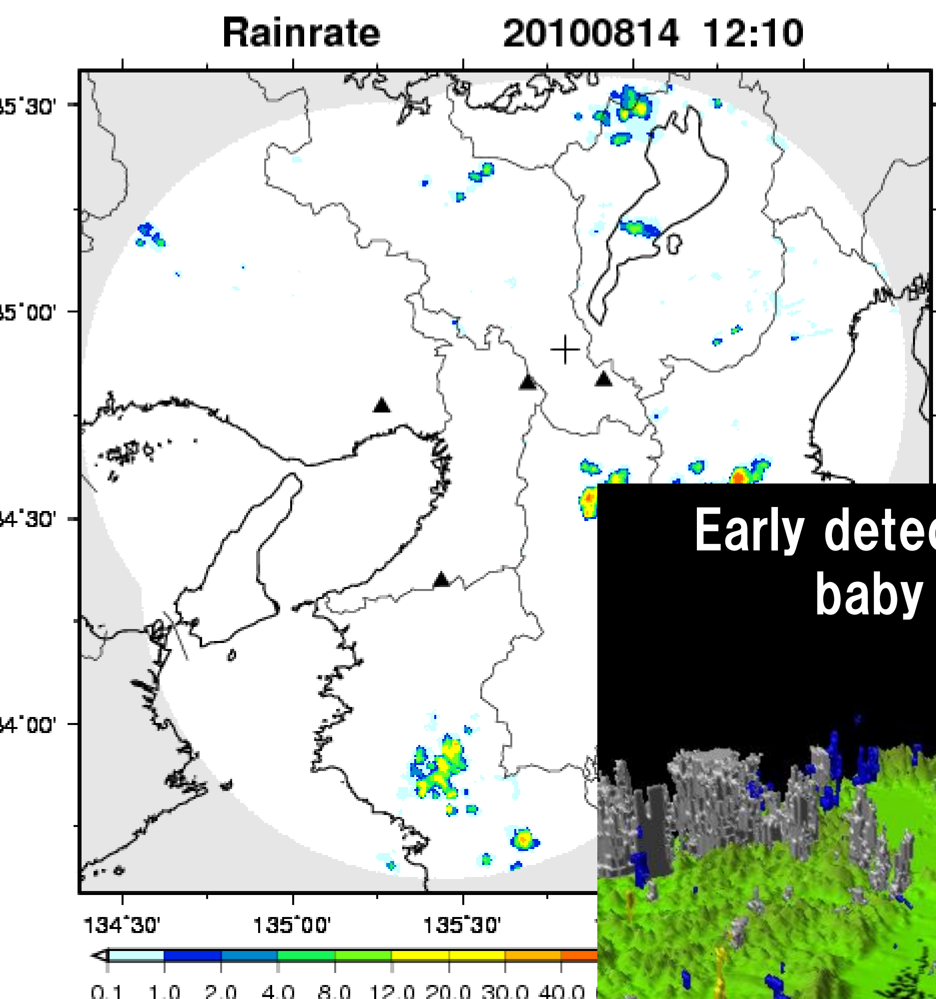


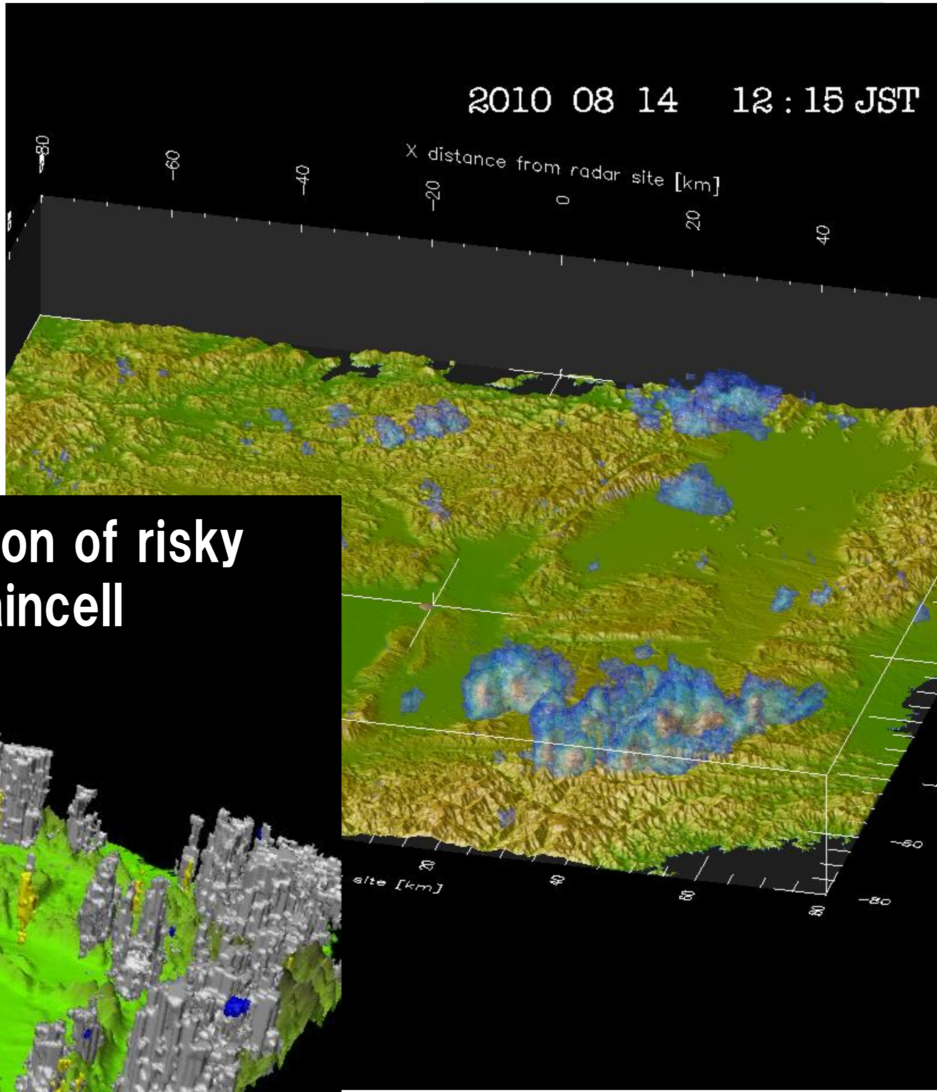


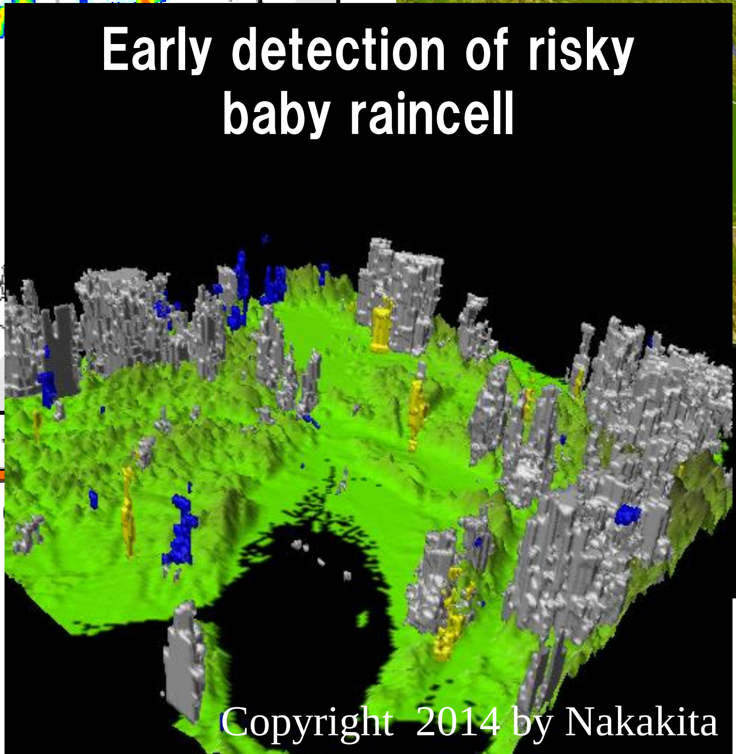


⇒ QPE for 10 min rainfall has been very improved by *K*DP.
⇒ Discrimination and movement of individual storm cell has been made clearer.
⇒Nowcast has been improved.

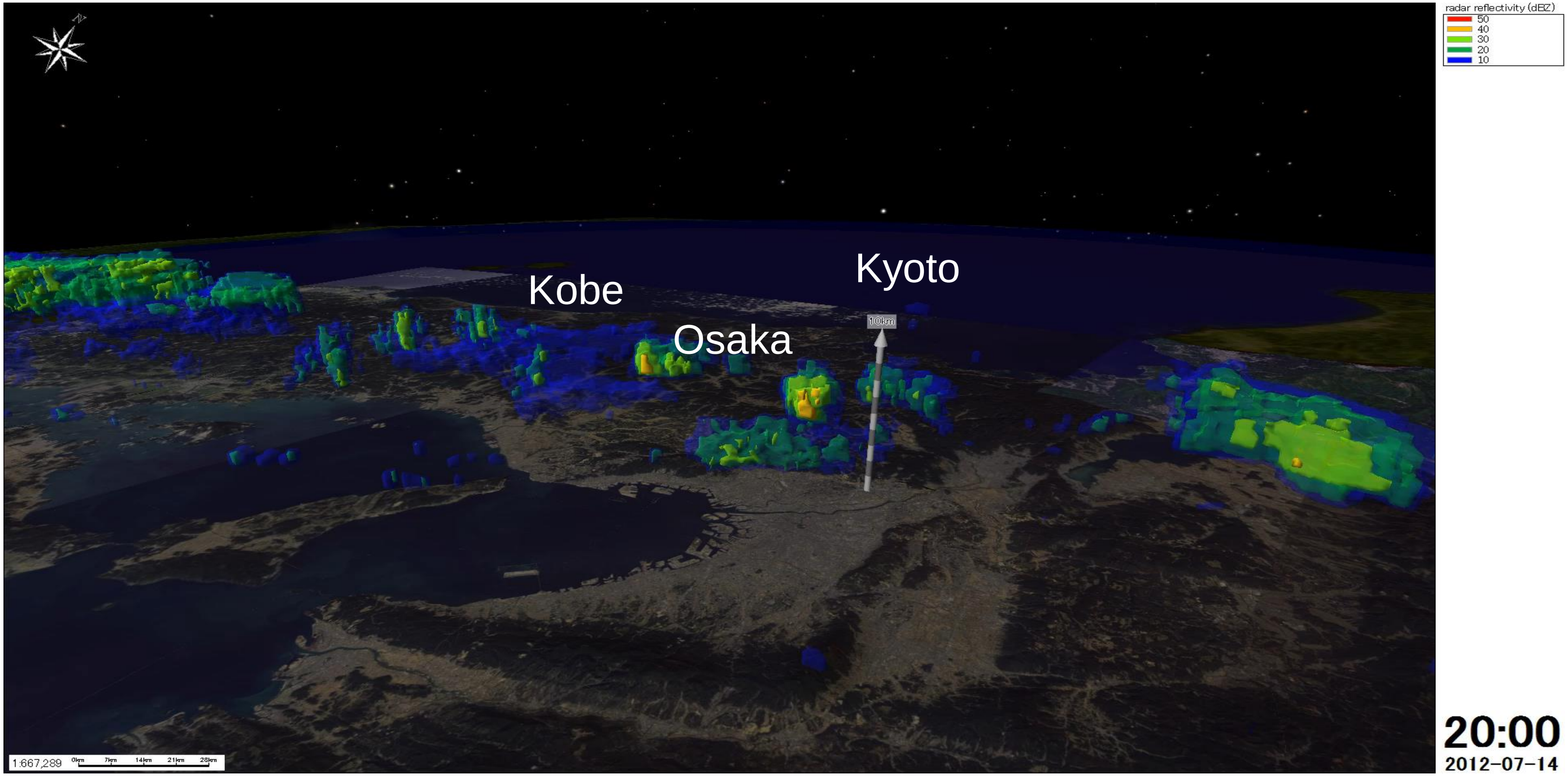
Radar images by XRAIN(1)





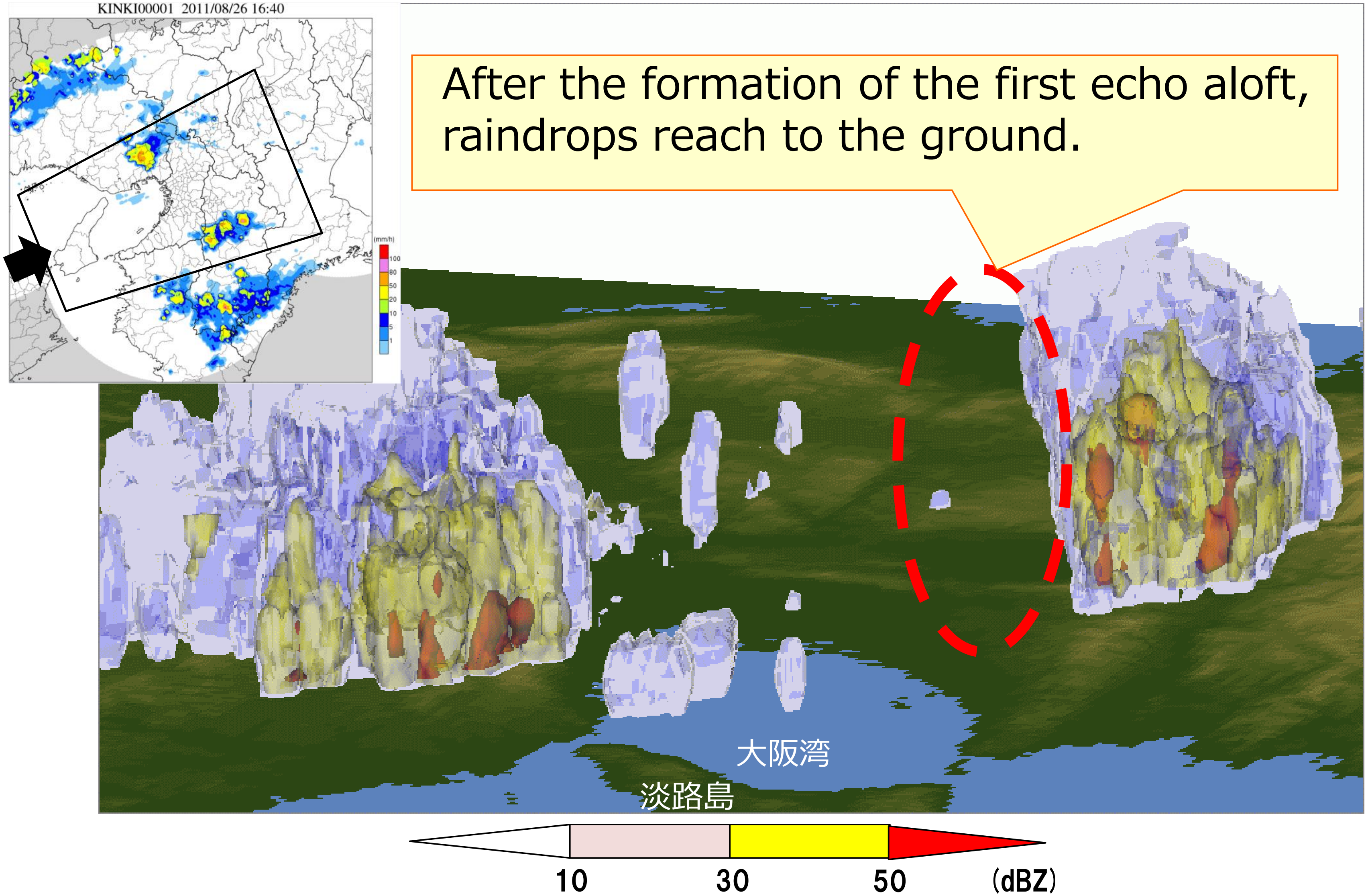


Radar images by XRAIN(2)
Line-shape sever stormes

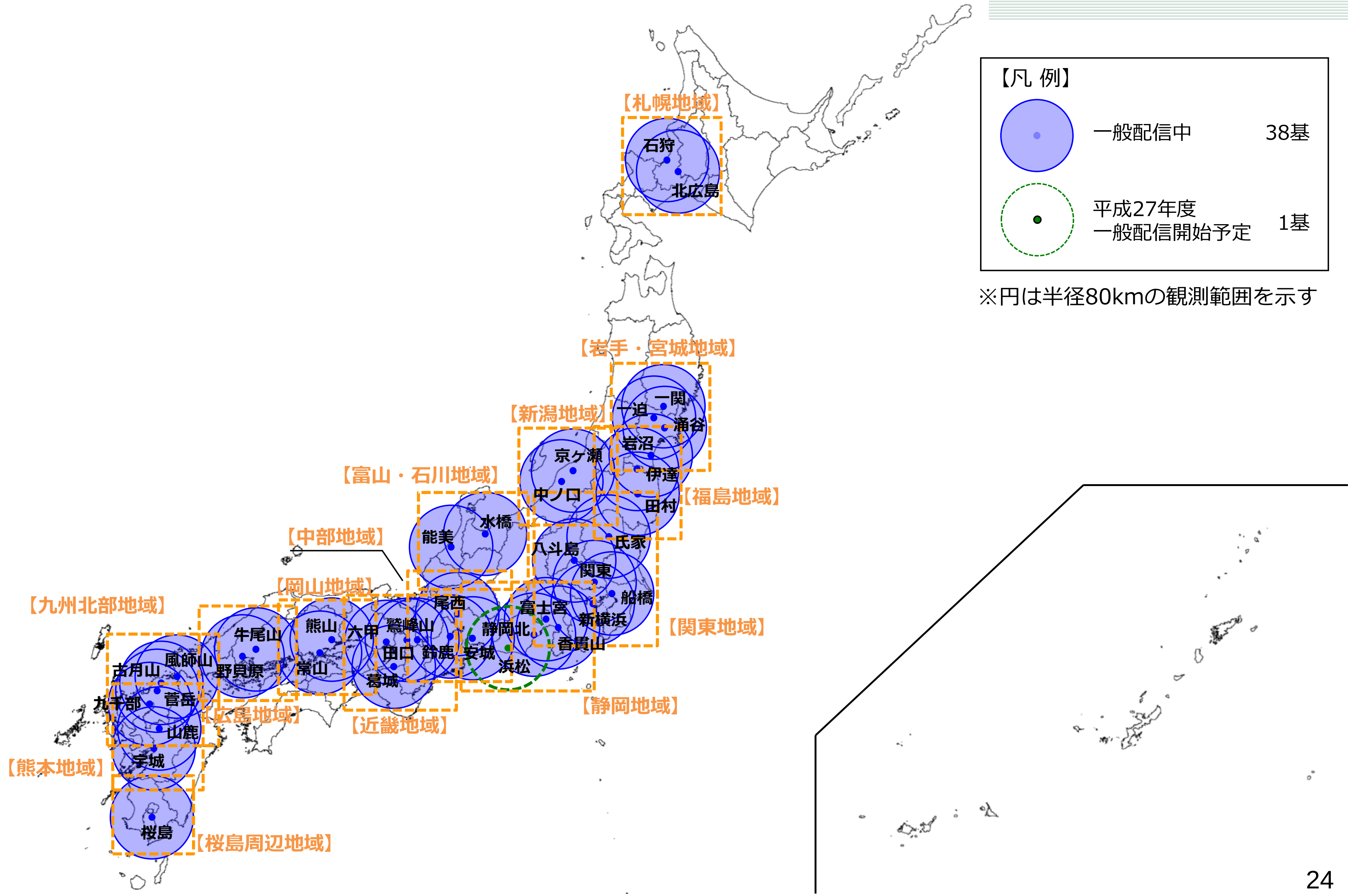


3D animation of development from the first echo with every one minute.

豪雨のタマゴの探知事例（2011年8月26日16:40～17:10、1コマ1分）



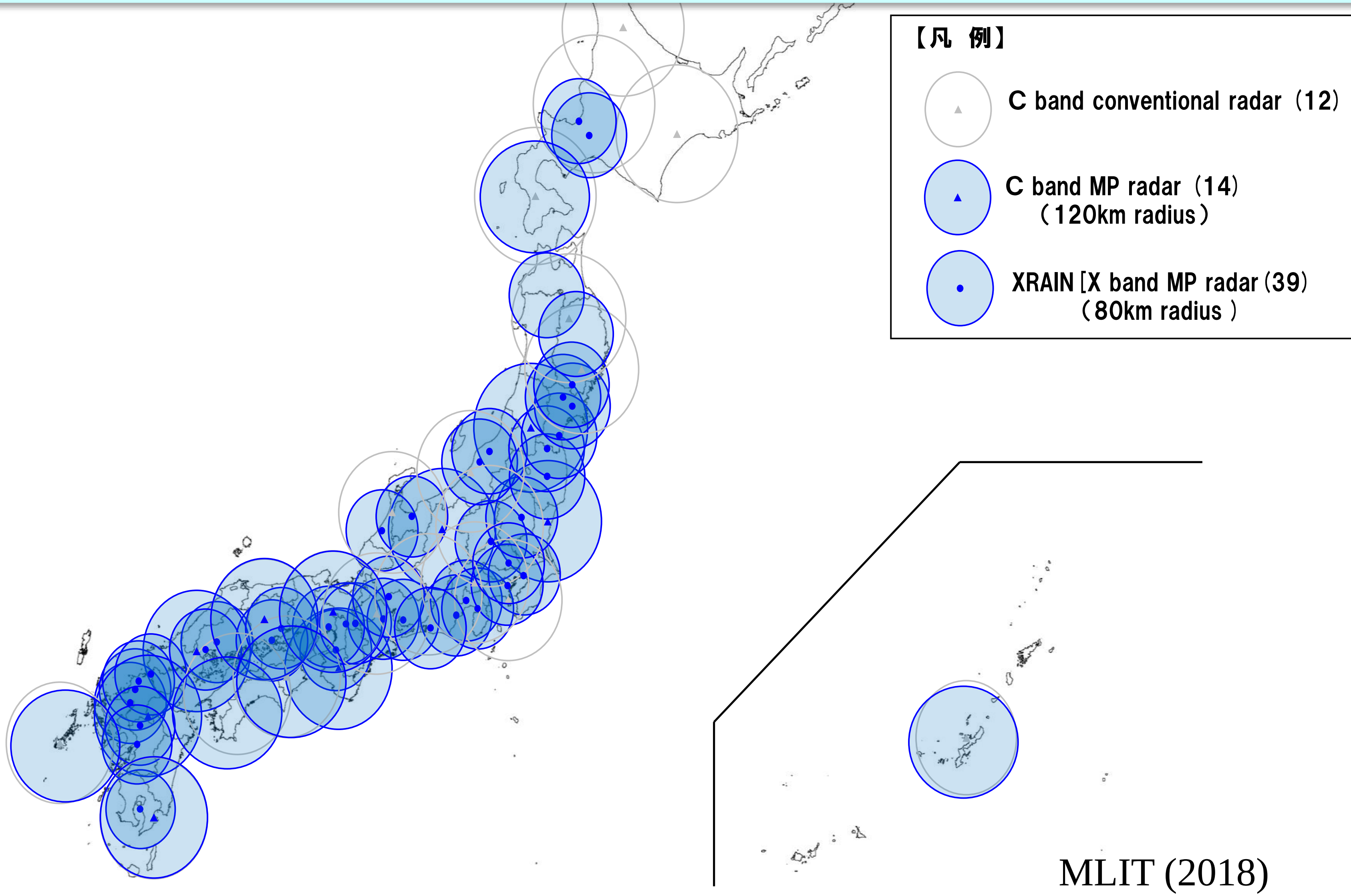
X-RAIN X-band Polerimetric (MP)operational radar network by MLIT



※円は半径80kmの観測範囲を示す

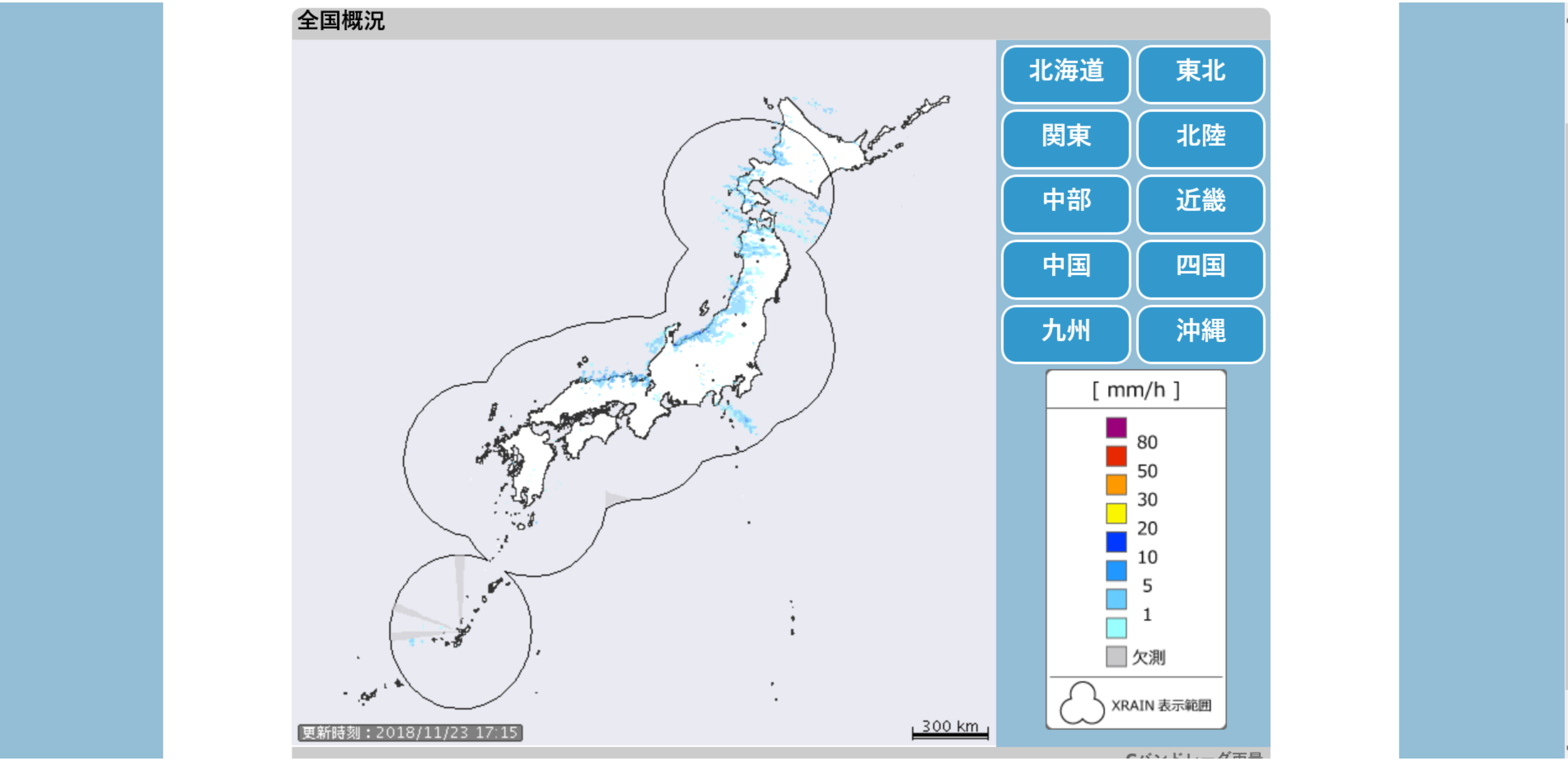
C and X band operational MP radars networks by MLIT

•Nation wide composite rainfall Map with 250 m spatial and 1 min temporal resolutions will be available from next summer



MLIT (2018)

Extended XRAIN by CMP+XMP（since July 1st in 2018）



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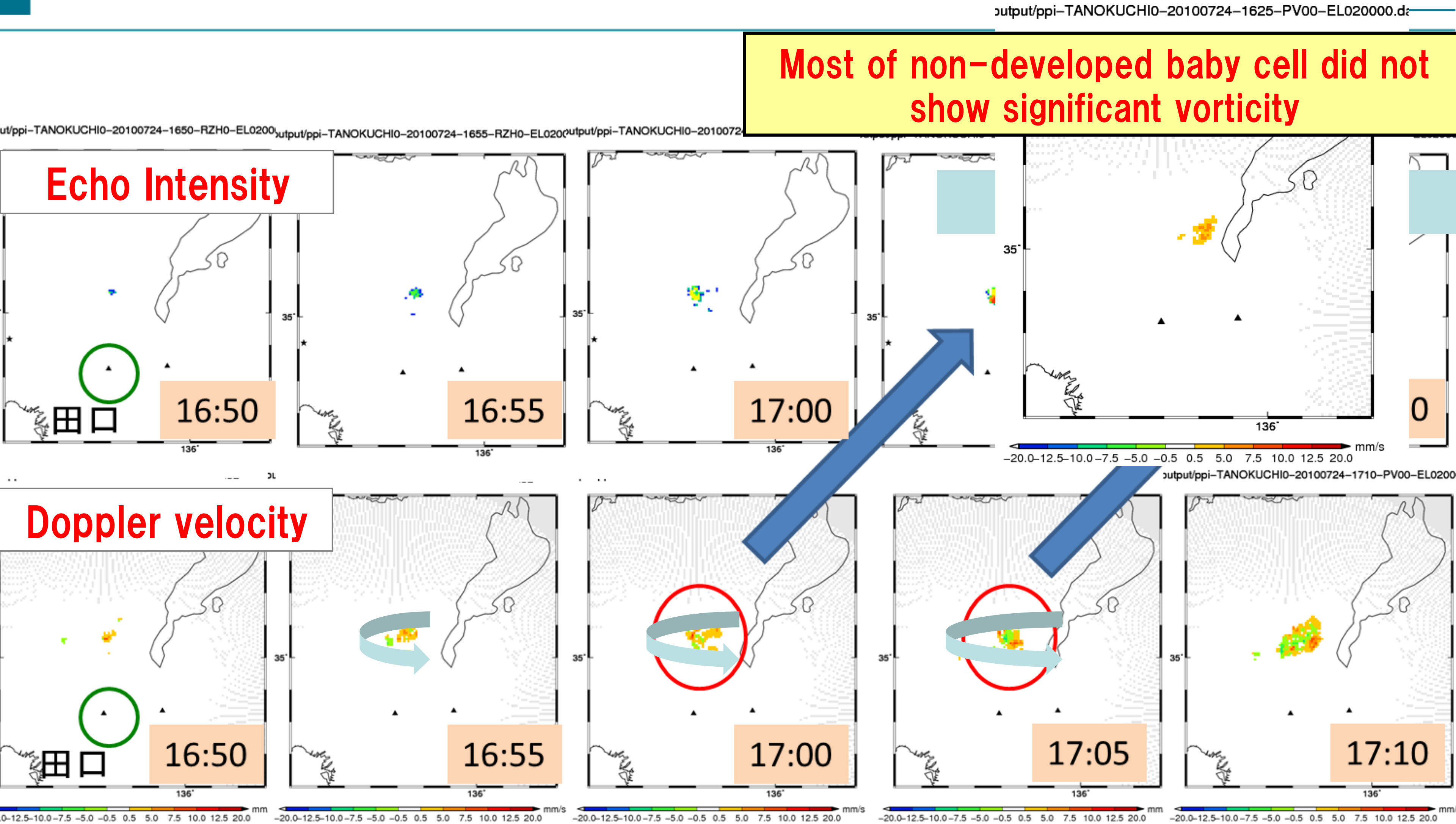
Risk projection based on vorticity

Most of non-developed baby cell did not show significant vorticity



Almost all rapidly grown baby cell showed vertical vorticity by Doppler velocity

Nakakita, Yamabe and Yamaguchi (2011)

Pseudo-Vorticity

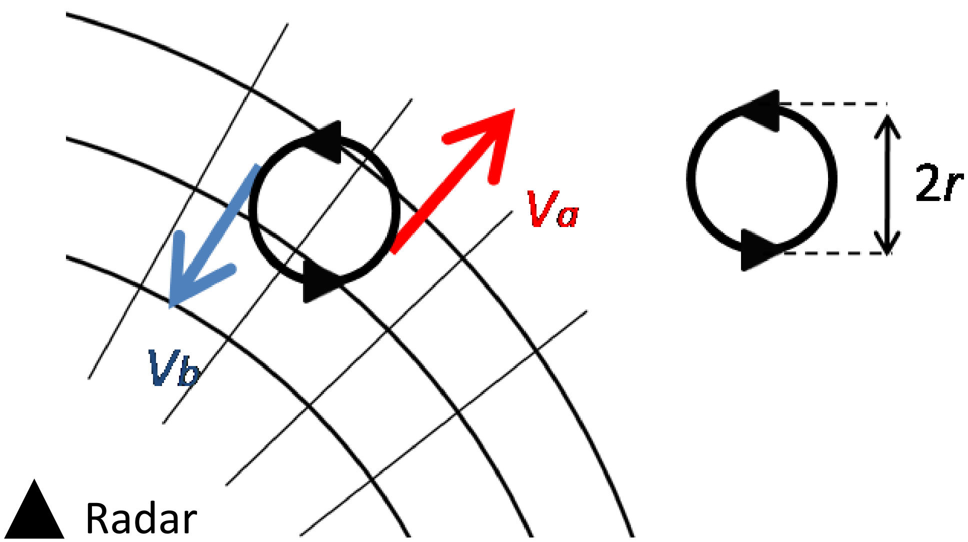
Doppler Velocity

$$v = -\frac{\lambda f_d}{2}$$

v : Doppler velocity
λ : Wavelength
f_d : Doppler frequency

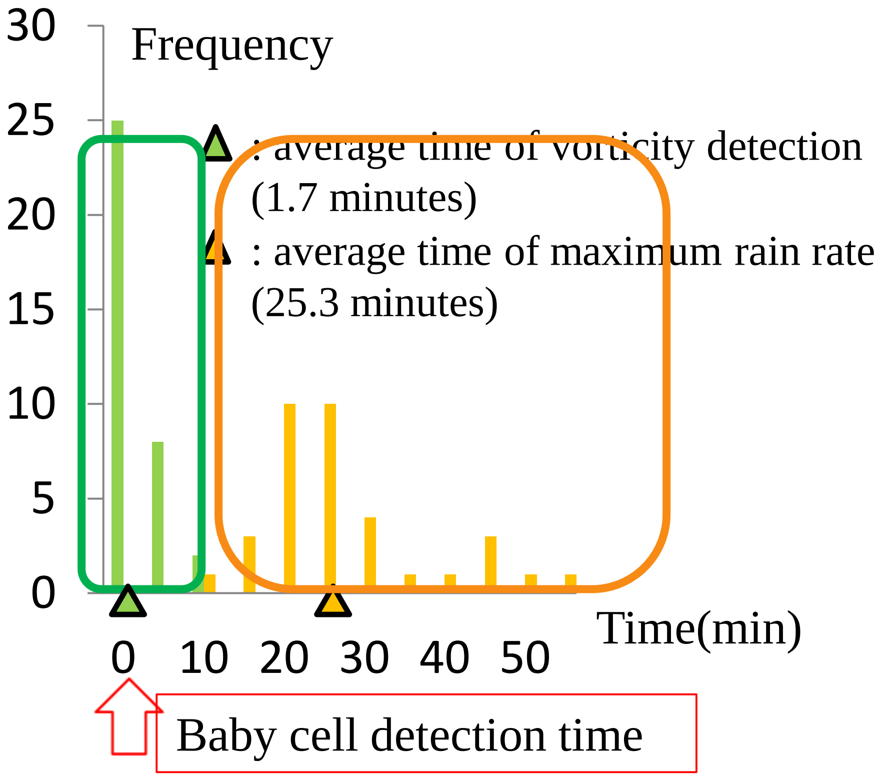
Pseudo-Vorticity

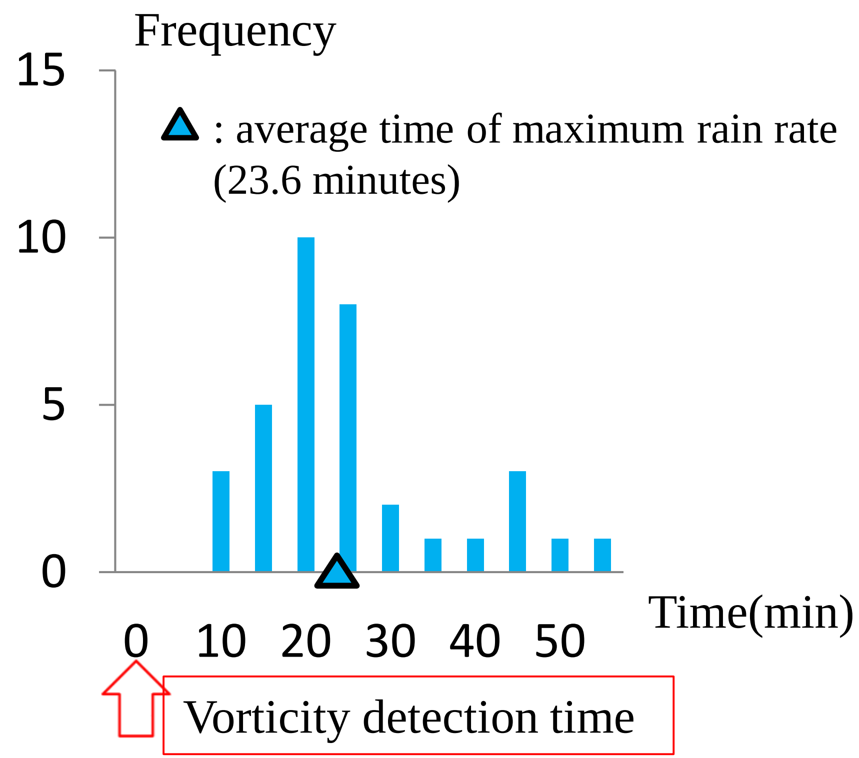
: Calculate pseudo-vorticity using Doppler velocity at two adjacent mesh



$$\zeta \equiv \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

$$\simeq 2 \times \frac{v_a - v_b}{2r}$$



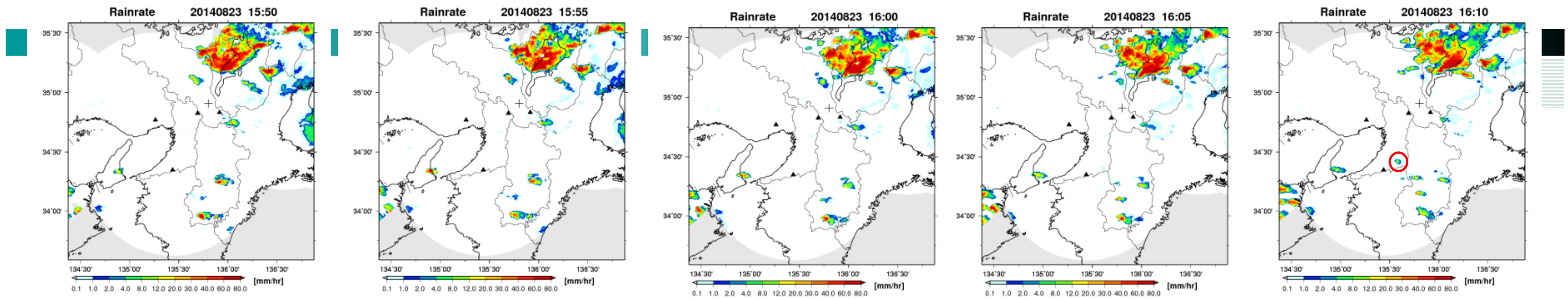


Vorticity ⇨ Torrential rainfall

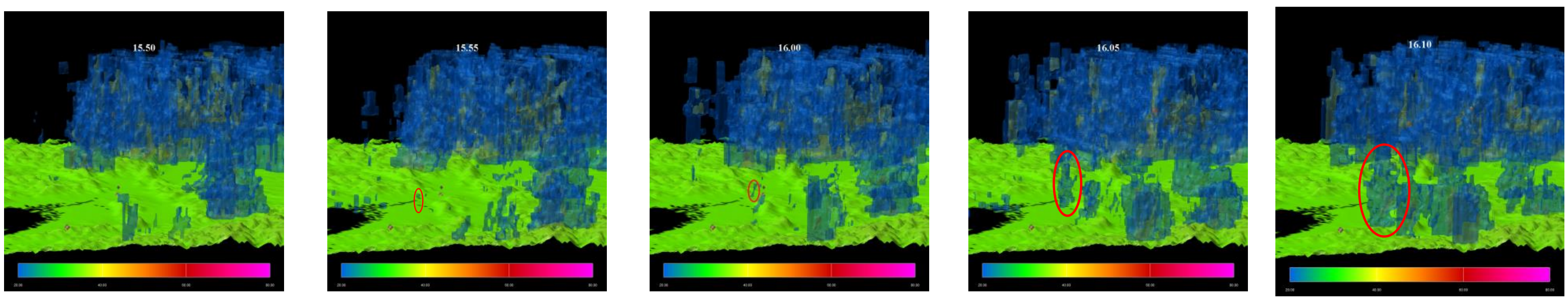
Vorticity is useful information to predict the risk

Nakakita, Satoh and Yamaguchi (2015)

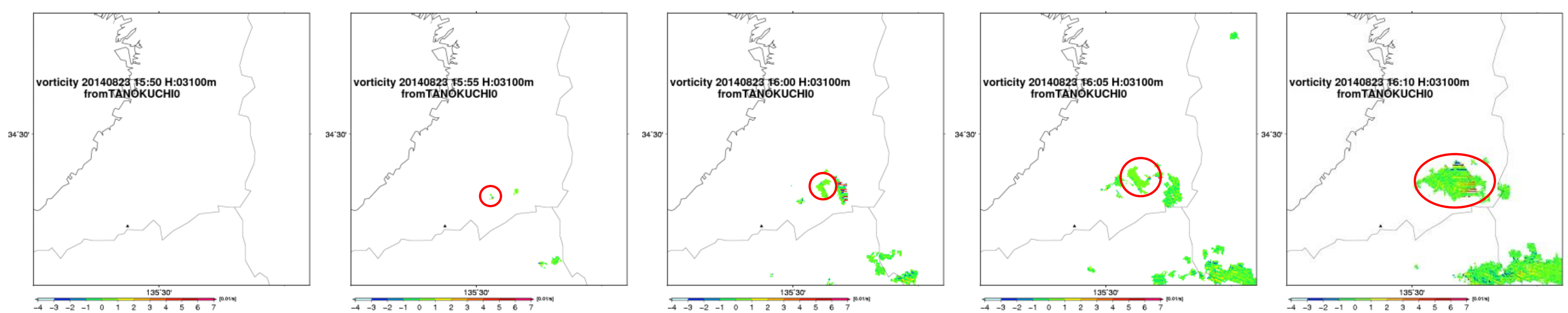
2次元降雨強度（地上での雨降り始め時刻16:06）**(Radar echo near surface)**



3次元降雨強度（豪雨のタマゴ発生確認時刻16:00）**(Three-dimensional view of Radar echo)**



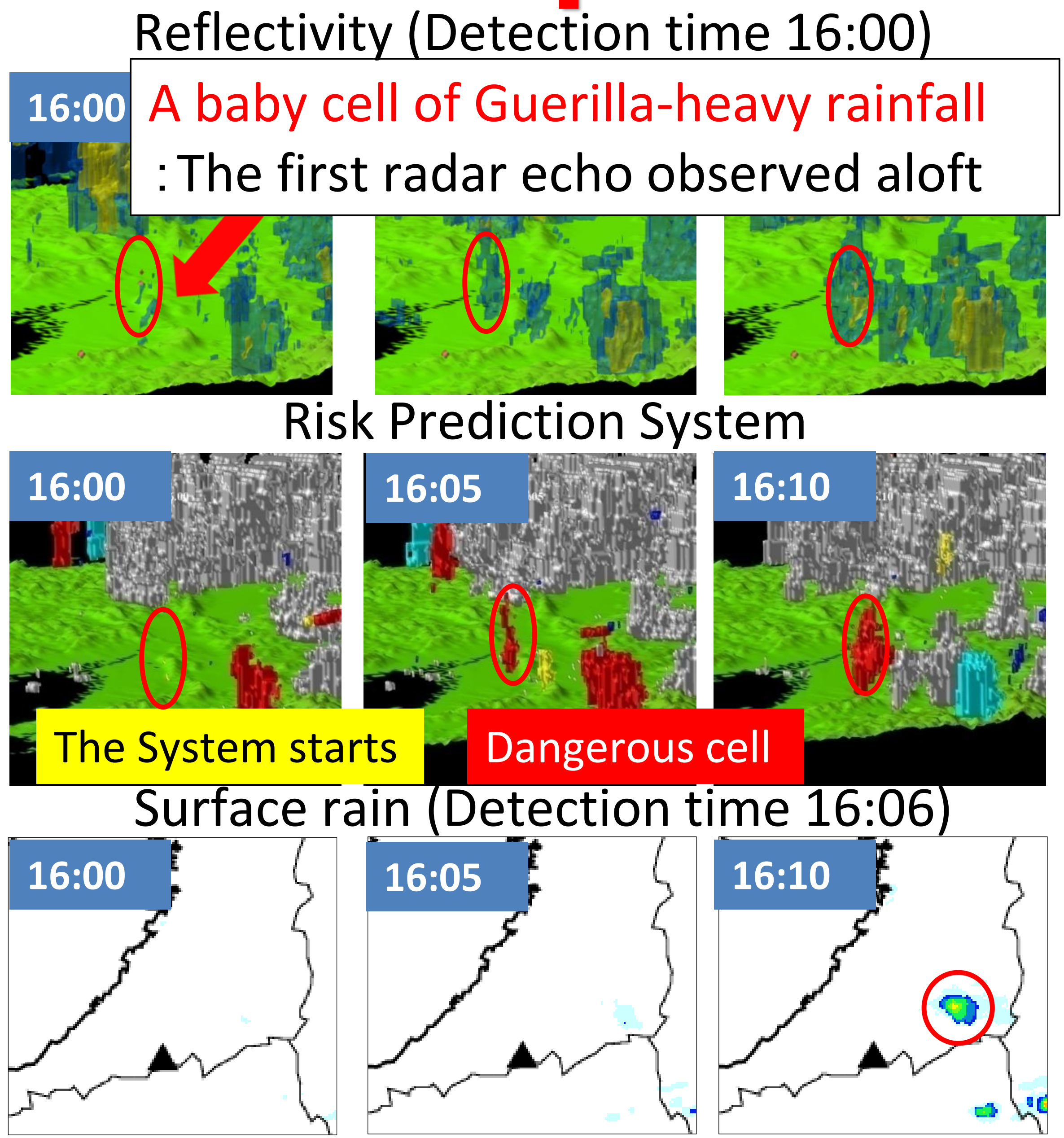
渦度（高度3100mでの渦度。渦度0.03を超えた時刻は16:00。15:55にも兆候）**(Estimated pseudo vorticity)**



Nakakita, Satoh and Yamaguchi (2015)

Early detection and risk prediction

The risk prediction system using maximum vertical vorticity information in the first radar echo

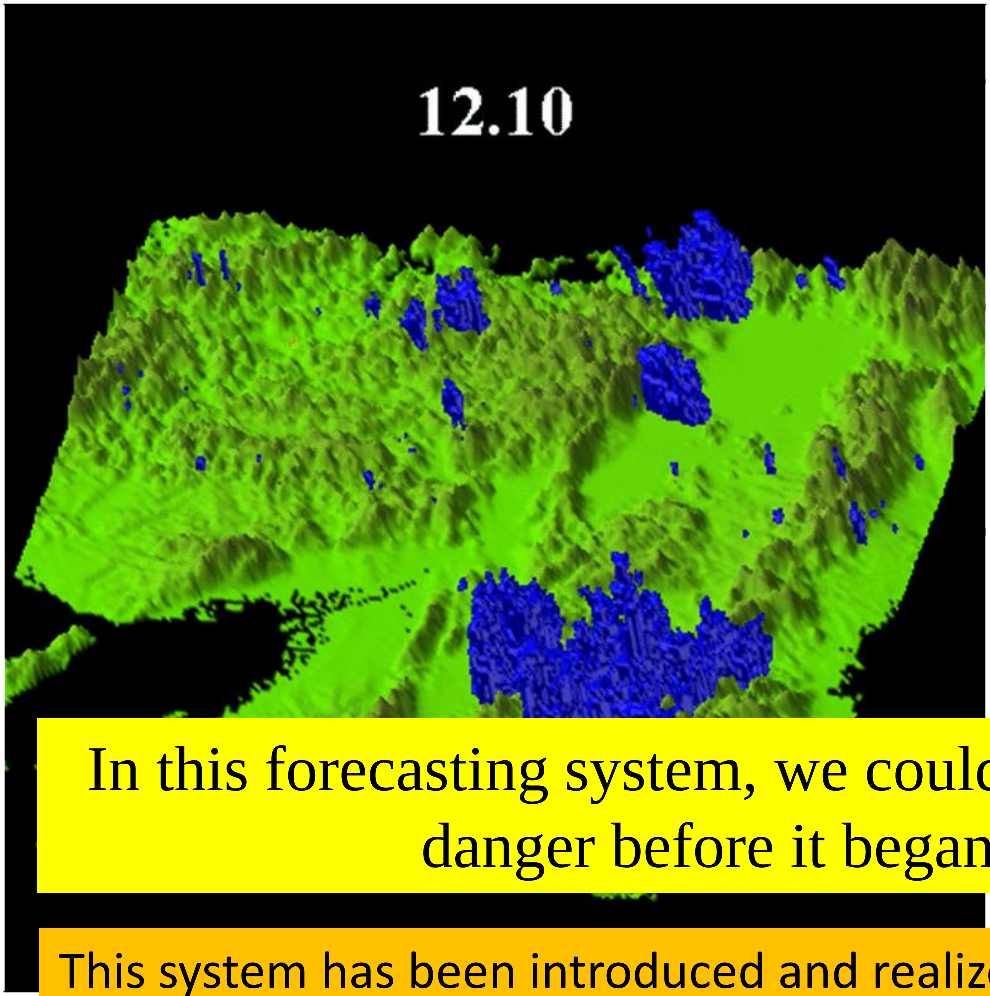


✓This risk prediction system identifies dangerous baby cells using vorticity information.

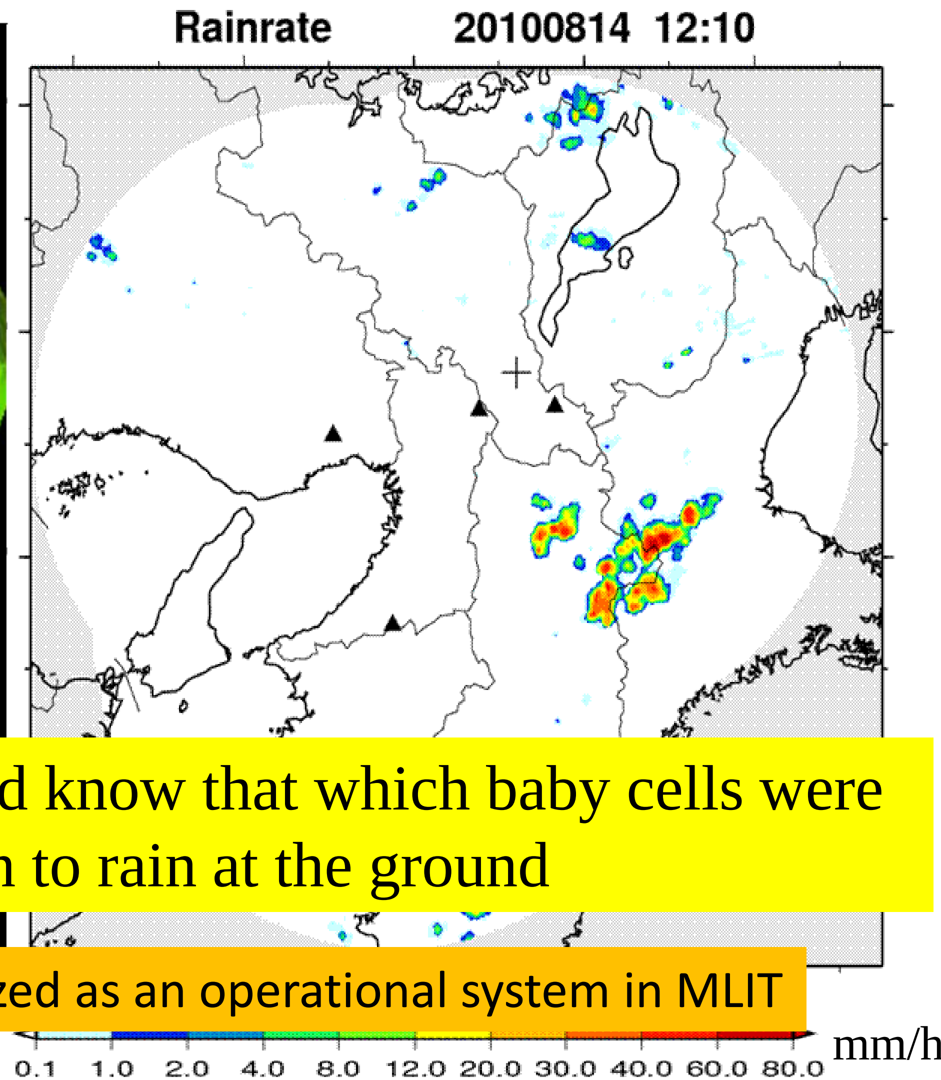
✓The different color cells show their risk levels.

A result of the auto forecasting system of localized severe rainfall

3D movie by auto prognostic system



2D rain distribution movie



In this forecasting system, we could know that which baby cells were danger before it began to rain at the ground

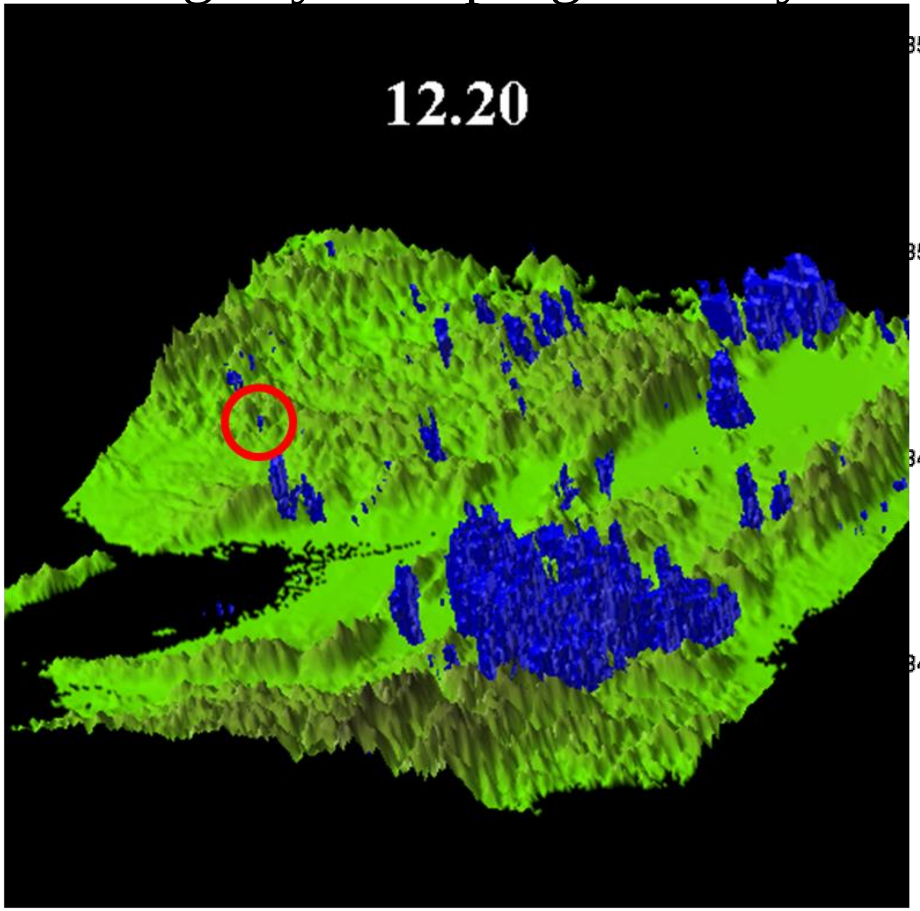
This system has been introduced and realized as an operational system in MLIT

Recognition as a dangerous baby cell is shown

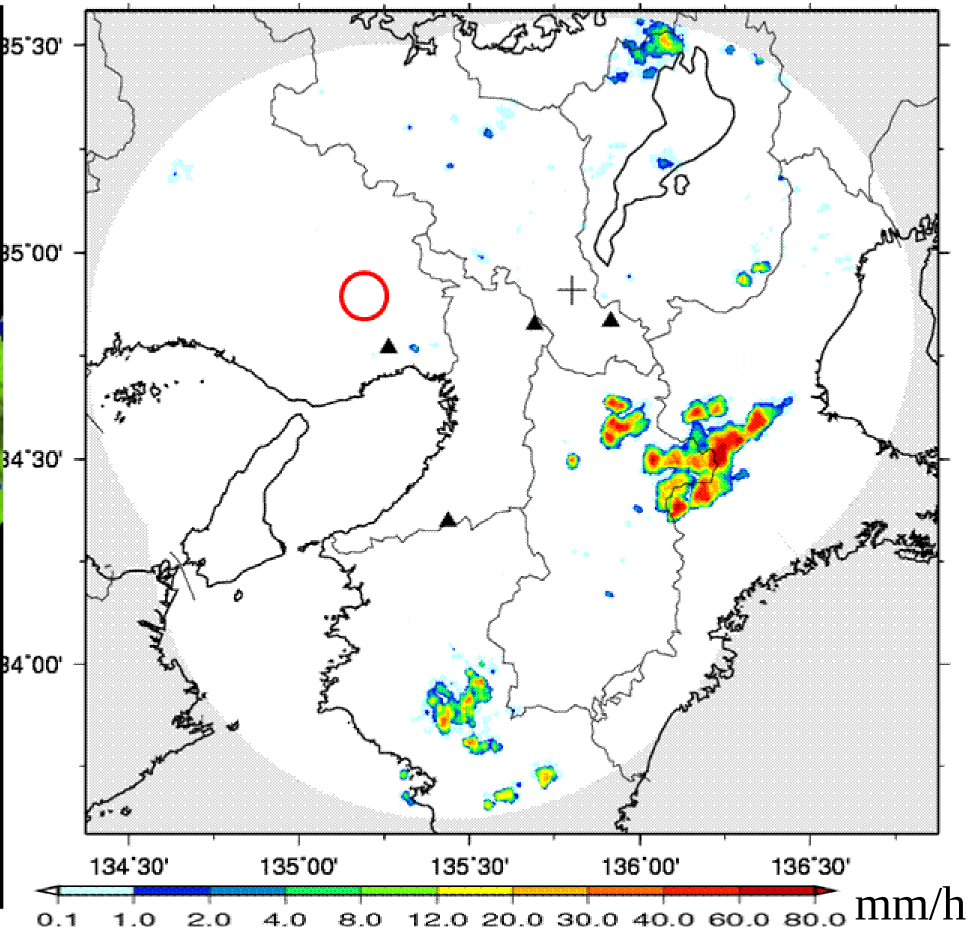
Nakakita, Nishiwaki and Yamaguchi (2013)

A result of the auto forecasting system of localized severe rainfall

3D image by auto prognostic system



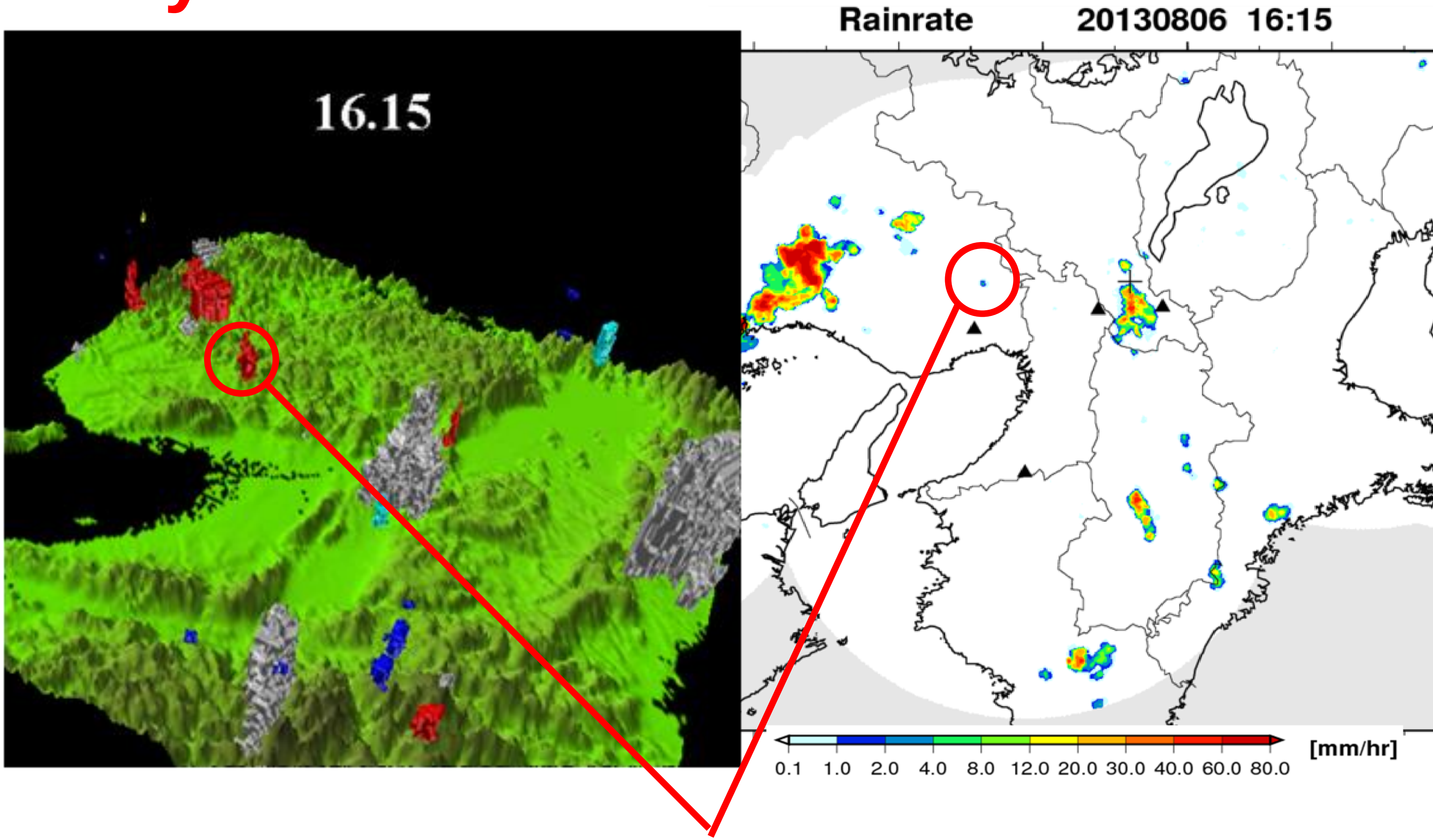
2D rain distribution at 12:20



When baby cell is detected, no surface radar echo exists.

Nakakita, Nishiwaki and Yamaguchi (2013)

A result of the auto forecasting system of localized severe rainfall

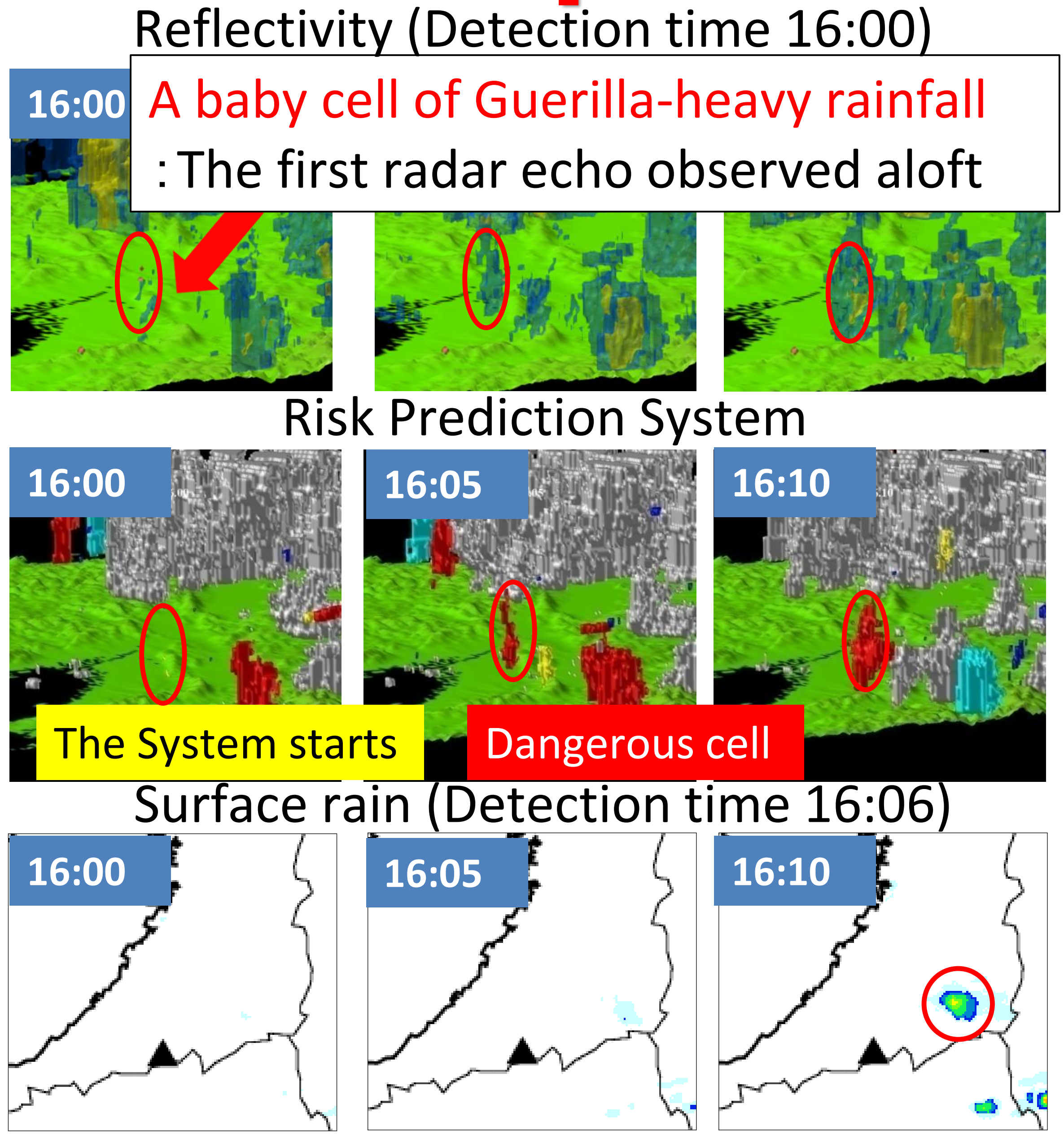


When surface echo appear, it's already judged as risky one.

Nakakita, Nishiwaki and Yamaguchi (2013)

Early detection and risk prediction

The risk prediction system using maximum vertical vorticity information in the first radar echo



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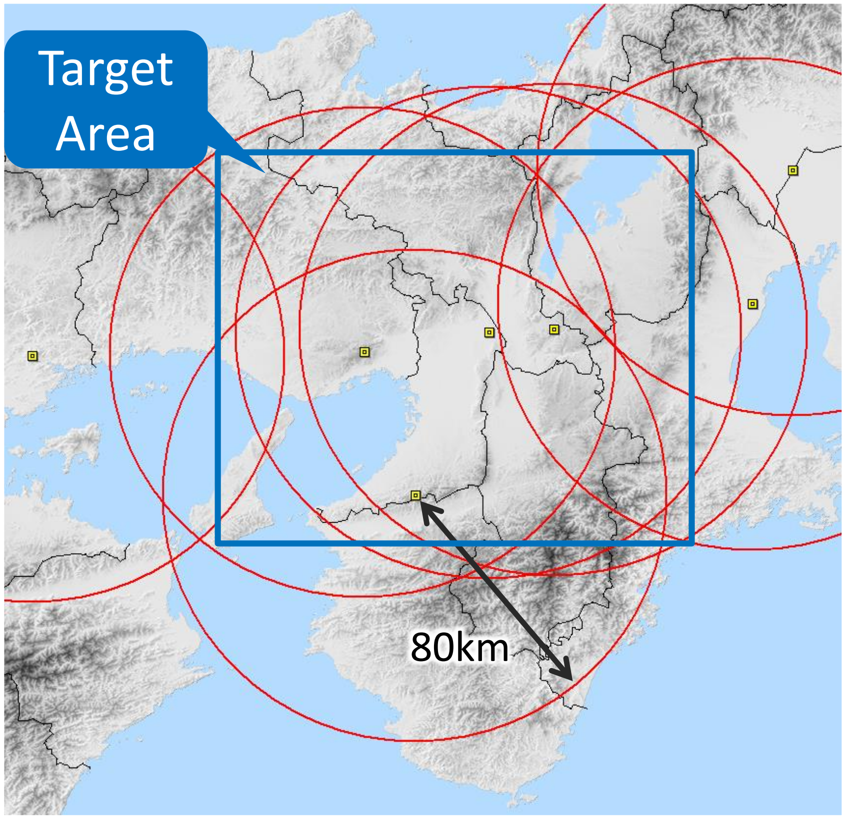
Utilization of five X-MP radars

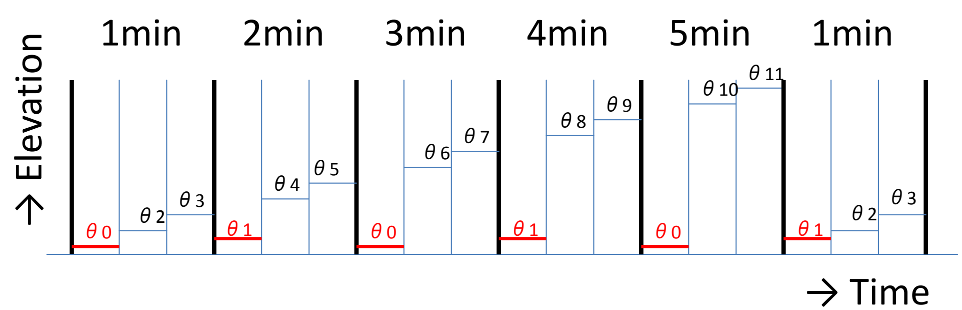
X-band Polarimetric Radar



3-dimensional data

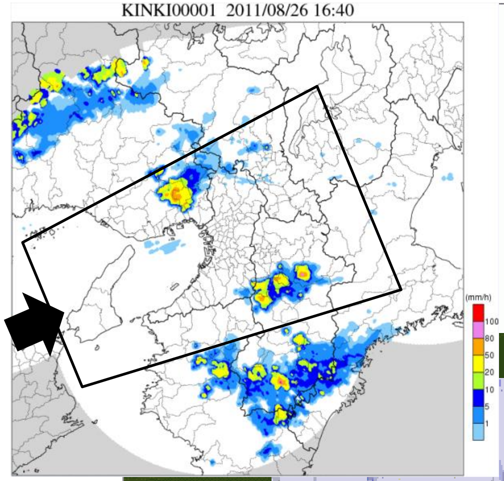
Number of radar sites	7
Horizontal grid spacing	250 m
Vertical grid spacing	500 m
Maximum altitude	10 km
Interval	1 min
Variables	R, Z_H, Z_{DR}, ρ_{HV}, K_{DP}

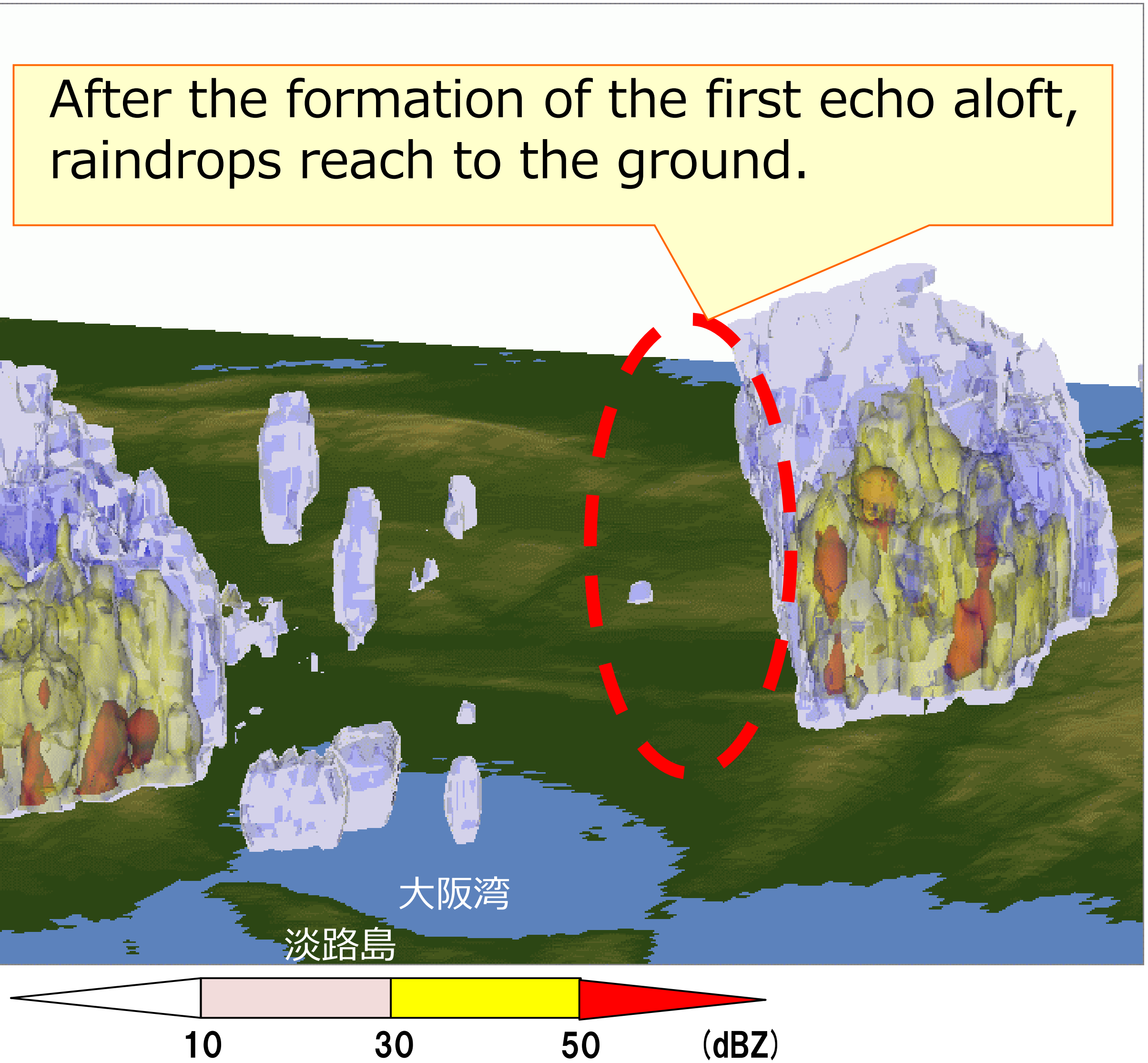
Observing schedule



3D animation of development from the first echo with every one minute.

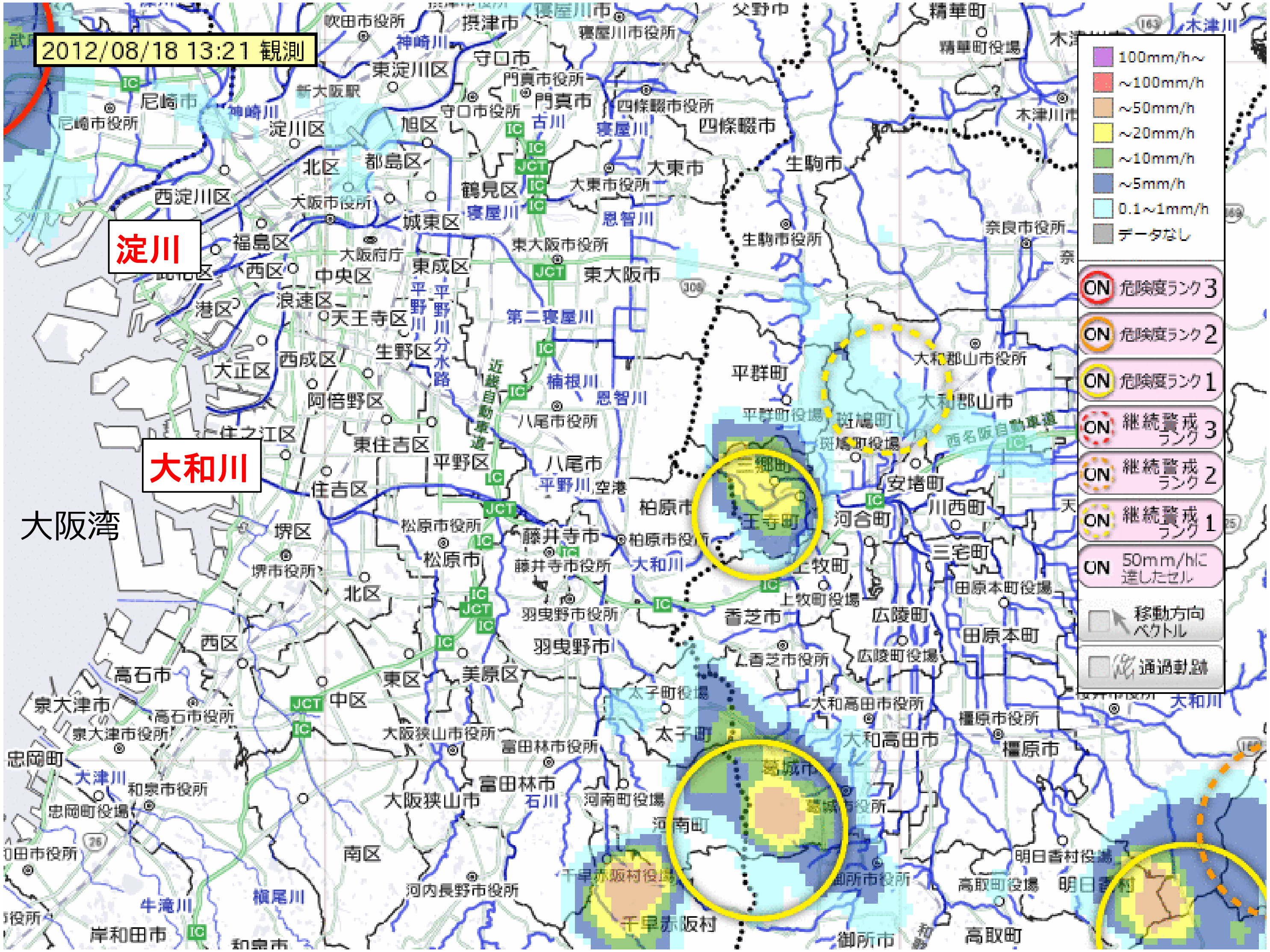
豪雨のタマゴの探知事例（2011年8月26日16:40～17:10、1コマ1分）



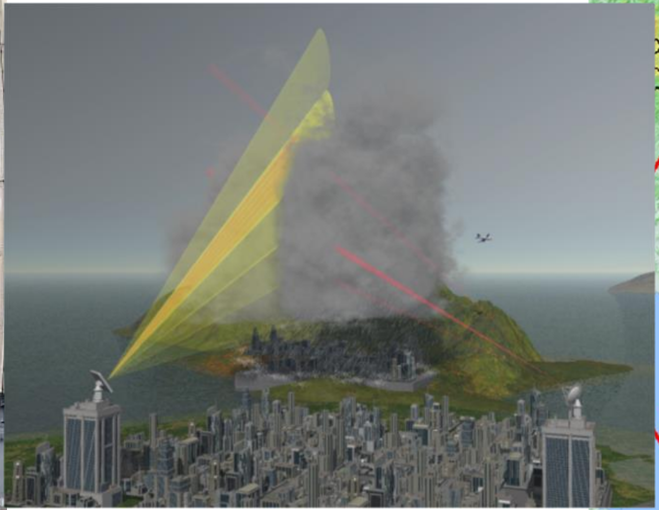


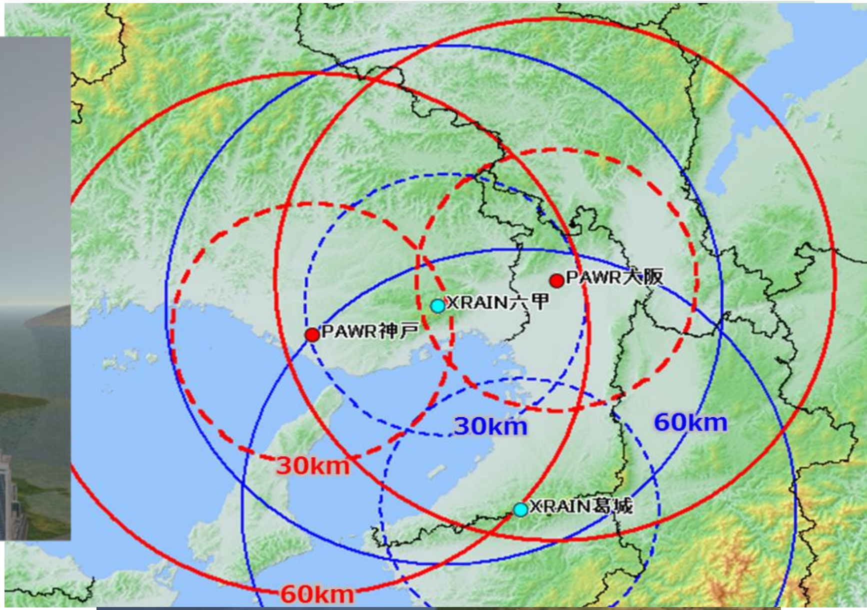
Operational system experimentally introduced in MLIT

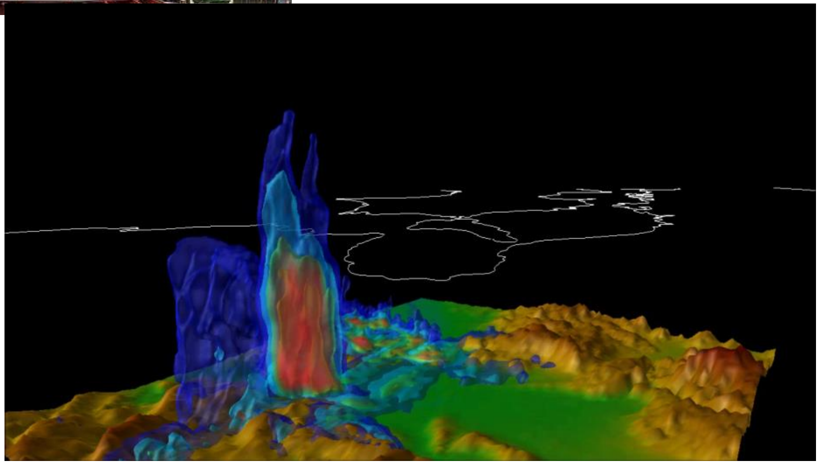
Operational system of early detection and risk prediction

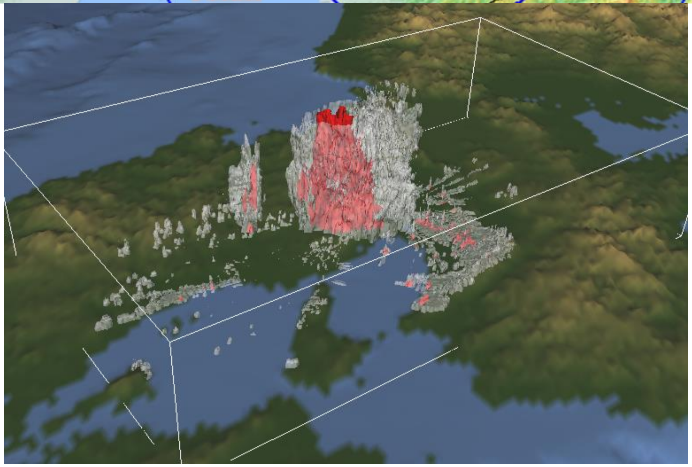


X-band phased array radars



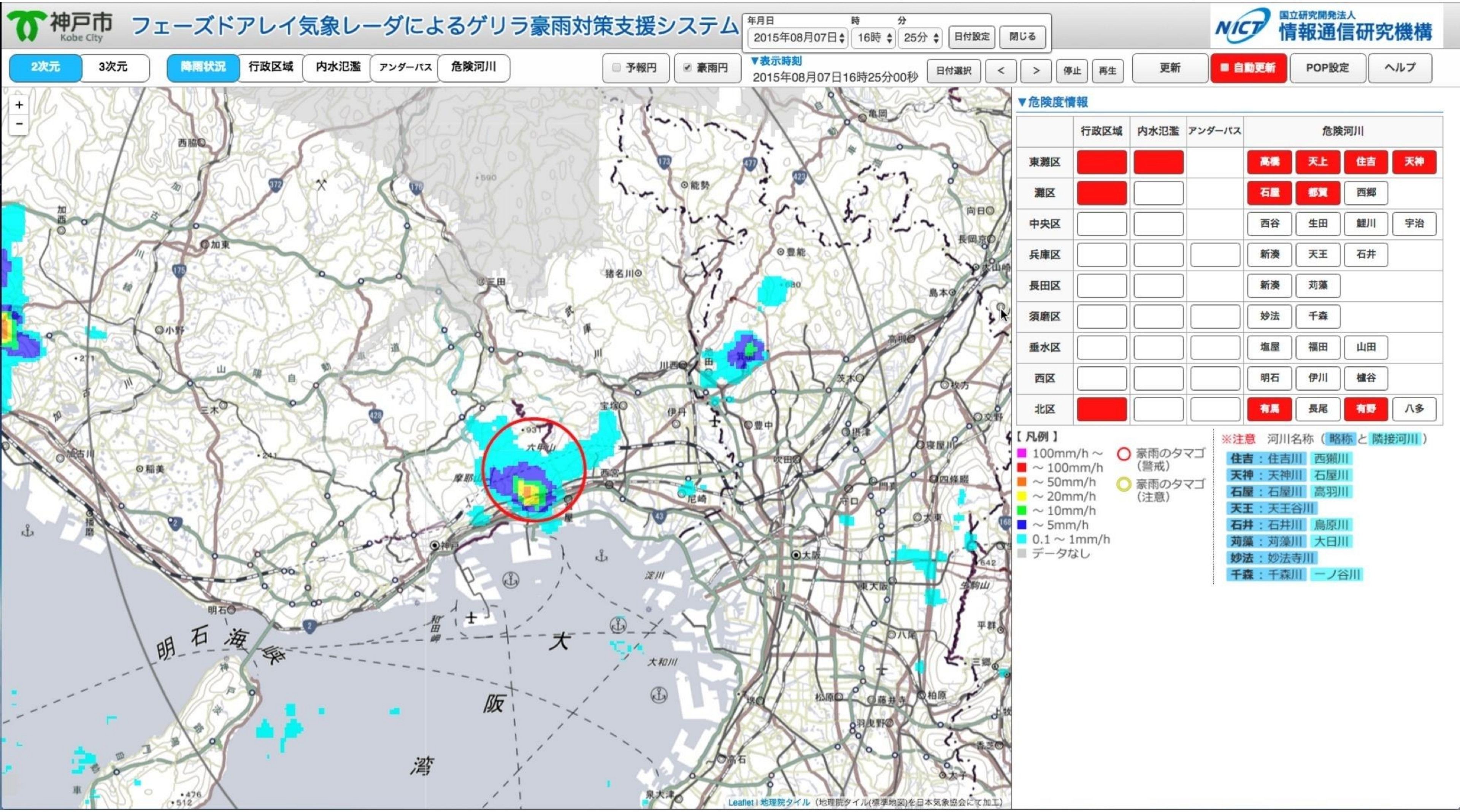






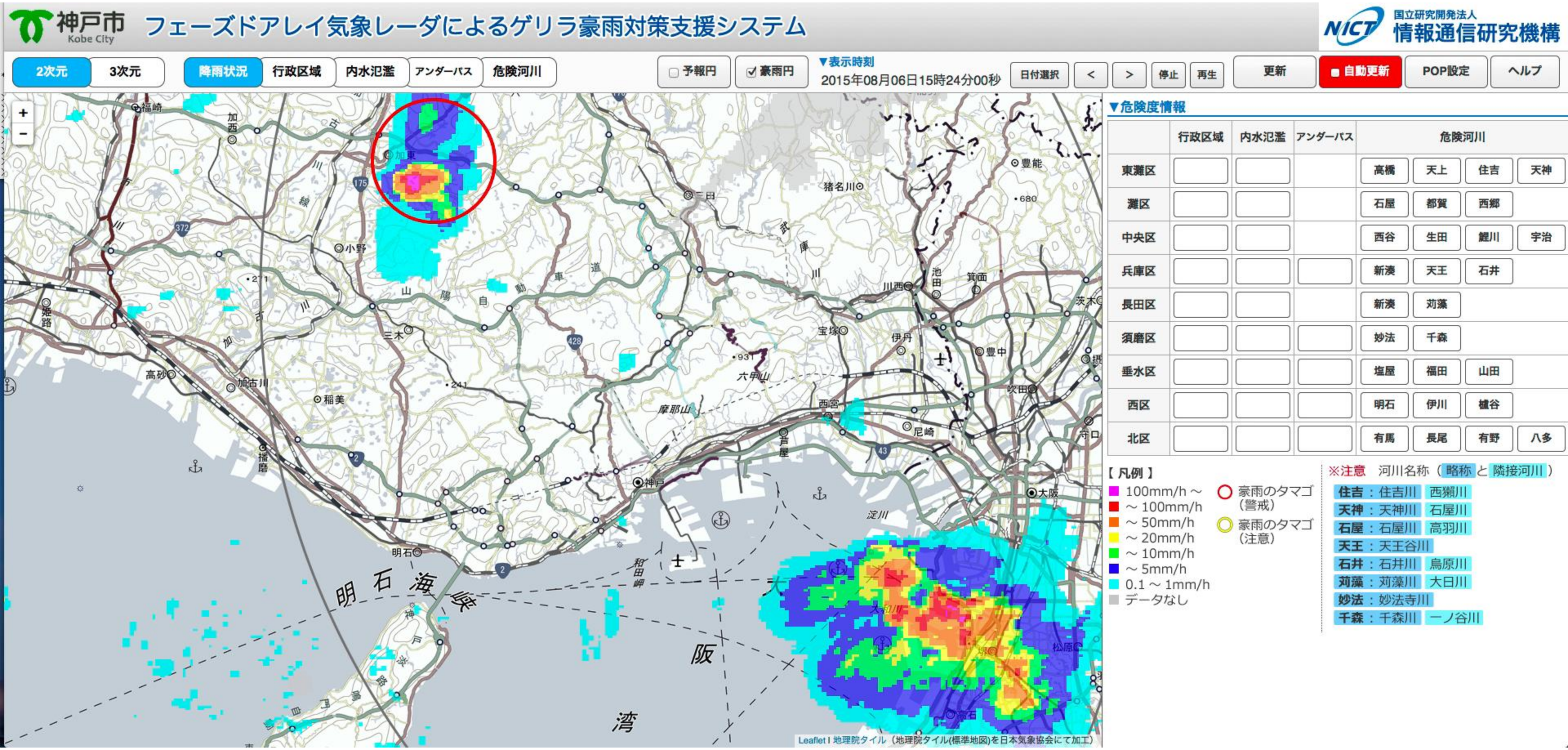
Ushio et. al (2012), NICT (2013, 2015)

Operational early warning system using dual phased array radars



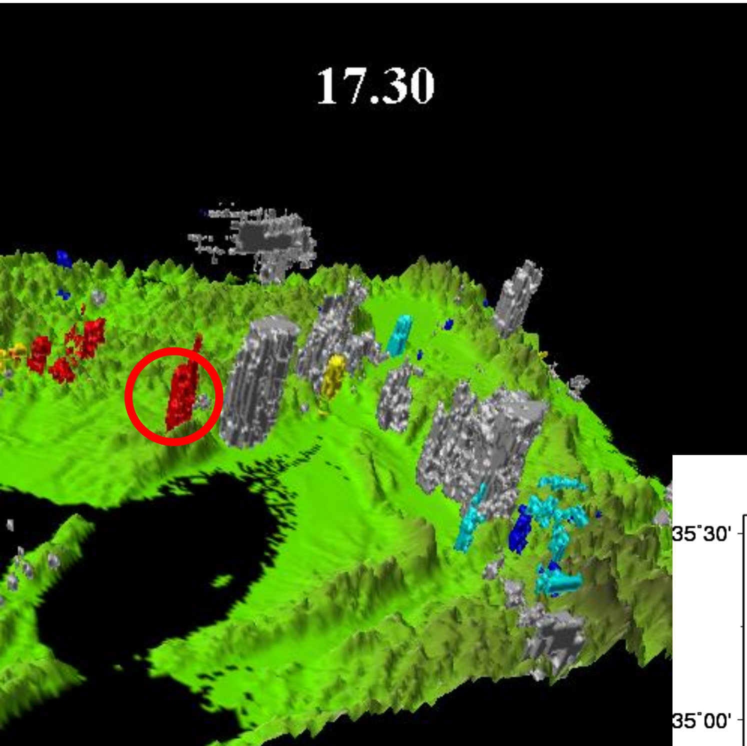
NICT and Kobe City (2016), Nakagawa, Masuda and Nakakita (2016), Nakagawa and Katayama et al., (WRaH 2017 Day2 RN07)

Operational early warning system using dual phased array radars

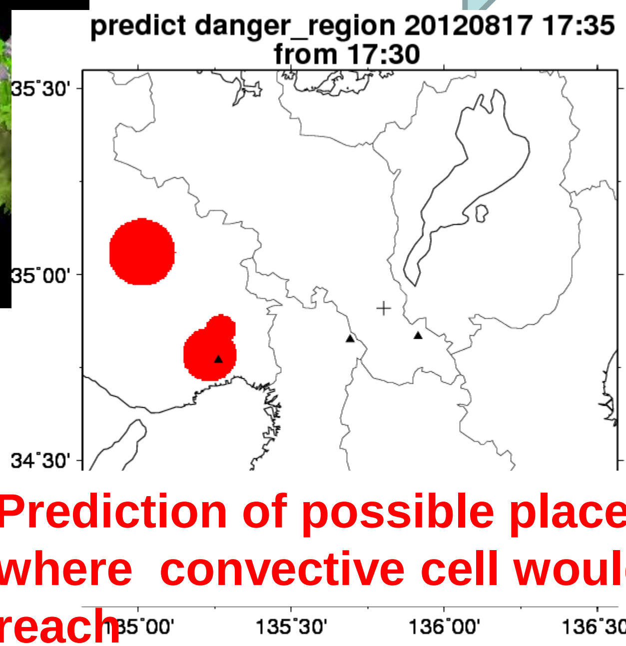


NICT and Kobe City (2016), Nakagawa, Masuda and Nakakita (2016), Nakagawa and Katayama et al., (WRaH 2017 Day2 RN07)

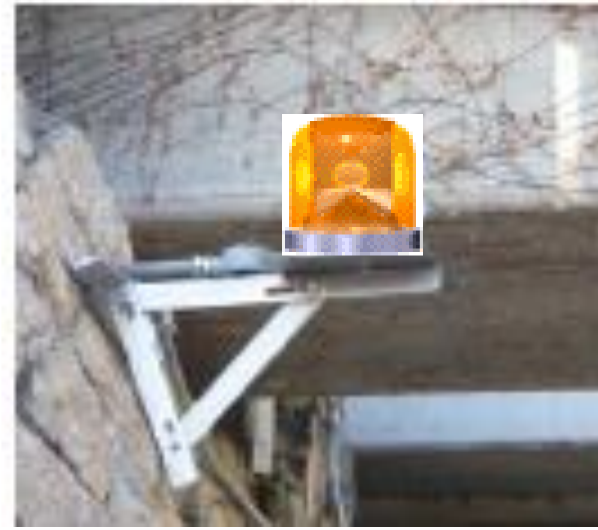
Application of the risk projection (Toga River Basin)



Projection weather convective cell would grow until bringing heavy rainfall on to ground surface



Prediction of possible place where convective cell would reach



An automatic warning system by emargency light before rainfall reach to ground at the target river side park!

At 17:30, it is projected that Toga River Basin will be covered by heavy rainfall within 5 to 10 min. Emergency light start illuminating at the basin to recommend people leave riverside.

This is a dreamed warning system heading to develop in these 8 years

Nakakita, Nishiwaki and Yamaguchi (2013)

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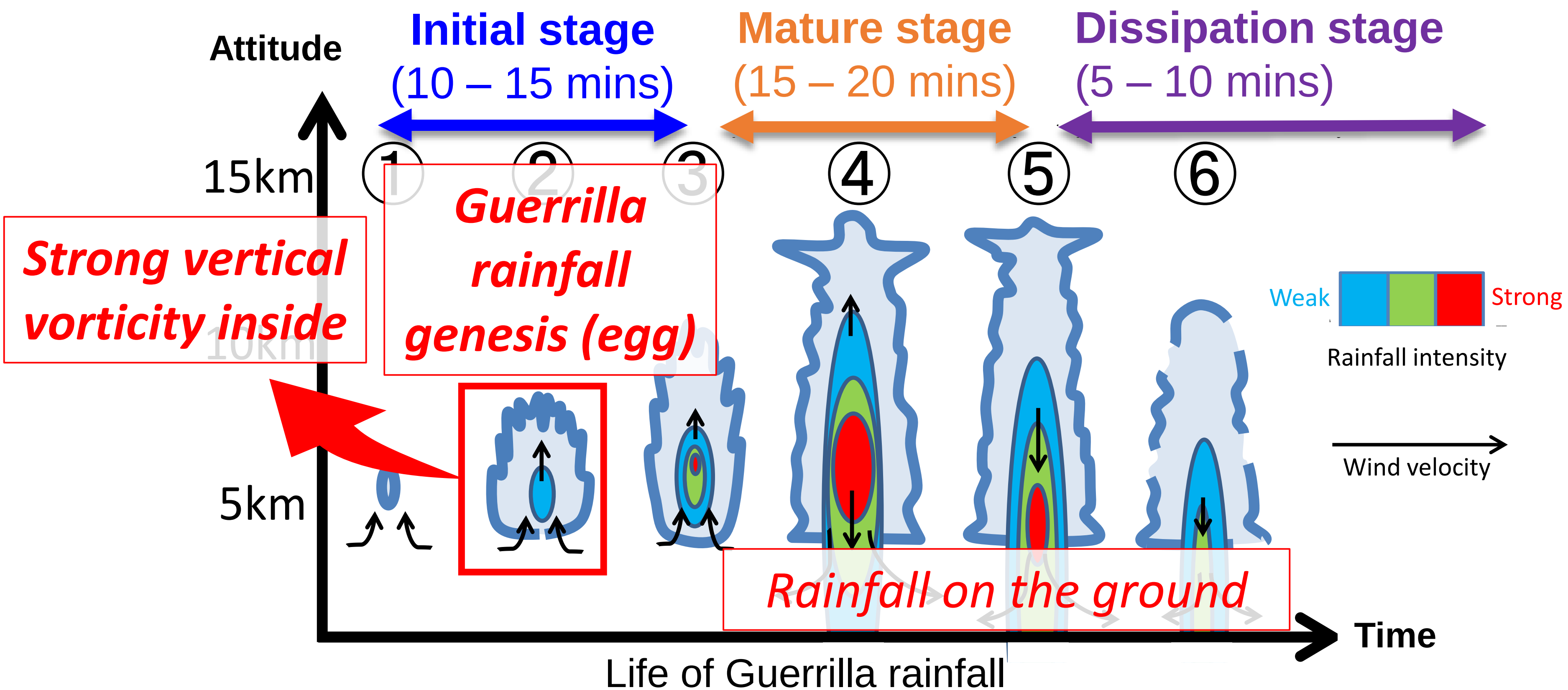
Previous Research

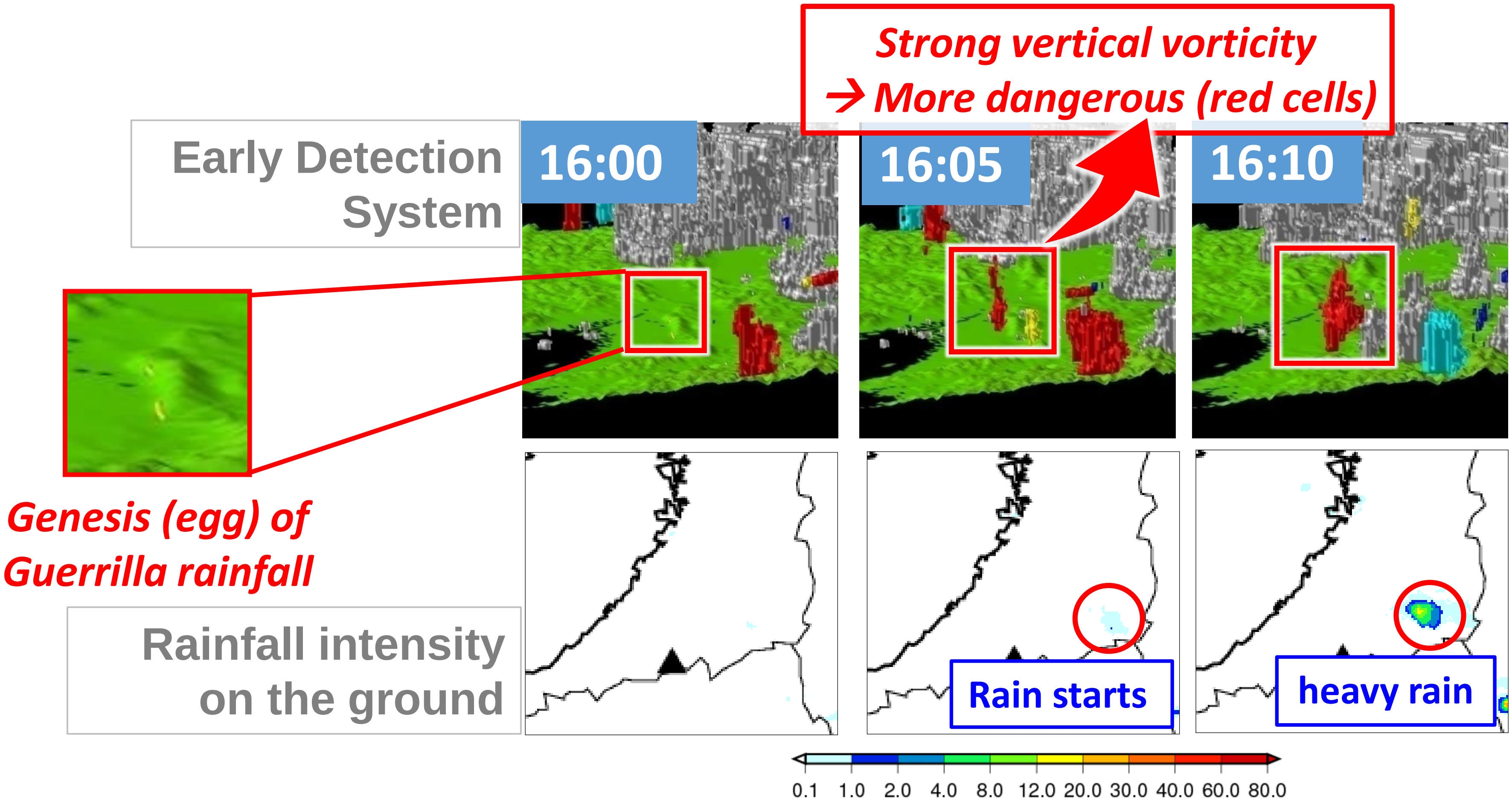
Prediction of Guerrilla rainfall risk using X-band radars
(Nakakita et al., 2010; 2013; 2014)



- Before rainfall: first echo of Guerrilla rainfall genesis
- Strong vorticity detected in the rainfall genesis

Previous Research

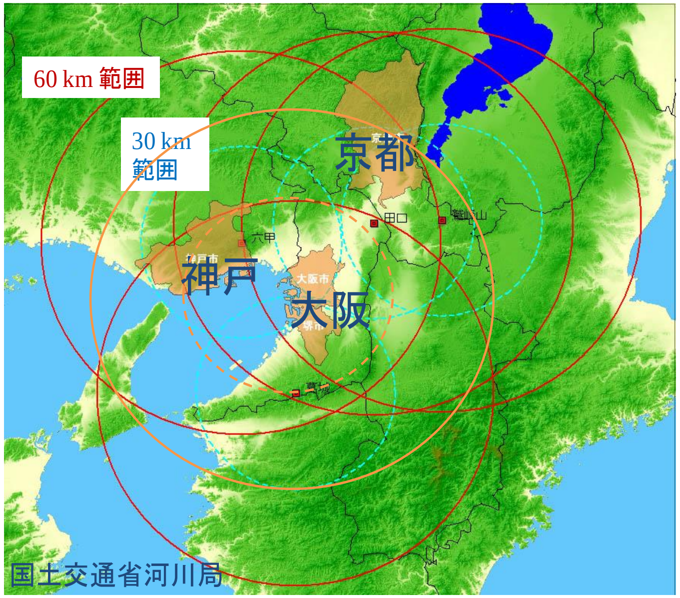
Prediction of Guerrilla rainfall risk using X-band radars
(Nakakita et al., 2010; 2013; 2014)



- Early detection of Guerrilla rainfall through its genesis
- Risk level based on strength of vertical vorticity in the genesis

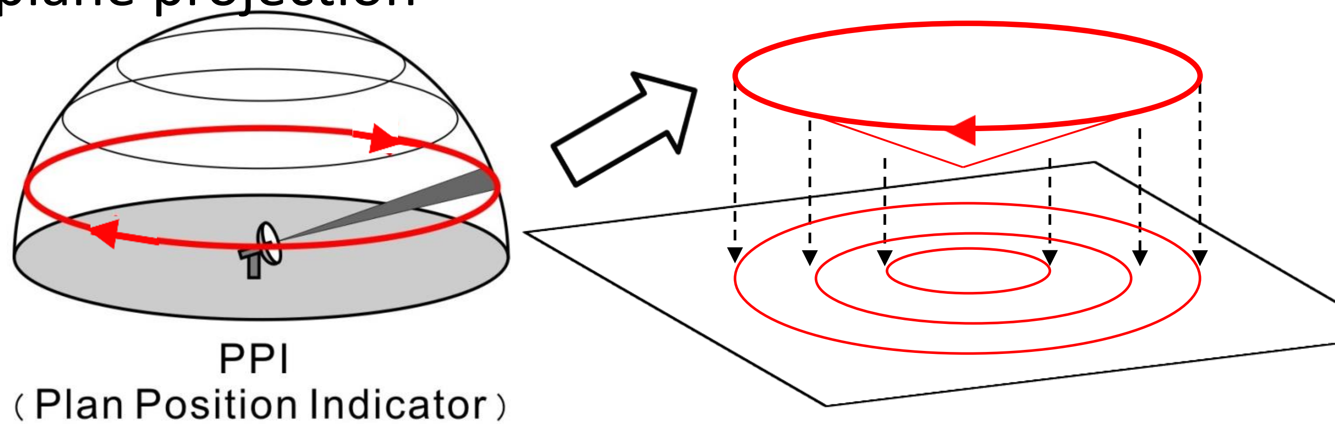
X-band Multi Parameter Radar

Radar	X-band MP radar
3D scan time	5 minutes (12 PPI scans)
Maximum range	80 km (150m)
Azimath angles	300 (1.2°)
Elevation angles	12
Parameters	Reflection intensity, Doppler velocity, Polarimetric parameters

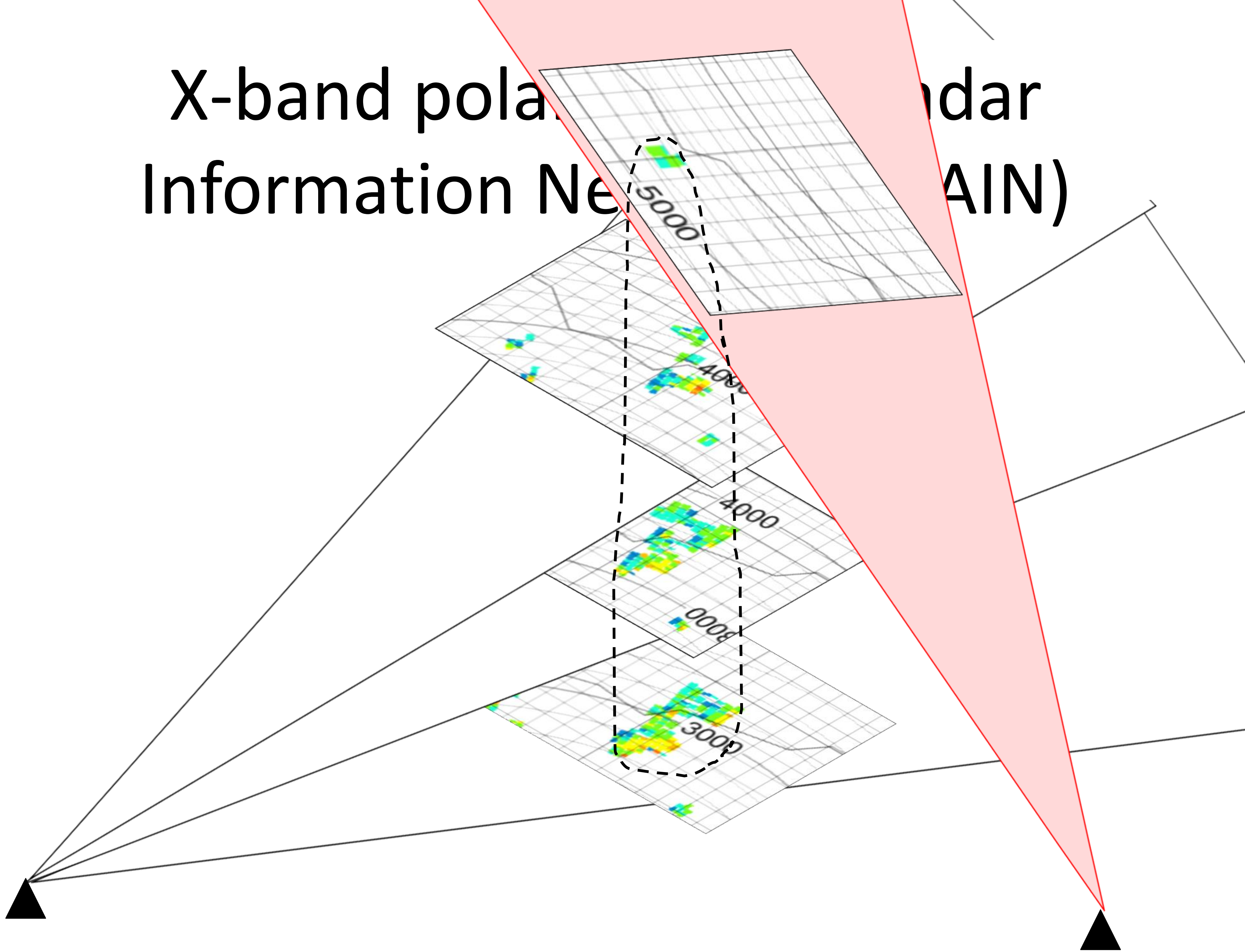


X-MP radar network in Kinki (MLIT HP)

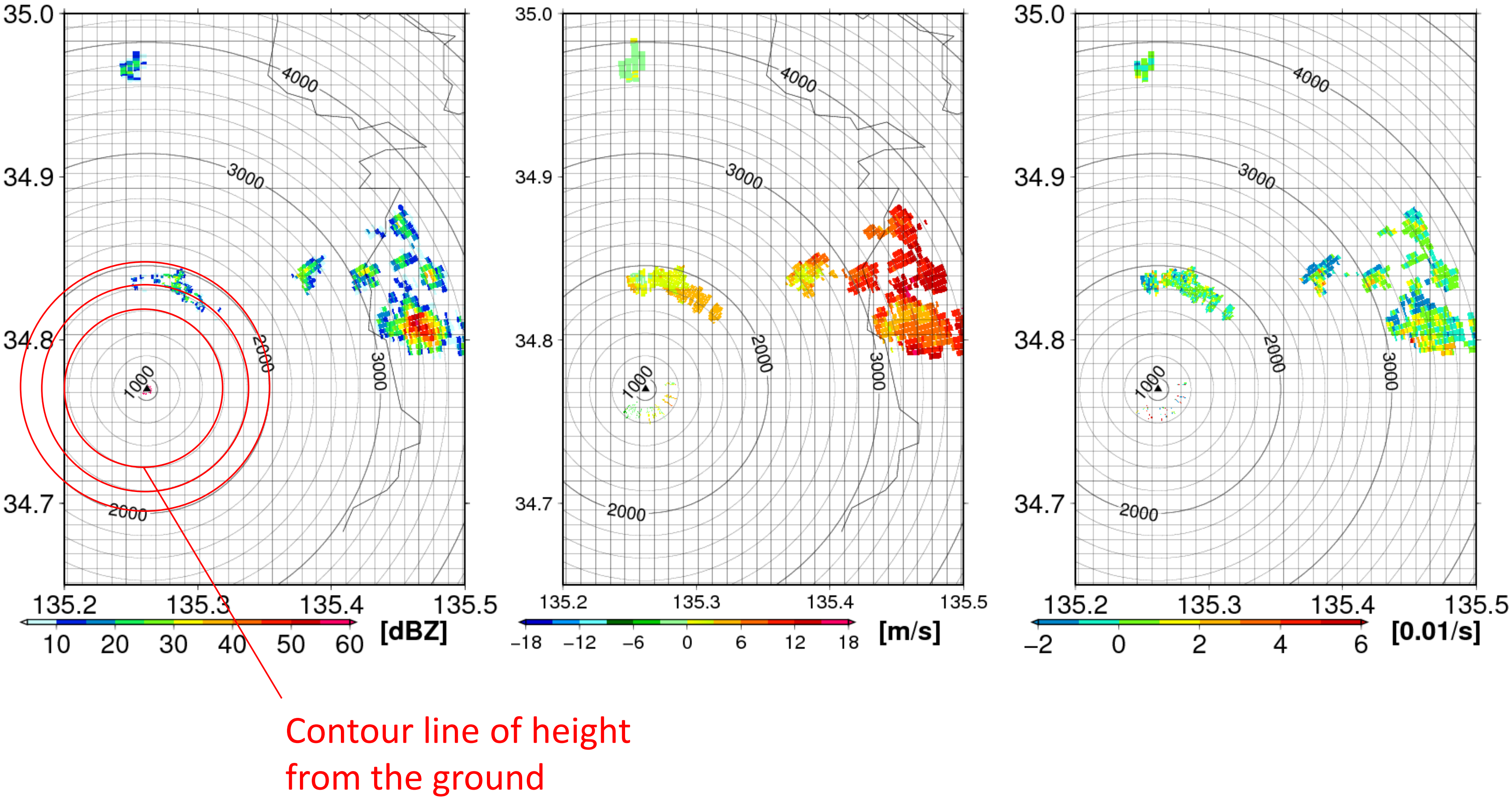
- ✓ Not interpolate
- ✓ Not combine
- ✓ Make figures by plane projection



X-band pola adar
Information Ne AIN)



Reflection Intensity | Doppler Velocity | Vorticity



Pseudo-Vorticity

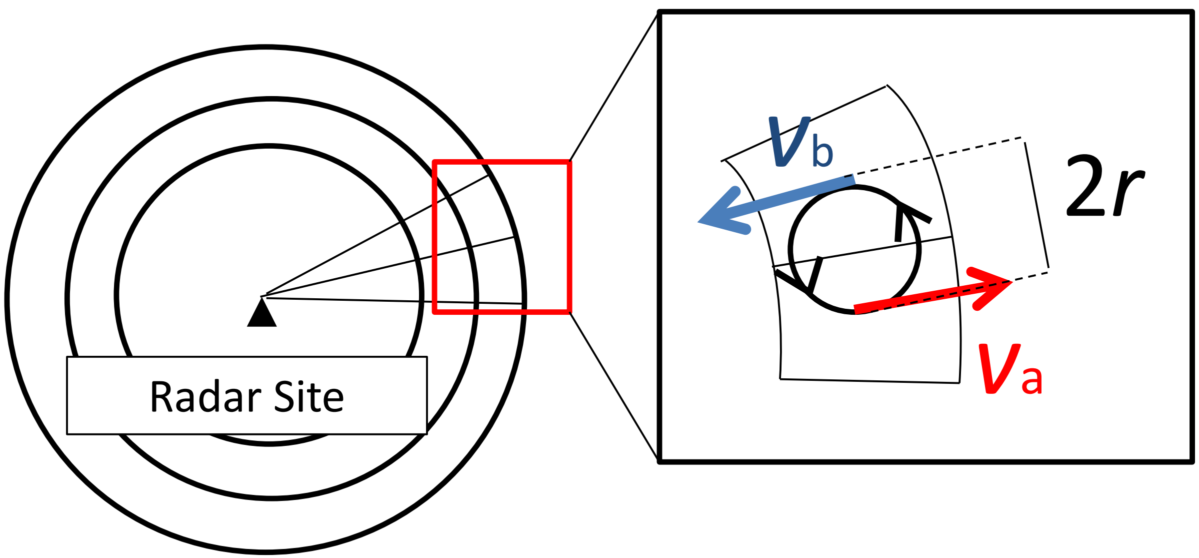
Doppler Velocity

$$v = -\frac{\lambda f_d}{2}$$

v : Doppler velocity
λ : Wavelength
f_d : Doppler frequency

Pseudo-Vorticity

: Calculate pseudo-vorticity using Doppler velocity at two adjacent mesh

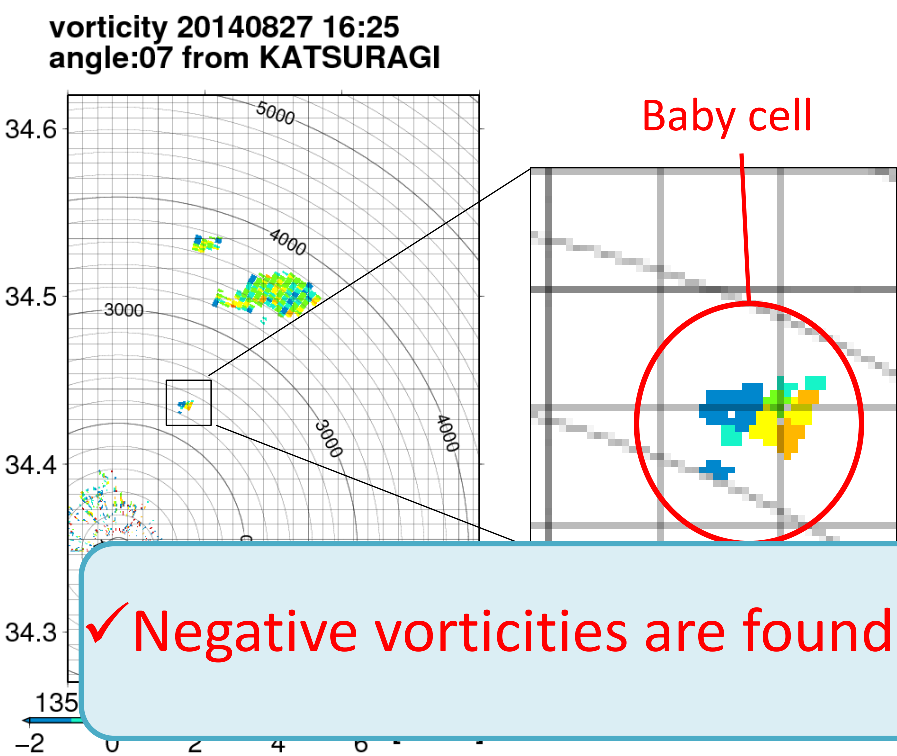


$$\zeta \equiv \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

$$\simeq 2 \times \frac{v_a - v_b}{2r}$$

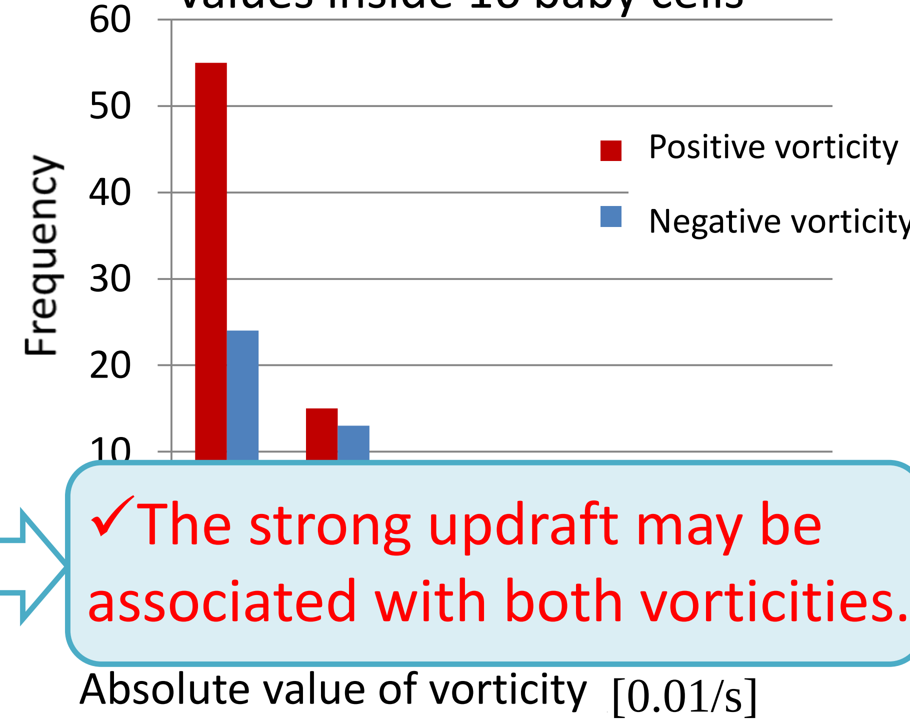
Analysis of Vorticity in the Baby Cells

(Extraction condition)
✓Suddenly appear and develop
✓Rain rate ≥ 50mm/h within 30 minutes from beginning of rainfall
✓16 events in August, 2013 and 2014



✓Negative vorticities are found.

Frequency distribution of vorticity values inside 16 baby cells



✓The strong updraft may be associated with both vorticities.

Nakakita, Satoh and Yamaguchi, 2015

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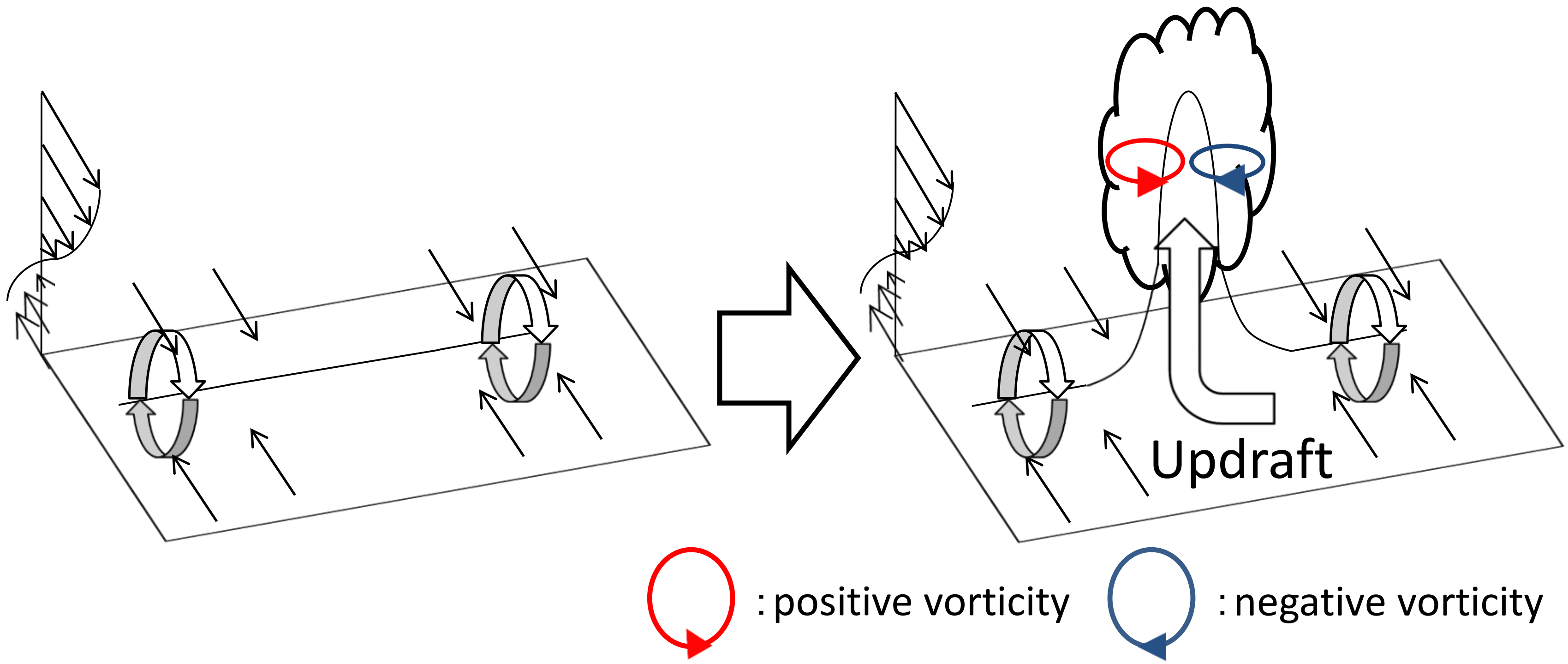
Initial Stage of Cumulonimbus Cloud



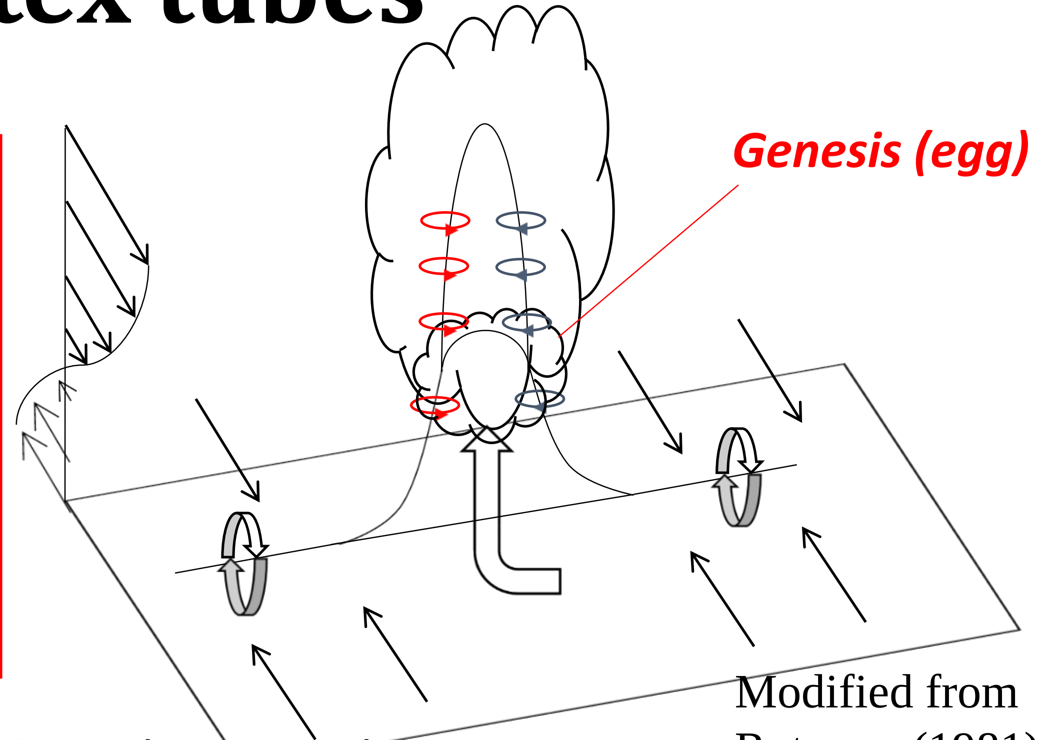
（Rotunno, 1981）

①The vertical shear generates a horizontal vortex tube.
②Updraft tilts the horizontal vortex tube.
③A pair of vortex tubes appears.

Initiation Mechanism of vertical vortex tubes

Positive vortex tube
- positive vorticity (counterclockwise)

Negative vortex tube
- negative vorticity (clockwise)



Modified from Rotunno (1981)

① Vertical wind shear induces horizontal vortex tube;
② Updraft tilts the vortex tube upward;
③ Water vapor is brought into higher air.

Upper process generates vertical vorticity, and causes a pair of positive & negative vortex tubes.

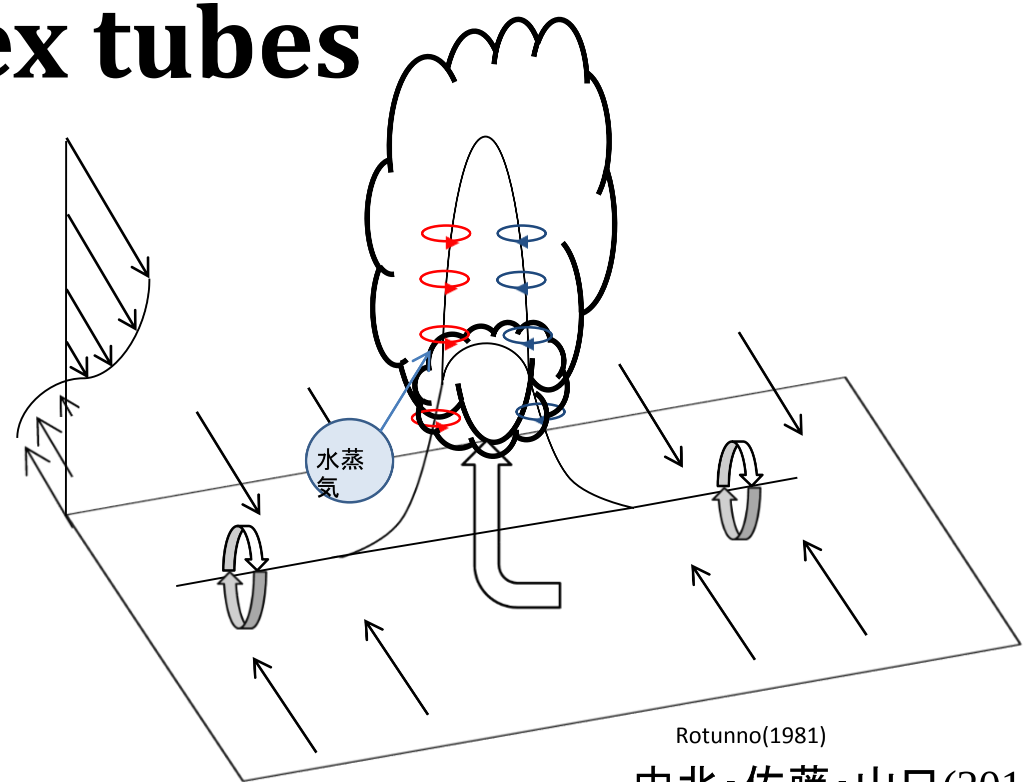
Initiation Mechanism of vertical vortex tubes

Positive vortex tube

- positive vorticity (counterclockwise)

Negative vortex tube

- negative vorticity (clockwise)



Rotunno(1981)

中北・佐藤・山口(2015)

Nakakita et al., 2017

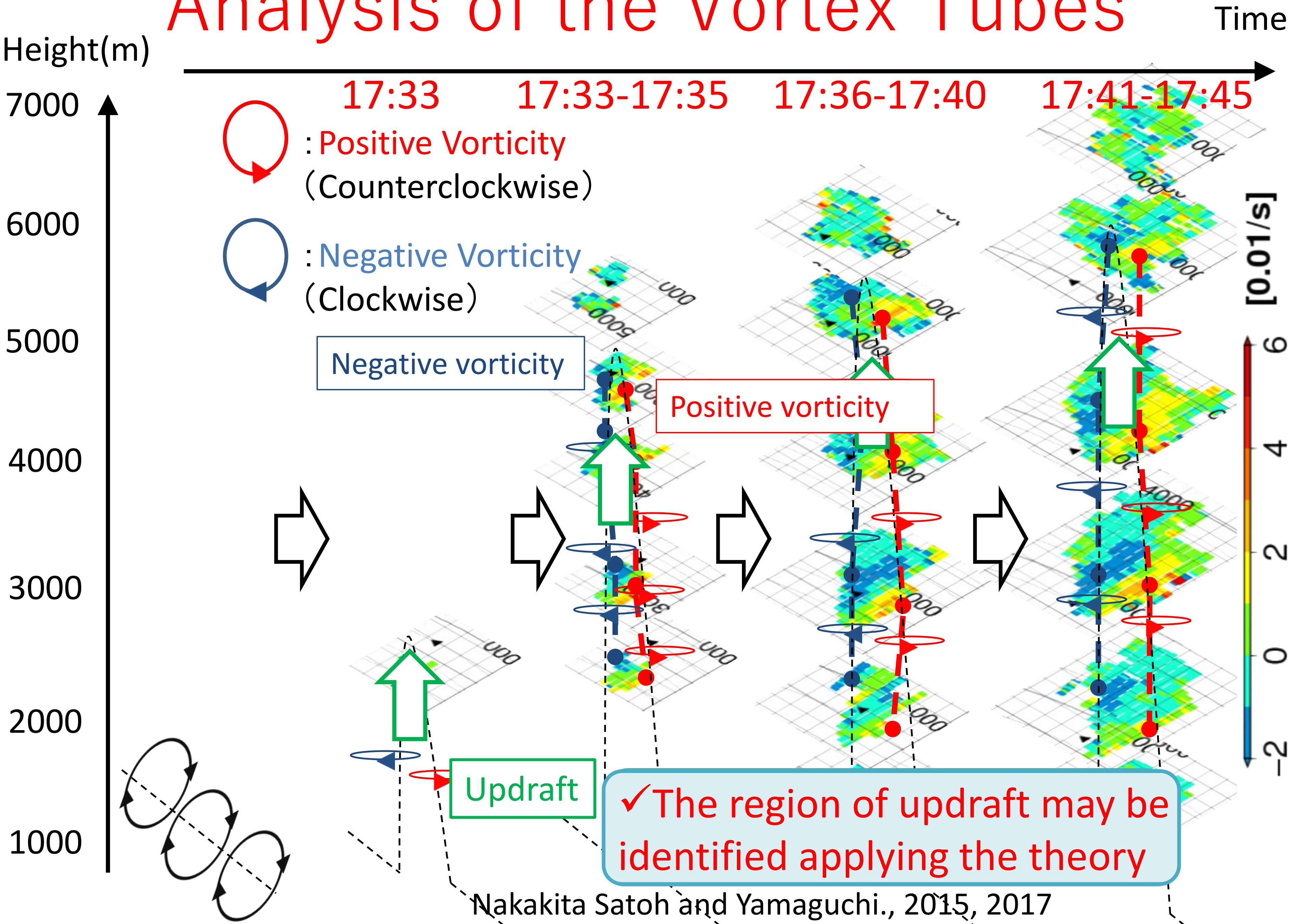
① Vertical wind shear induces horizontal vortex tube;

② Updraft tilts the vortex tube upward;

③ Water vapor is brought into higher air.

Upper process generates vertical vorticity, and causes a pair of positive & negative vortex tubes.

Analysis of the Vortex Tubes



✓The region of updraft may be identified applying the theory

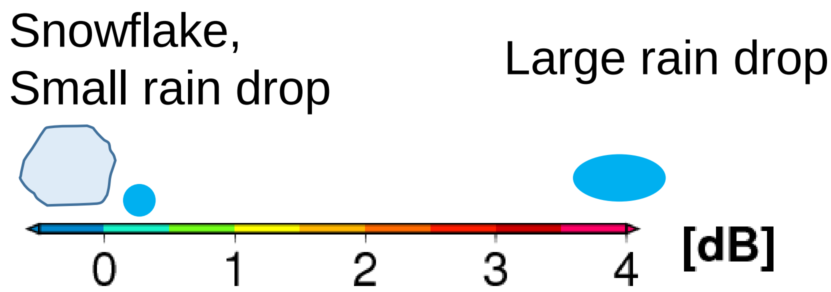
Nakakita Satoh and Yamaguchi., 2015, 2017

Methodology(ZDR Colum)

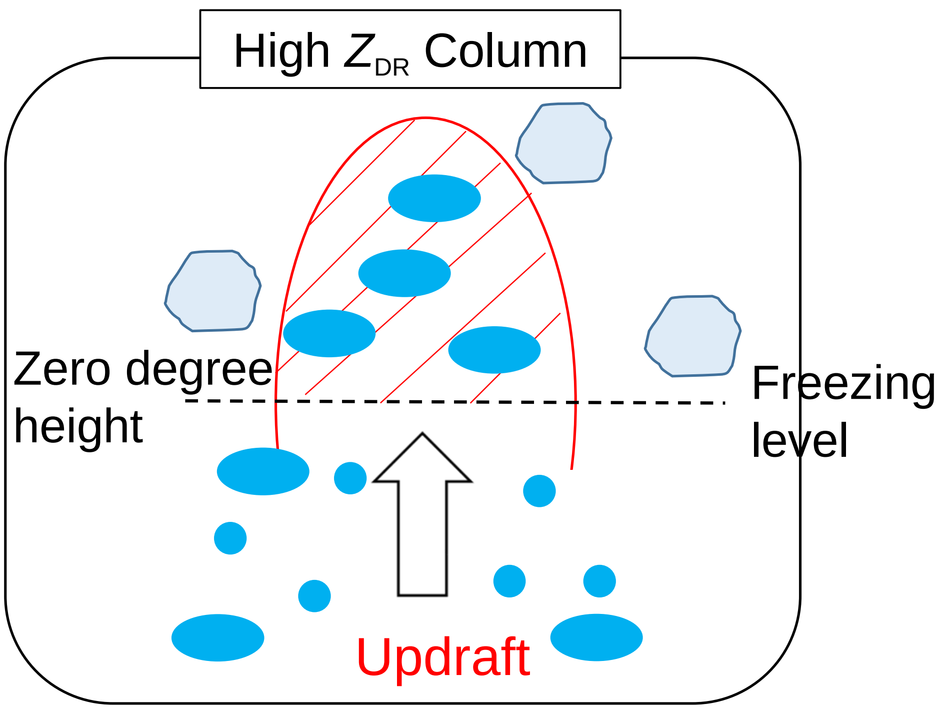
Polarimetric radar ; Differential reflectivity (Z_{DR})

Z_{DR} = Differential reflectivity [dB]

Z_{DR} depend on the shape of hydrometeor

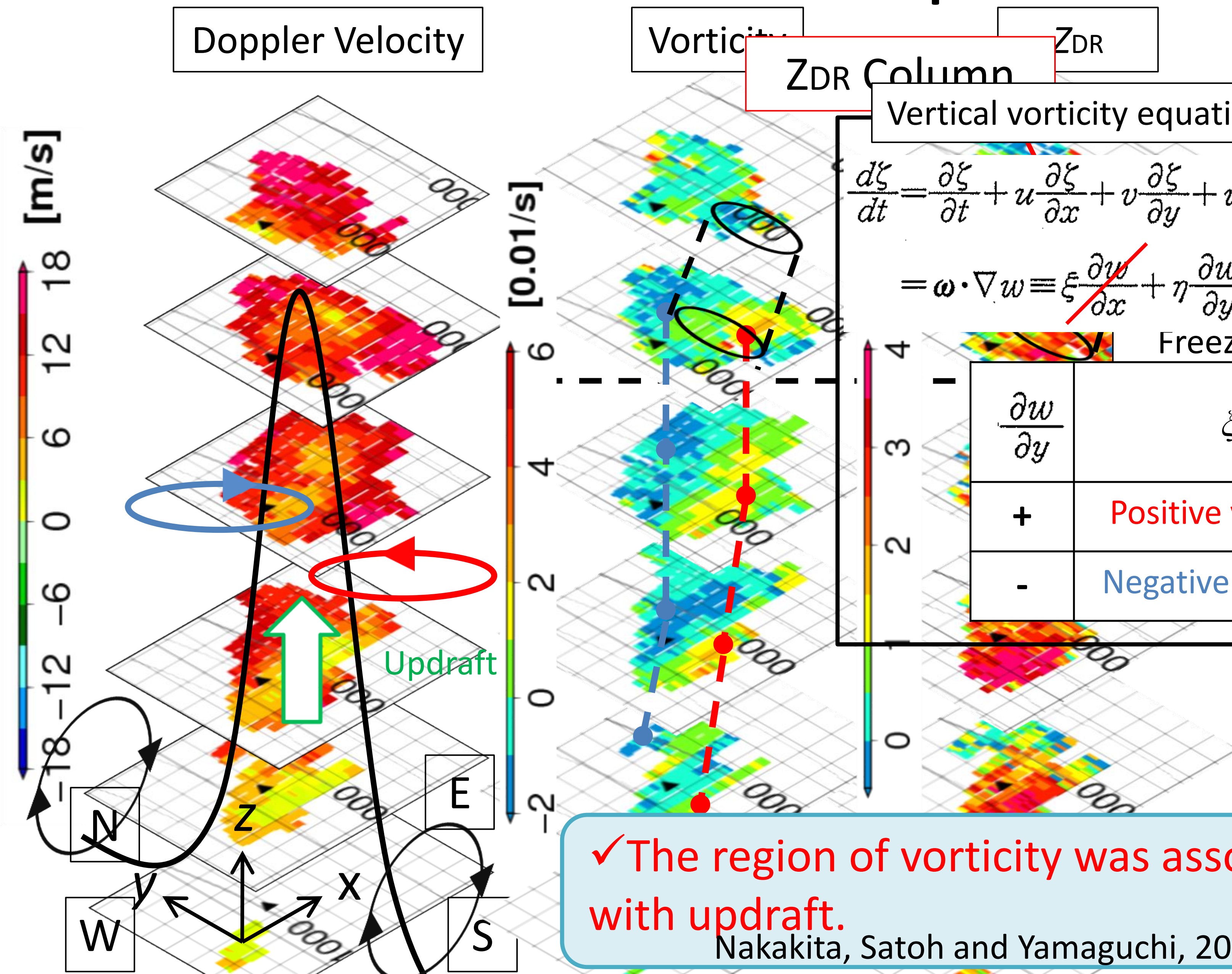


The high Z_{DR} column which detected above the freezing level indicates the detection of raindrops which lifted by strong updraft.



Seliga and bringi (1976), Adachi, et al. (2013), Masuda and Nakakita (2014), Snyder et al 2015

Identification of a Updraft



Vertical vorticity equation

$$\frac{d\zeta}{dt} = \frac{\partial \zeta}{\partial t} + u\frac{\partial \zeta}{\partial x} + v\frac{\partial \zeta}{\partial y} + w\frac{\partial \zeta}{\partial z}$$

$$= \boldsymbol{\omega}\cdot\nabla w \equiv \xi\cancel{\frac{\partial w}{\partial x}} + \eta\frac{\partial w}{\partial y} + \zeta\cancel{\frac{\partial w}{\partial z}}$$

$\frac{\partial w}{\partial y}$	ξ
+	Positive vorticity
-	Negative vorticity

✓The region of vorticity was associated with updraft.

Nakakita, Satoh and Yamaguchi, 2015、2017

Methodology (Multi Doppler Analysis)

Updraft Analysis

Multi Doppler analysis using *variational technique*

Shimizu and Maesaka (2007)

✓A cost function J is minimized in entire analysis domain.

✓$J(u, v, w) = J_o + J_d$

Difference between observed and analyzed radial velocity

$$J_o = \frac{1}{2}\sum_{i,j,k,m} \lambda_o (rv_m - u\cos A - v\cos B - (w + w_t)\cos C)^2$$

Continuity equation error

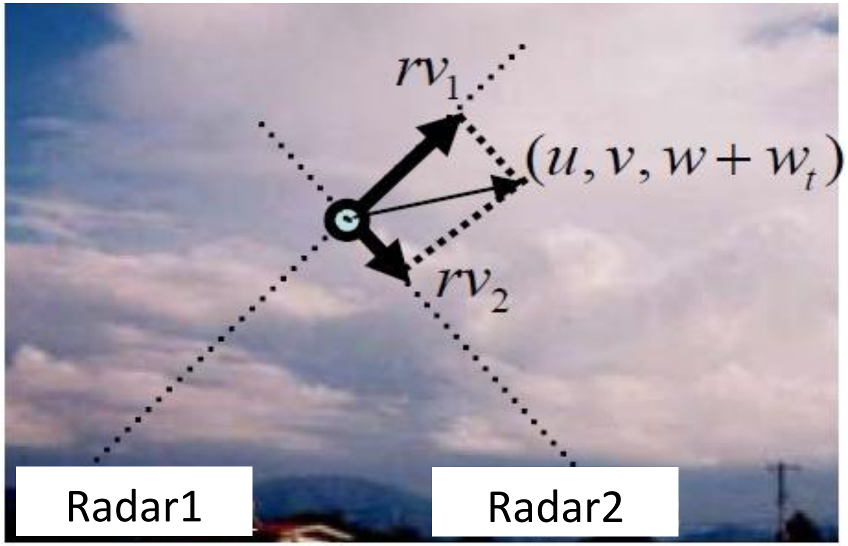
$$J_d = \frac{1}{2}\sum_{i,j,k} \lambda_d D^2 \quad (D = \frac{\partial \bar{\rho} u}{\partial x} + \frac{\partial \bar{\rho} v}{\partial y} + \frac{\partial \bar{\rho} w}{\partial z})$$

u, v, w : Velocity components of wind

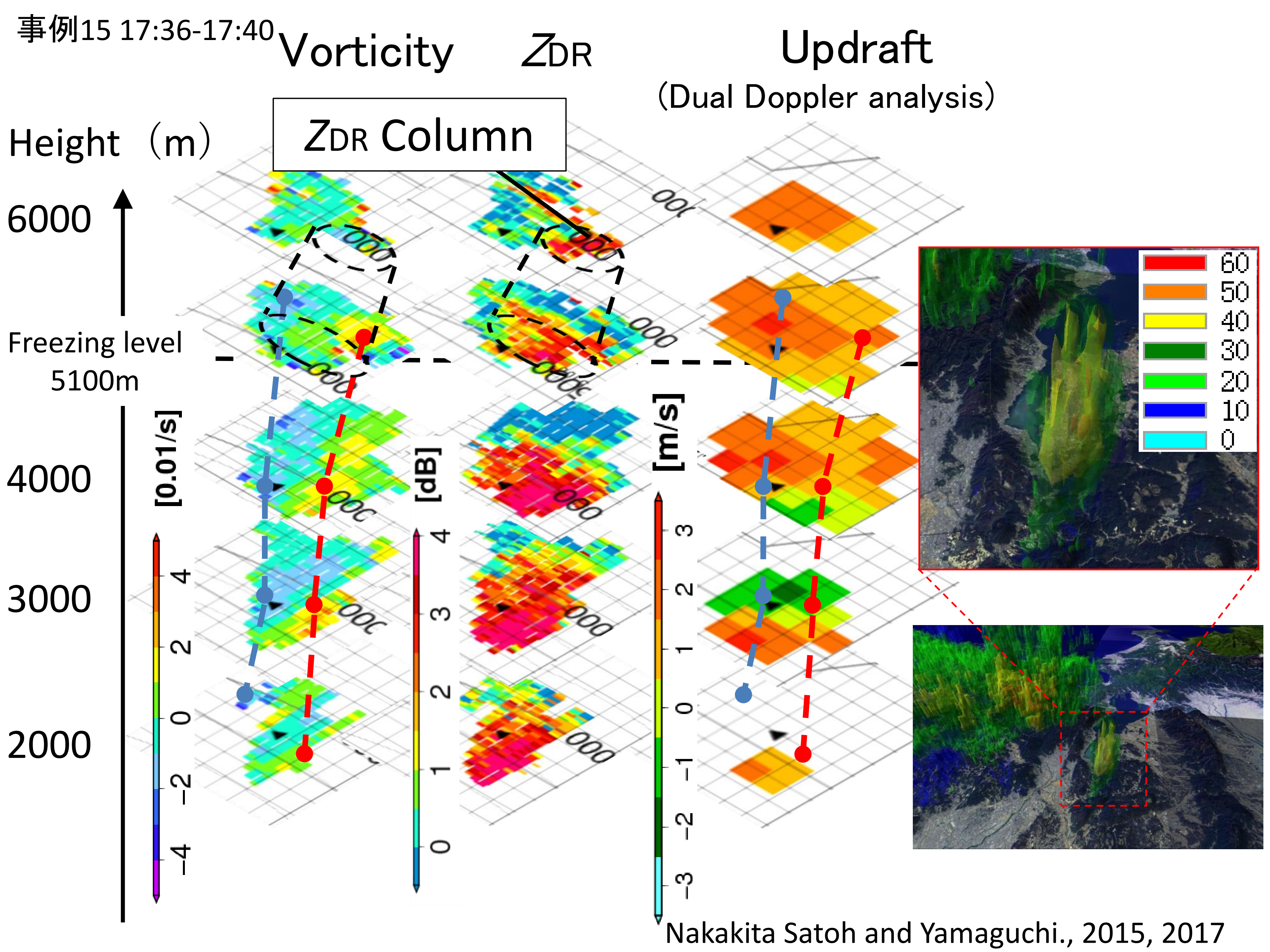
m : Number of radars

rv : Observed Doppler velocity

w_t : Target drop velocity



電力中央研究所
criepi.denken.or.jp/jp/env/outline/2004/07.pdfより引用


事例15 17:36-17:40
Vorticity
ZDR
Updraft
(Dual Doppler analysis)
ZDR Column
Height (m)
6000
Freezing level
5100m
4000
3000
2000
[0.01/s]
[dB]
[m/s]
60
50
40
30
20
10
0
Nakakita Satoh and Yamaguchi., 2015, 2017

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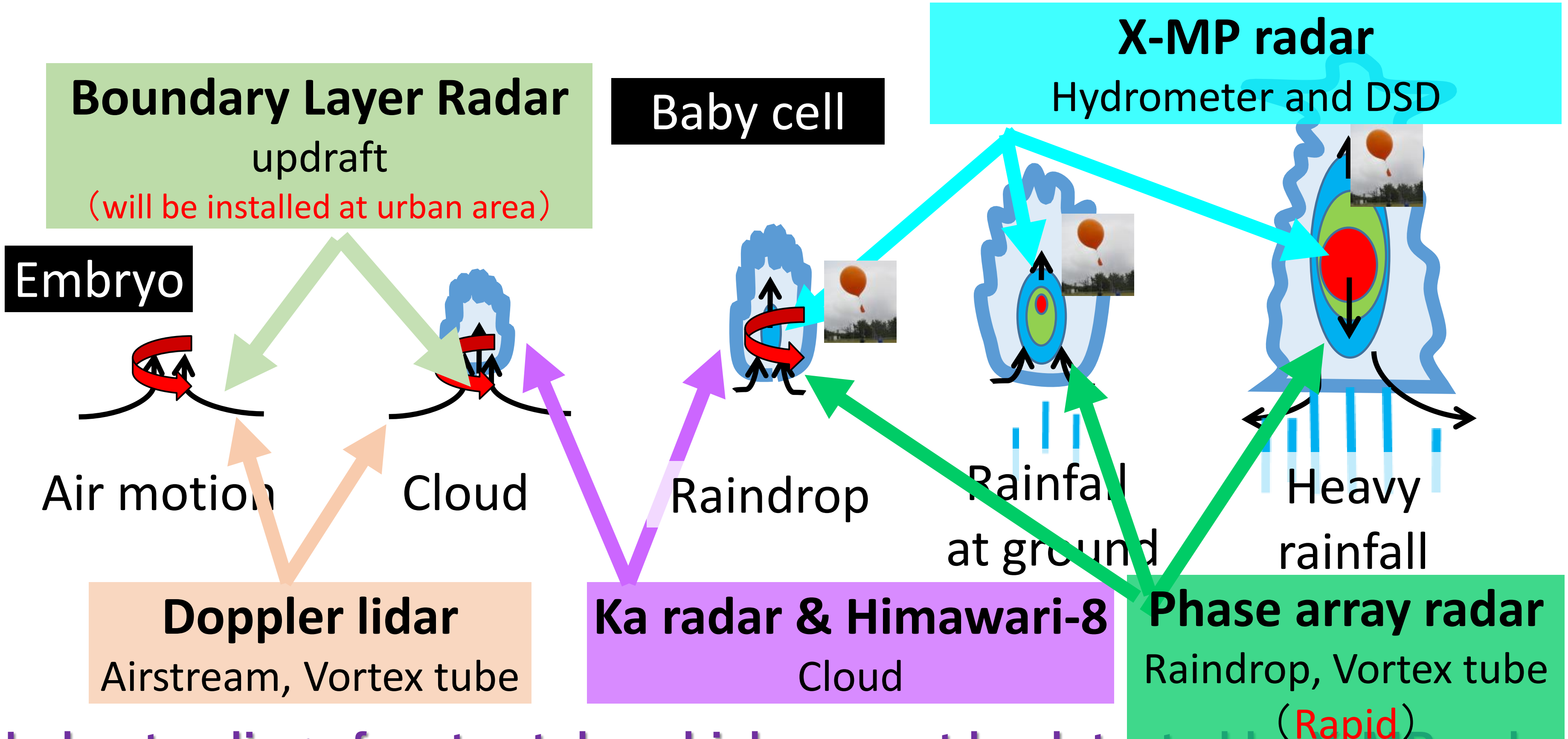
Targets of each sensors



Understanding of vortex tube which can not be detected by X-MP radar

Generation of baby cell

updraft (airplume)→vortex formulation

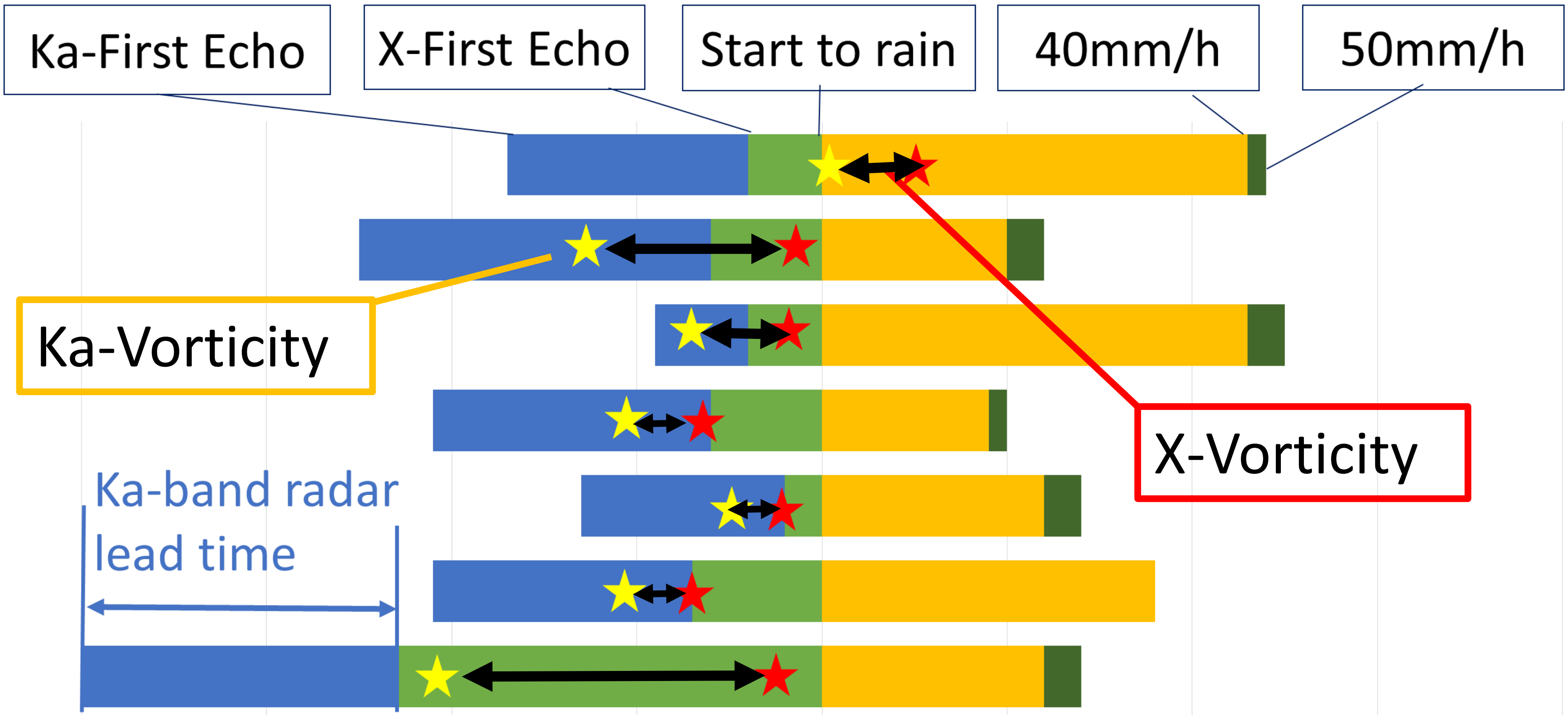
Developing of baby cell

vortex formulation→precipitation formulation

Radar Information

		
Radar	X-band Radar	Ka-band Radar
Wave length	3.0 cm	0.86 cm
Observation area	80 km	30 km
Time of Volume Scan	5 minutes	**10 minutes**
Spatial resolution	150 m / 1.2°	**75 m / 0.35°**
Observed parameter	Z Doppler velocity Polarimetric parameter	Z Doppler velocity Polarimetric parameter

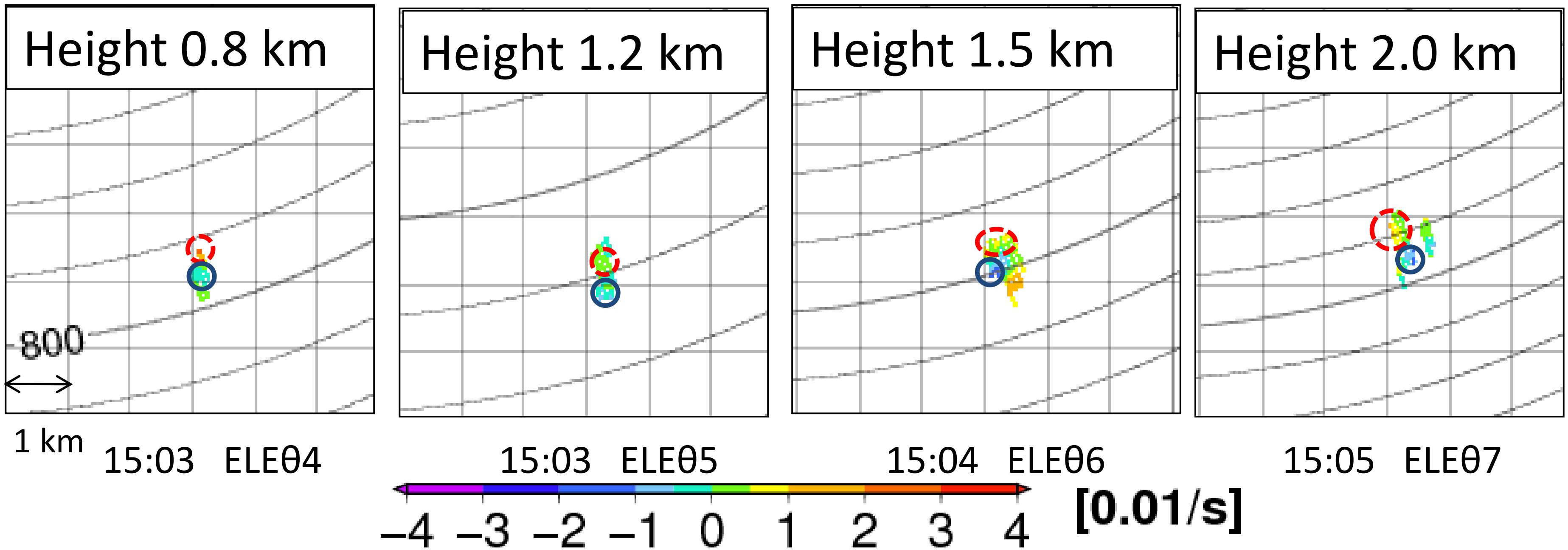
Echo and Vorticity detection time



In 7cases, Ka-band radar can detect vorticity more than 0.02/s earlier than X-band radar

Nakakita and Niibo et al, (2017)

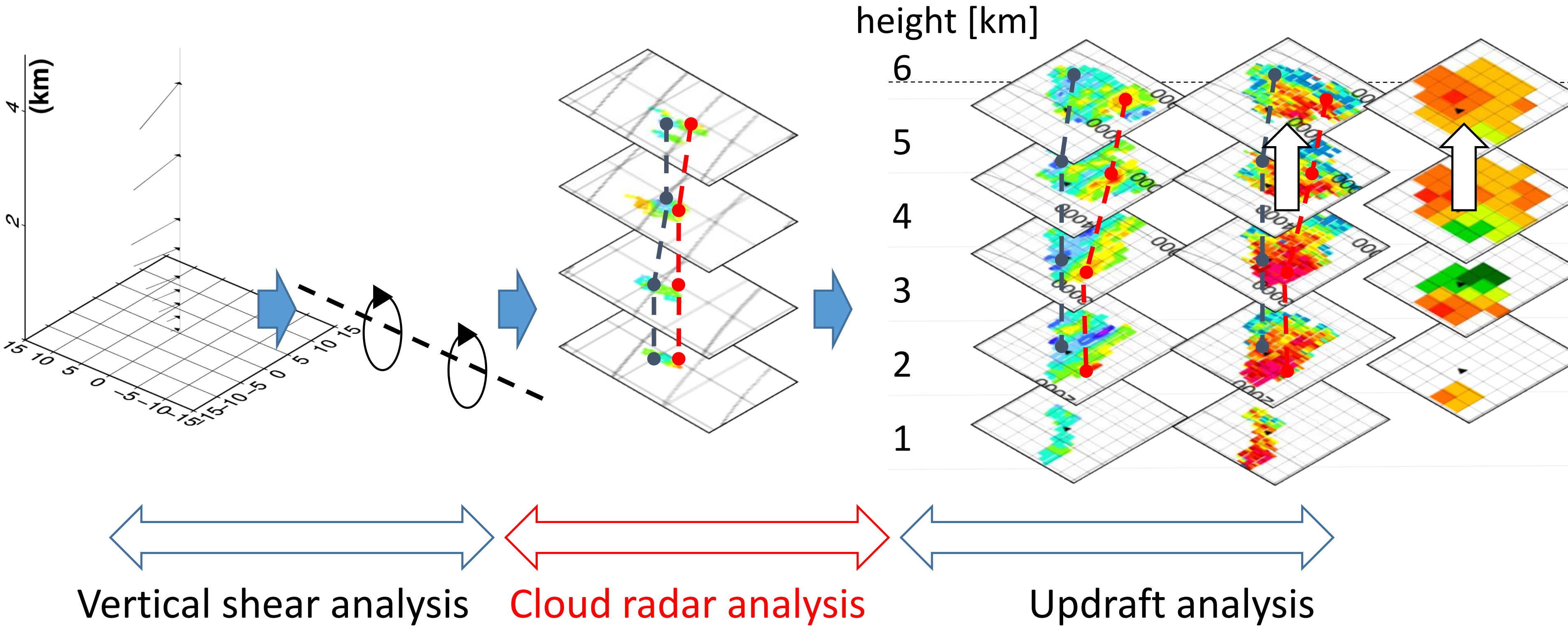
Vortex analysis in the earlier stage



✓In some events, Ka-band vorticity distributions are corresponded with X-band radar ones.
✓Vortex tubes were observed in earlier stage.

Nakakita and Niibo et al, (2017)

Formulation vertical vortex tube



✓Guerrilla-heavy rainfall is caused by weak vertical shear of horizontal wind.
✓Vertical vortex tube was found in the cloud using cloud radar.
✓Updraft was associated with a pair of vertical vortex tubes.
✓We found horizontal vortex tube caused by vertical shear of wind is titled into vertical vertex tube by an updraft in Guerrilla-heavy rainfall events.

Nakakita and Niibo et al,（2017）

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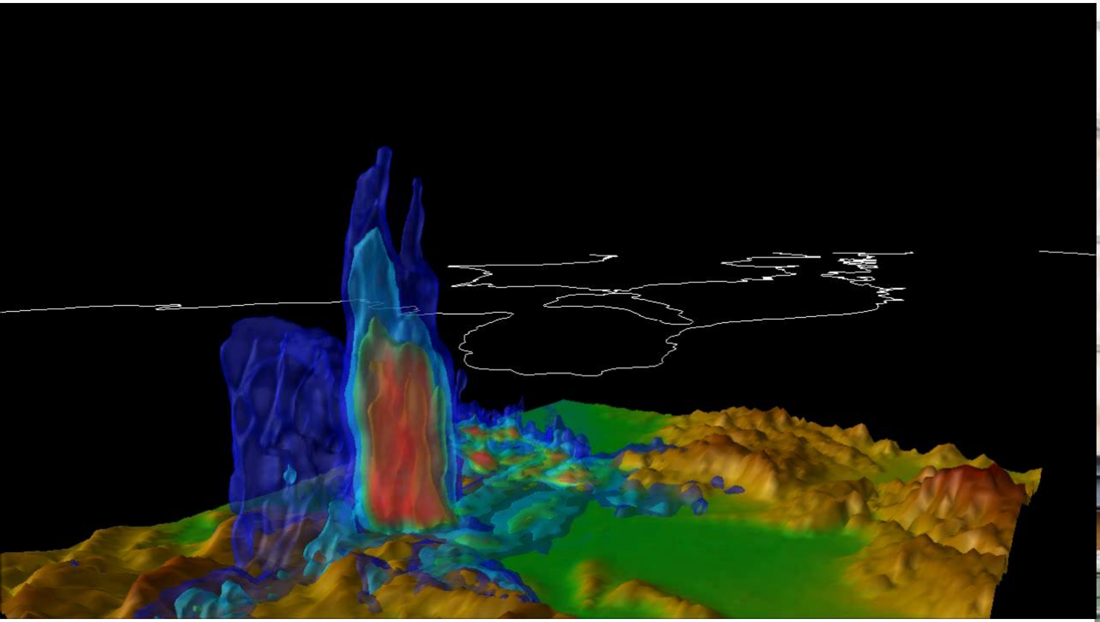
Phased Array Weather Radars (PAWR)



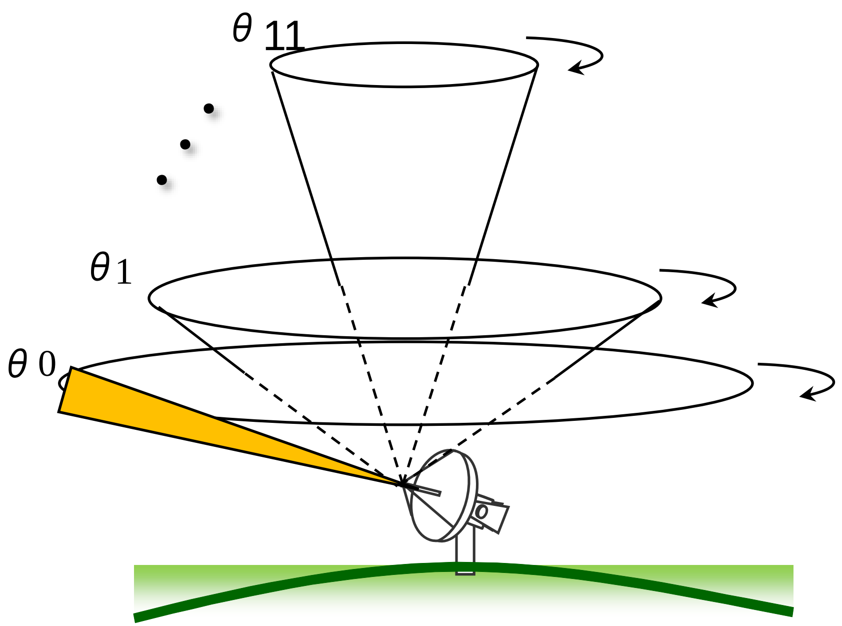
Reflectivity of Cumulonimbus could

Phased Array Weather Radar

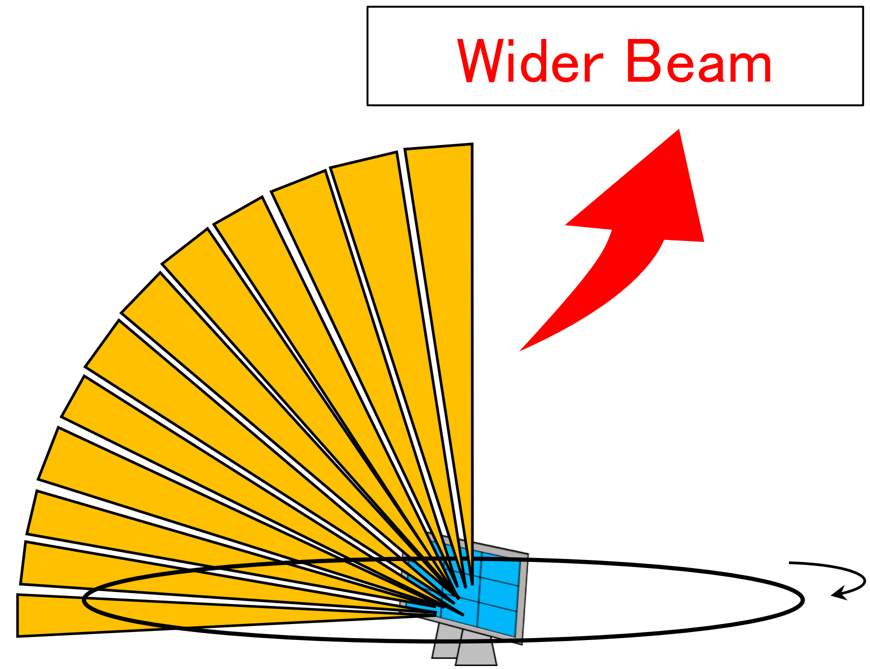
Wider elevation angle (about 100°) is available;
Time resolution of 3D observation is about 30 second.

Figure source: National Institute of Information and Communications Technology (NICT)

Advantage of PAWR for 3D observation



X-Band MP radars require multiple scans.

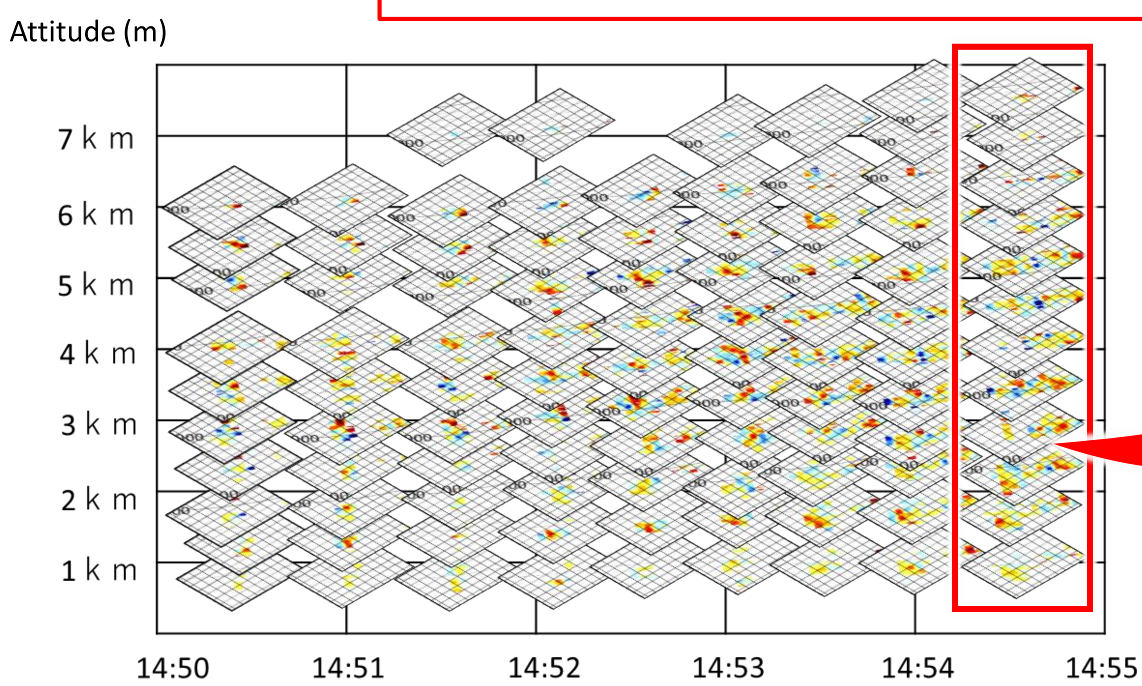


PAWR finishes in one scan.

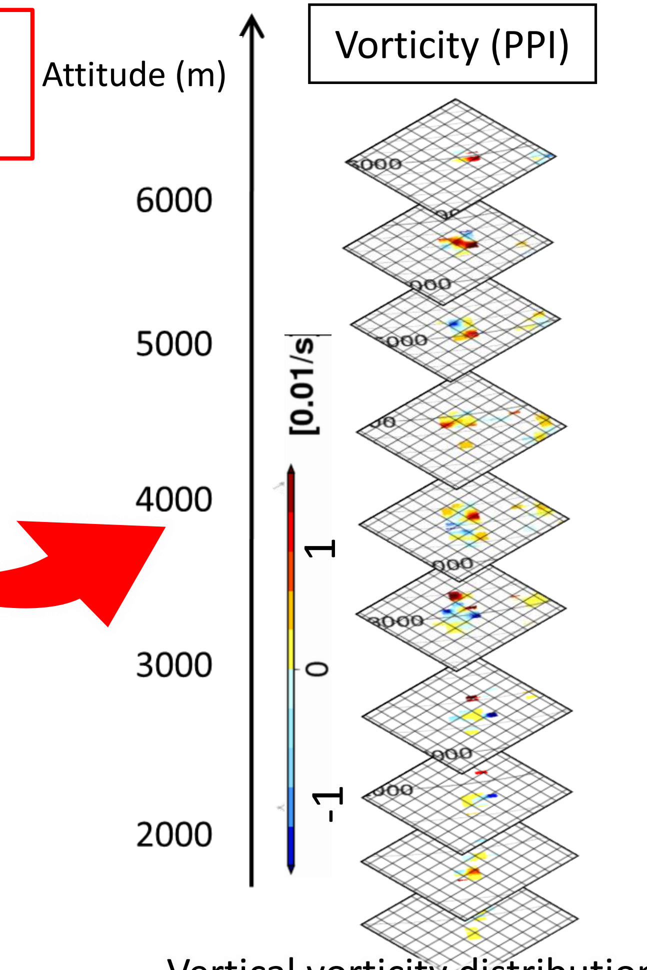
Wider elevation angle (about 100°) is available;
Time resolution of 3D observation is about 30 second.

Performance of PAWR

Obtain information of a cumulonimbus cloud at once



Distribution of vertical vorticity of time variation using X-Band MP radar observation.



Vertical vorticity distribution

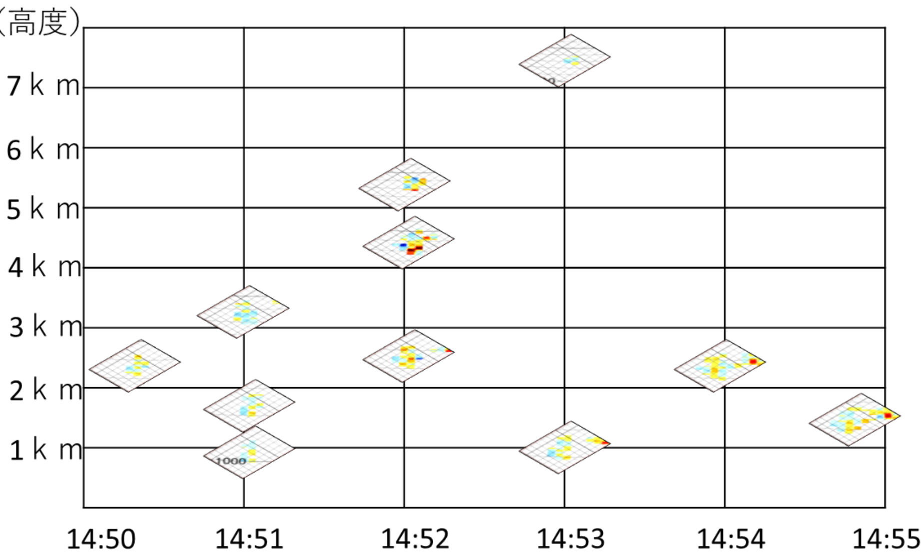
Wider elevation angle (about 100°) is available;
Time resolution of 3D observation is about 30 second.

Nakakita, Takao, Niibo, Yamaguchi and Nakagawa（2019）

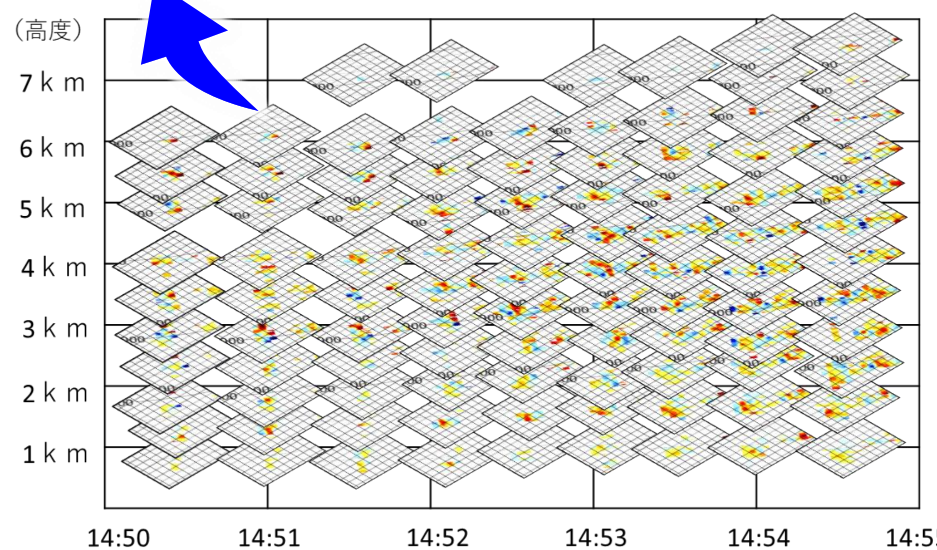
Comparison between X-MP radars and PAWR

Time-varying vertical vorticity distribution

Data density is extraordinarily higher!



X-Band MP radars



Phased Array Weather Radars

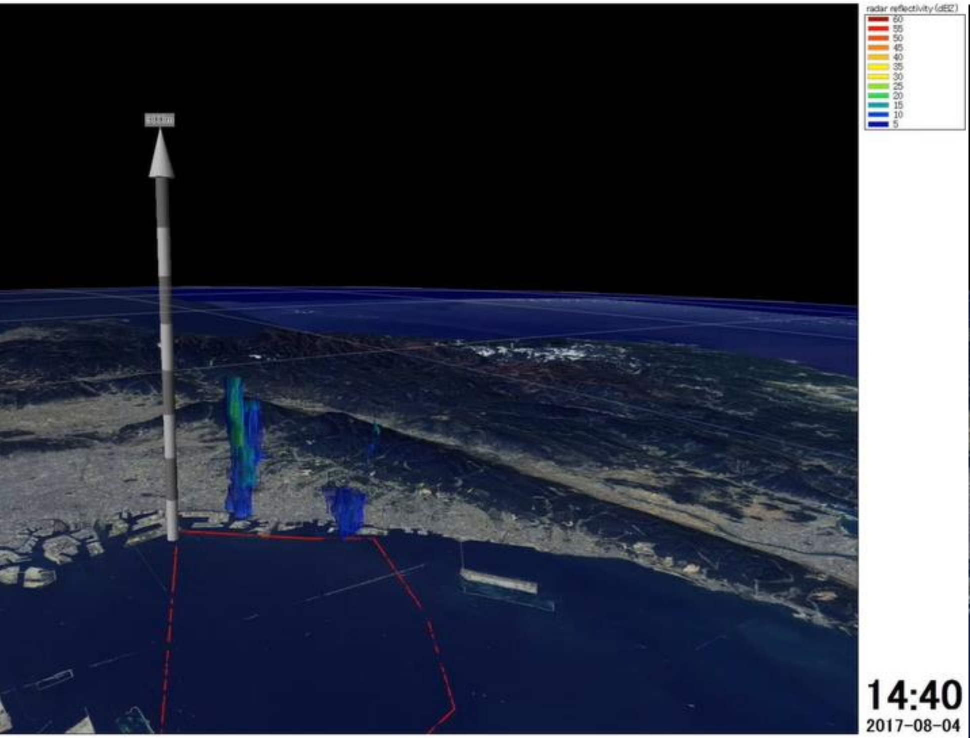
Time resolution: 5 mins → 30 seconds

Observation angle of elevation: 15° → 110°

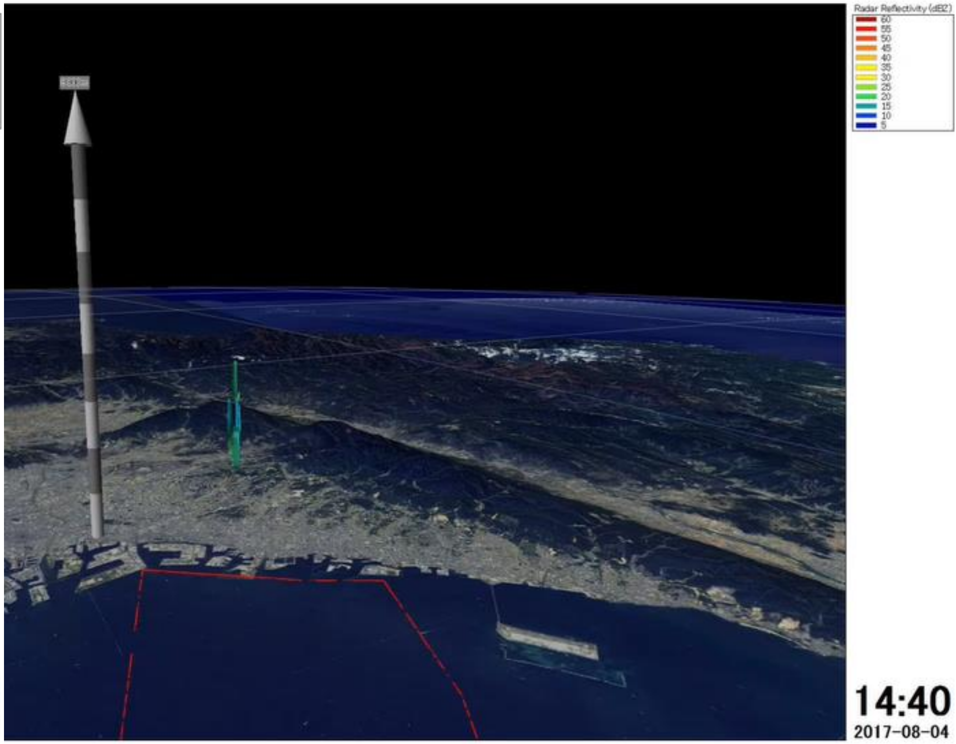
Phenomena in smaller scales can be captured by PAWR than X-MP radars.

Nakakita, Takao, Niibo, Yamaguchi and Nakagawa（2019）

Time change of reflectivity echoes by X-Band MP radar & PAWR



Observation by X-band MP radar
(Every 5 min)



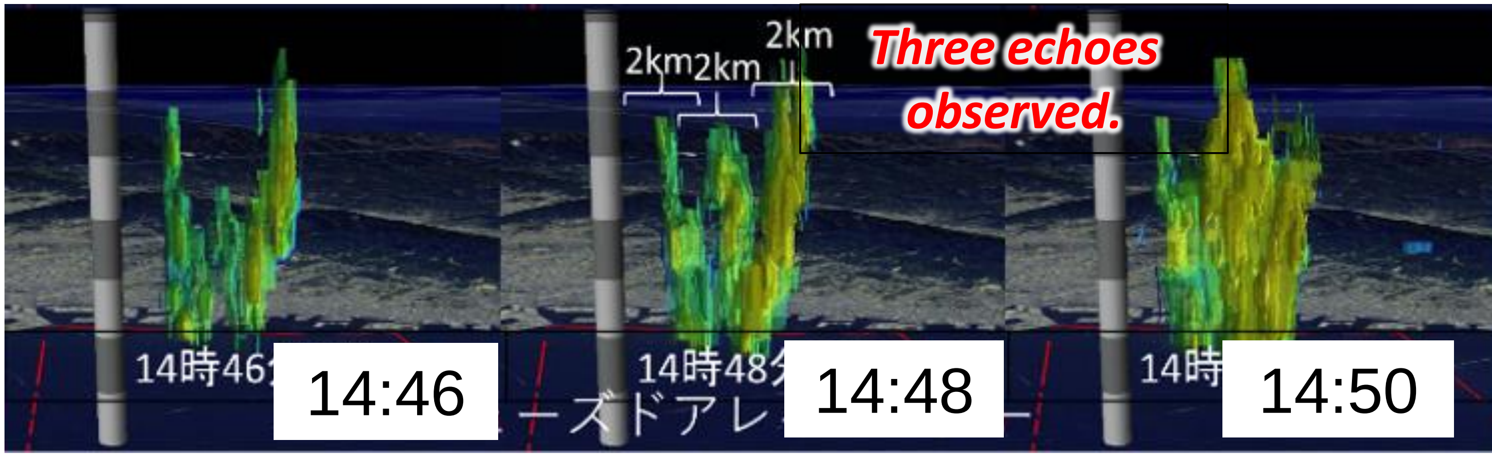
Observation by phased array weather radar (Every 30 seconds)

Movements in small echo can be captured smoothly by using phased array weather radar.

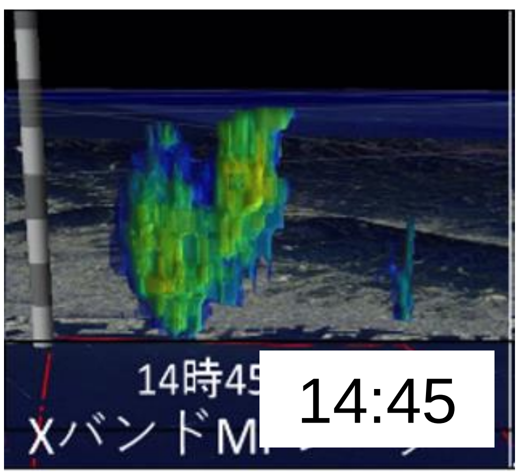
Nakakita, Takao, Niibo, Yamaguchi and Nakagawa（2019）

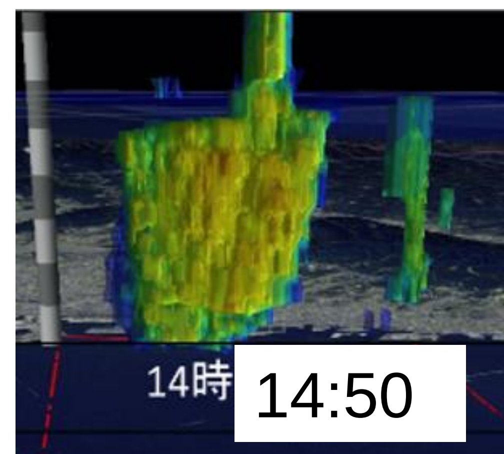
Time change of reflectivity echoes by X-Band MP radar & PAWR

Phased Array Weather Radar



X-Band MP Radar





The growing process of three bulks of echo in small spatio-temporal scales was captured.

Nakakita, Takao, Niibo, Yamaguchi and Nakagawa（2019）

Discussion

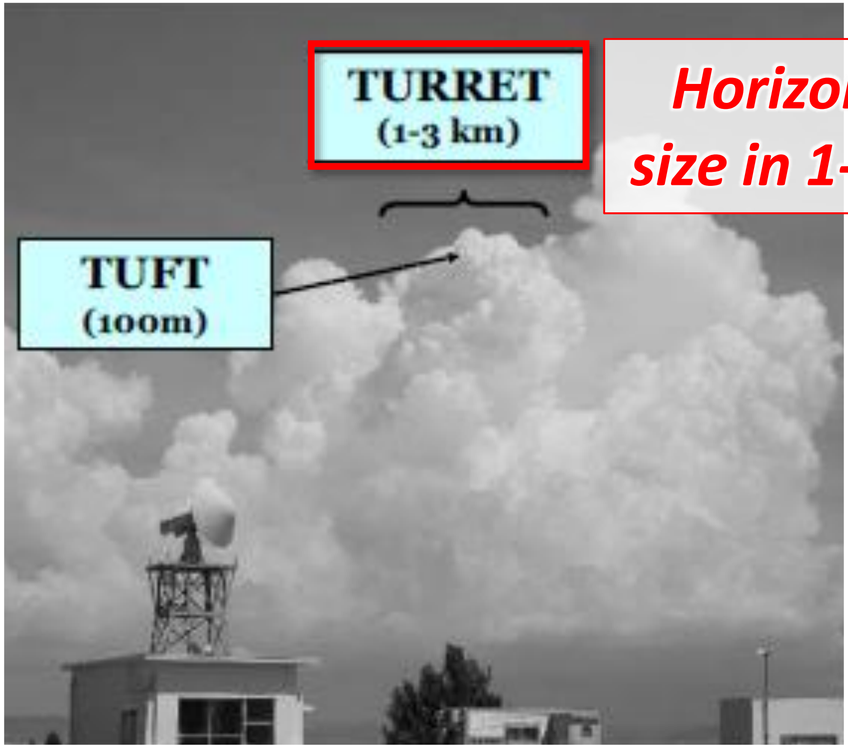
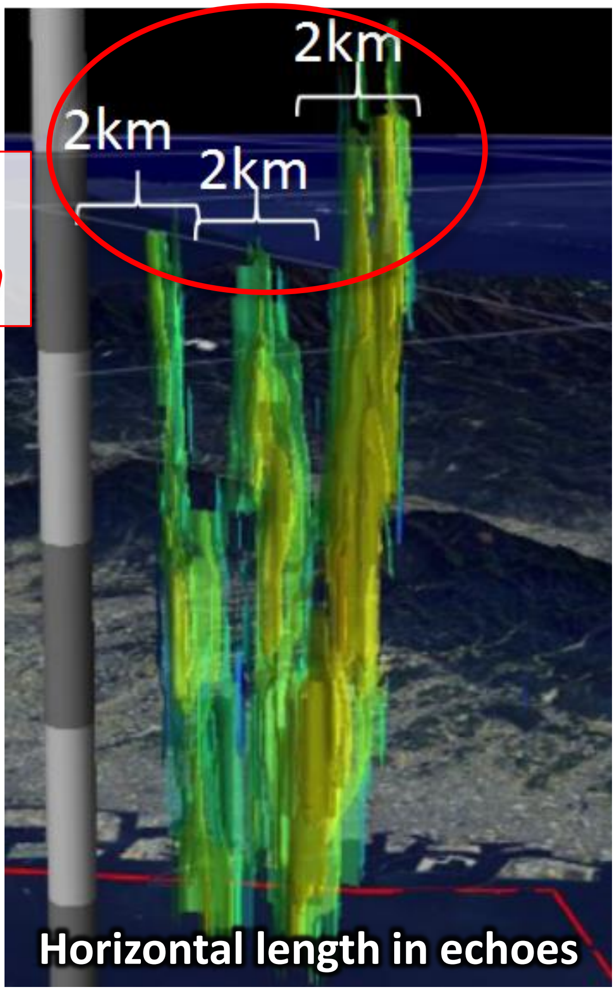


Photo of turret (Kobayashi et al., 2012)

Horizontal size in 1-3 km

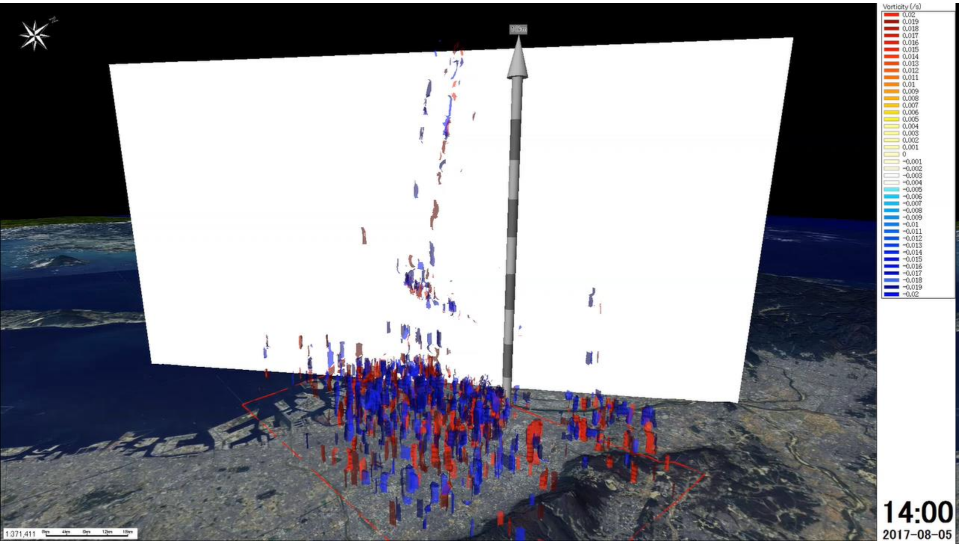


The horizontal length of echoes approximate turret's length.

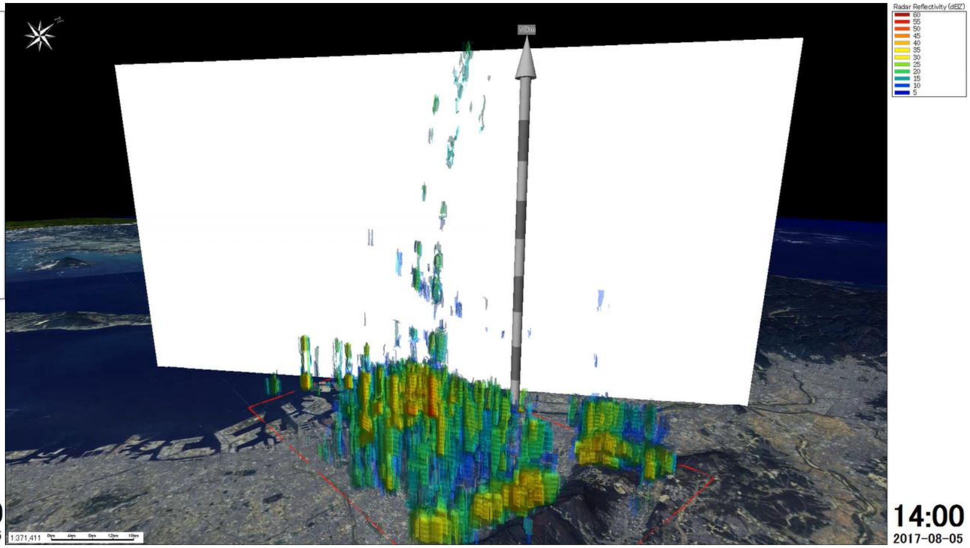
→could observe precipitation particles in turrets in cumulonimbus clouds.

Nakakita, Takao, Niibo, Yamaguchi and Nakagawa (2019)

Time change of Vorticity and reflectivity echoes observed by PAWR



Vertical Vorticity



Radar Reflectivity

Observation by PAWR on 14:00 on 2017/08/05

The *development of cumulonimbus clouds* as well as *the positive-negative vortex tube pair* were captured by PAWR every 30 seconds.

Nakakita, Takao, Niibo, Yamaguchi and Nakagawa（2019）

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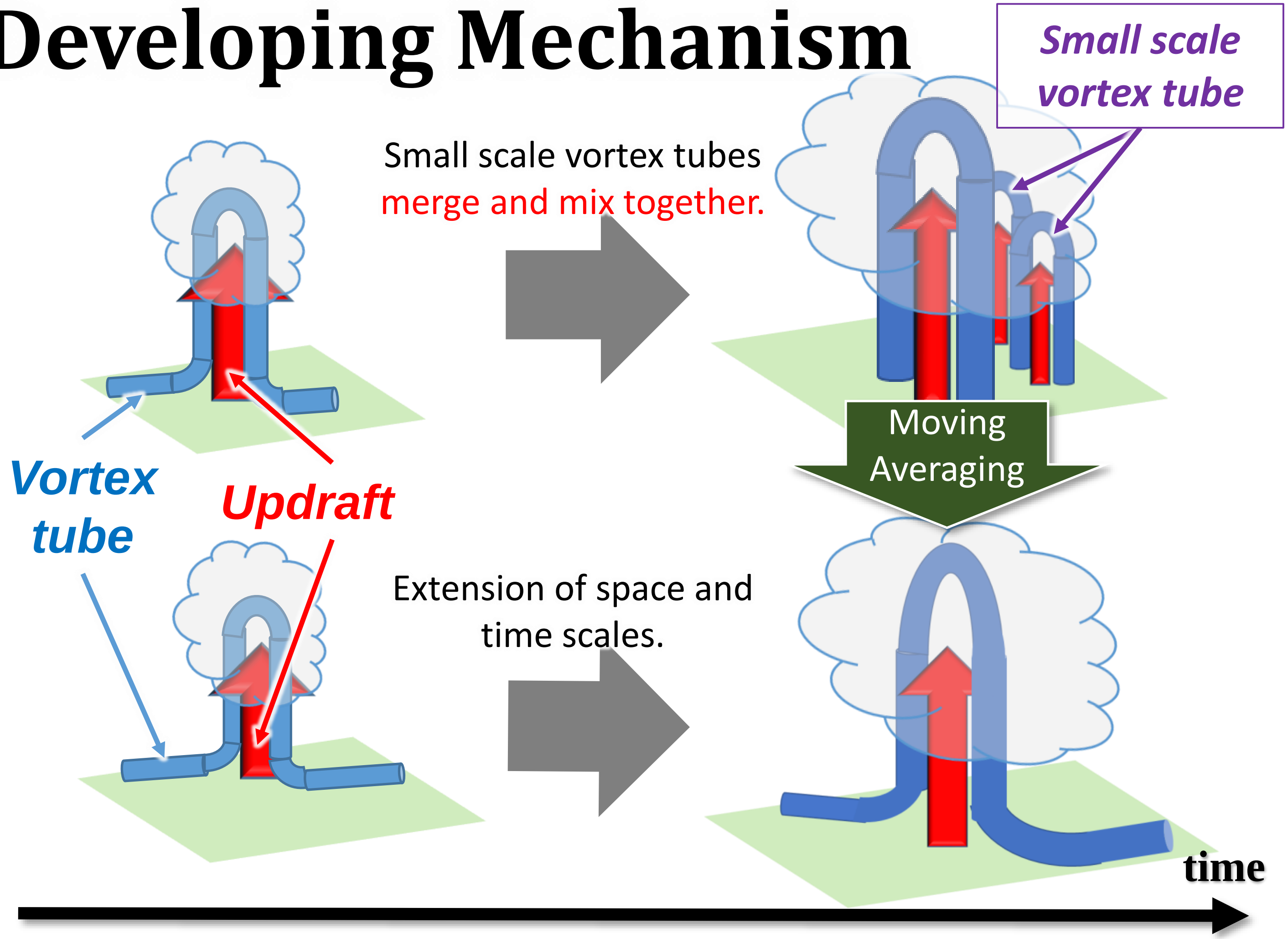
- **Operational early warning systems based on radar echo and vorticity aloft**
- **Analysis on vortex tube in early and developing stages of single sever storm using**
  - **X-band weather radar**
  - **Ka-band cloud radar**
  - **X-band phased array weather radar**
- **Conclusion**

Discussion of Vorticity Developing Mechanism

Phased Array Weather Radar equivalent resolution

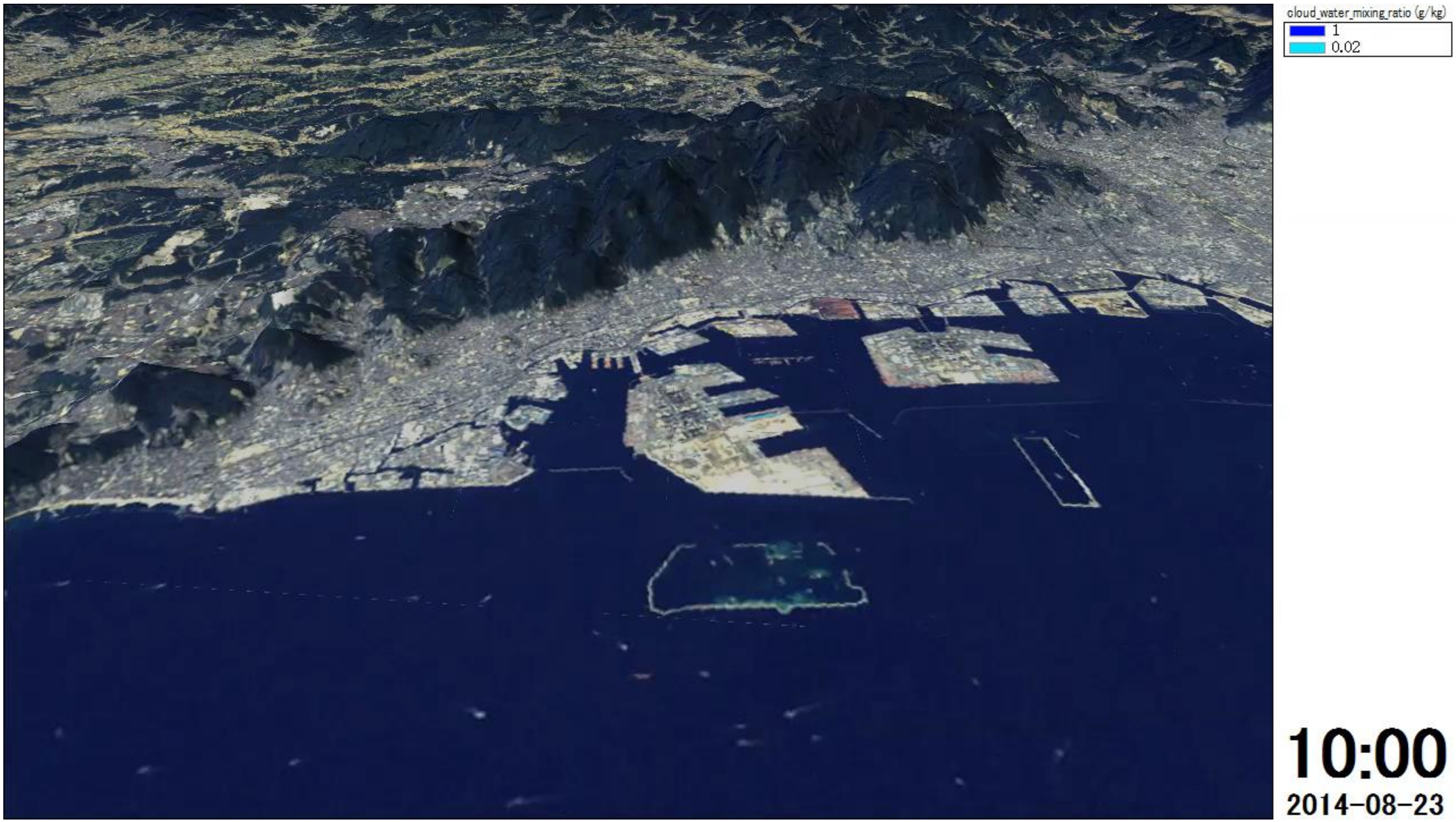
X-Band MP Radar equivalent resolution



Multiple vortex tubes in small spatiotemporal scale *gather* and *merge* together to generate vortex tubes in larger spatiotemporal scales.

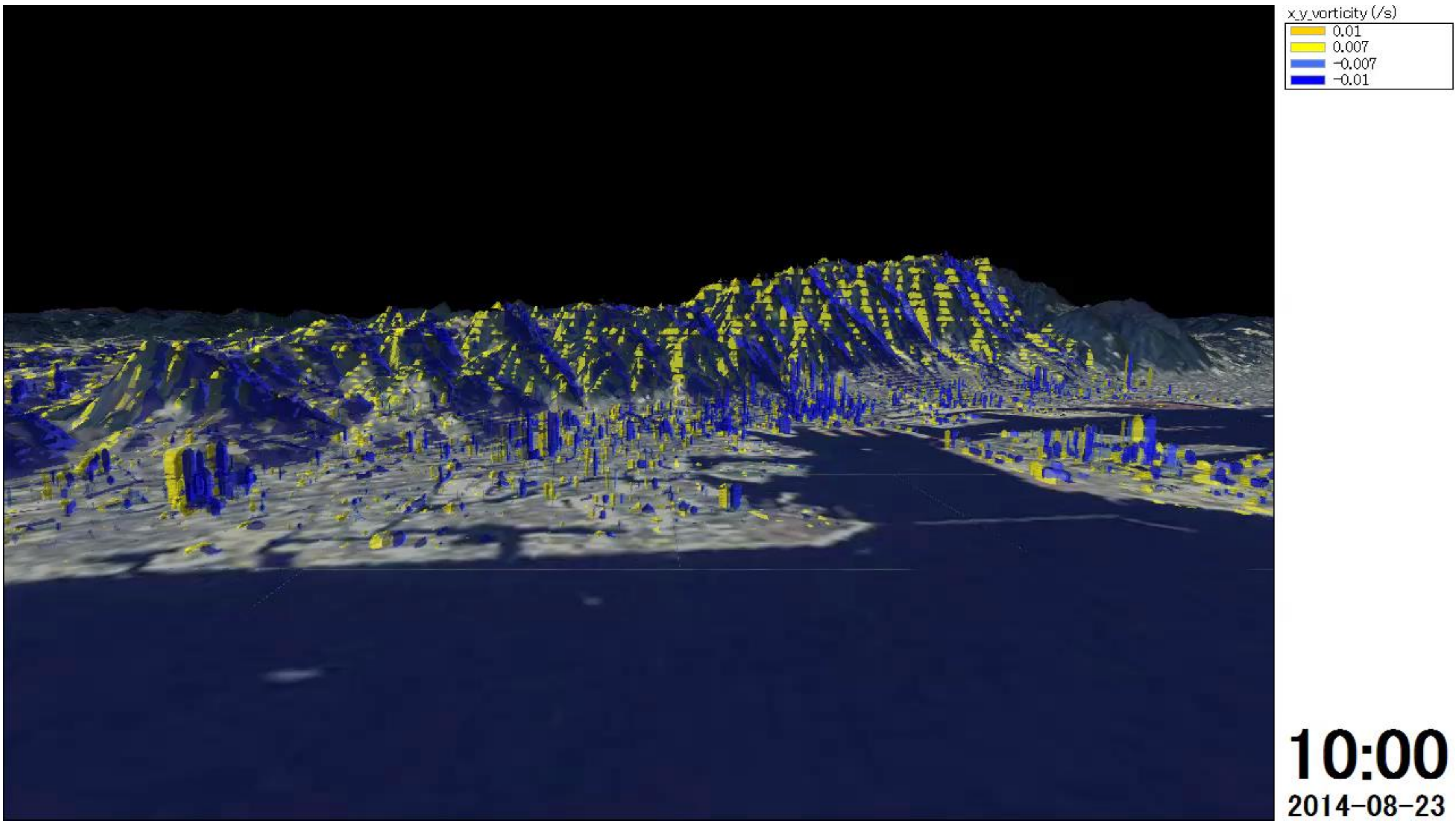
Nakakita, Takao, Niibo, Yamaguchi and Nakagawa（2019）

Cloud generation simulated by developed LES model (cloud water mixing ratio)



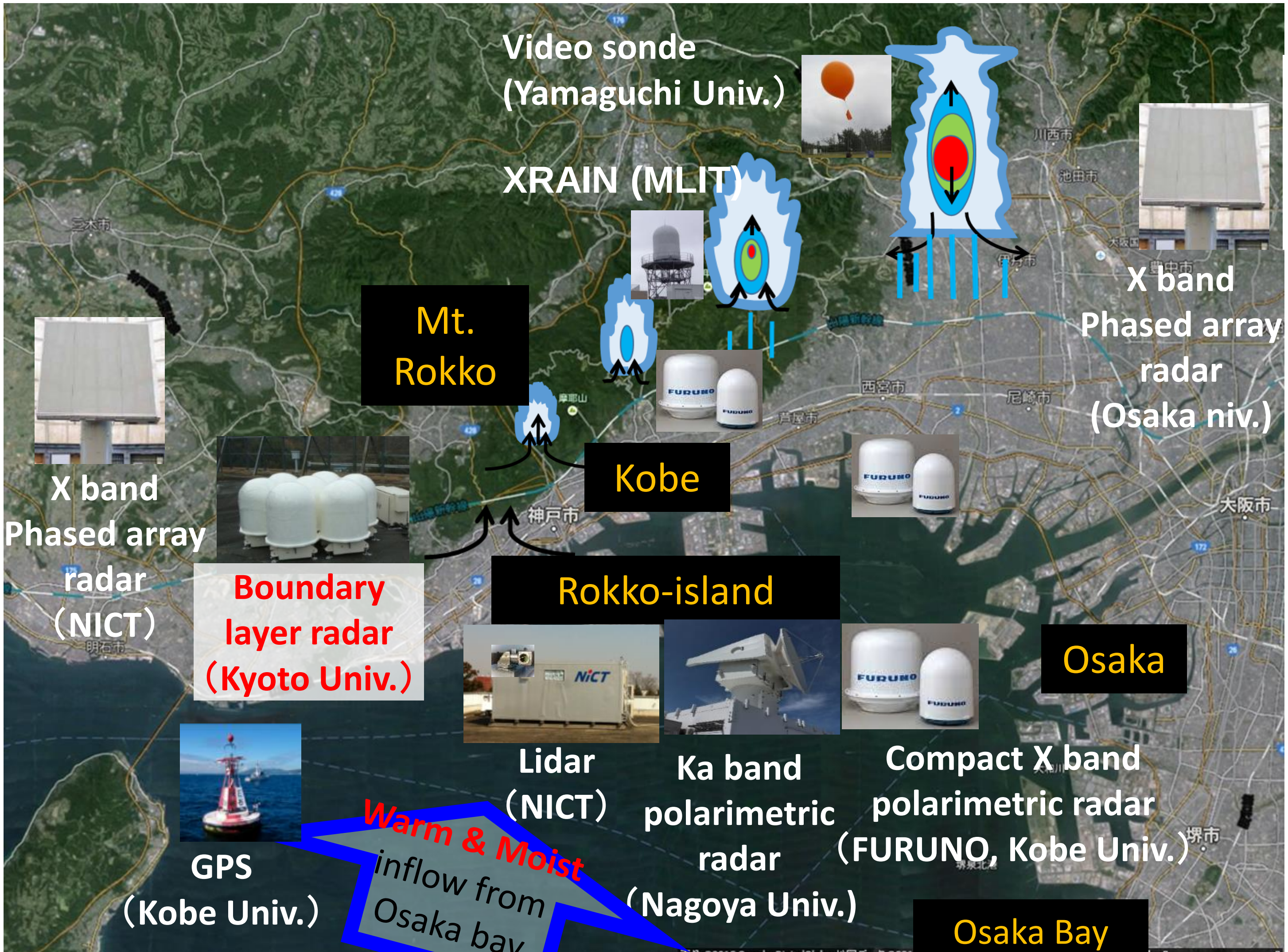
LES model (Yamaguchi, et al.(2016, 2017))

Cloud generation simulated by developed LES model (vertical vortex tube)



LES model (Yamaguchi, et al.(2016, 2017))

new multi-sensors observation of storm-genesis, Kobe (2017-2019)



Since 2007

Nakakita, Eiichi, “Scientific and Integrated Reserach by In-situ Campaign Observations Synchronizing Polarimetric Radar with Video-Sonde”, Journal of Disaster Research, Vol.8, No.1, pp.157-158, 2013.

Thank you for your attention!。

Okinawa campaign observation with researchers and students from various universities and institutes.

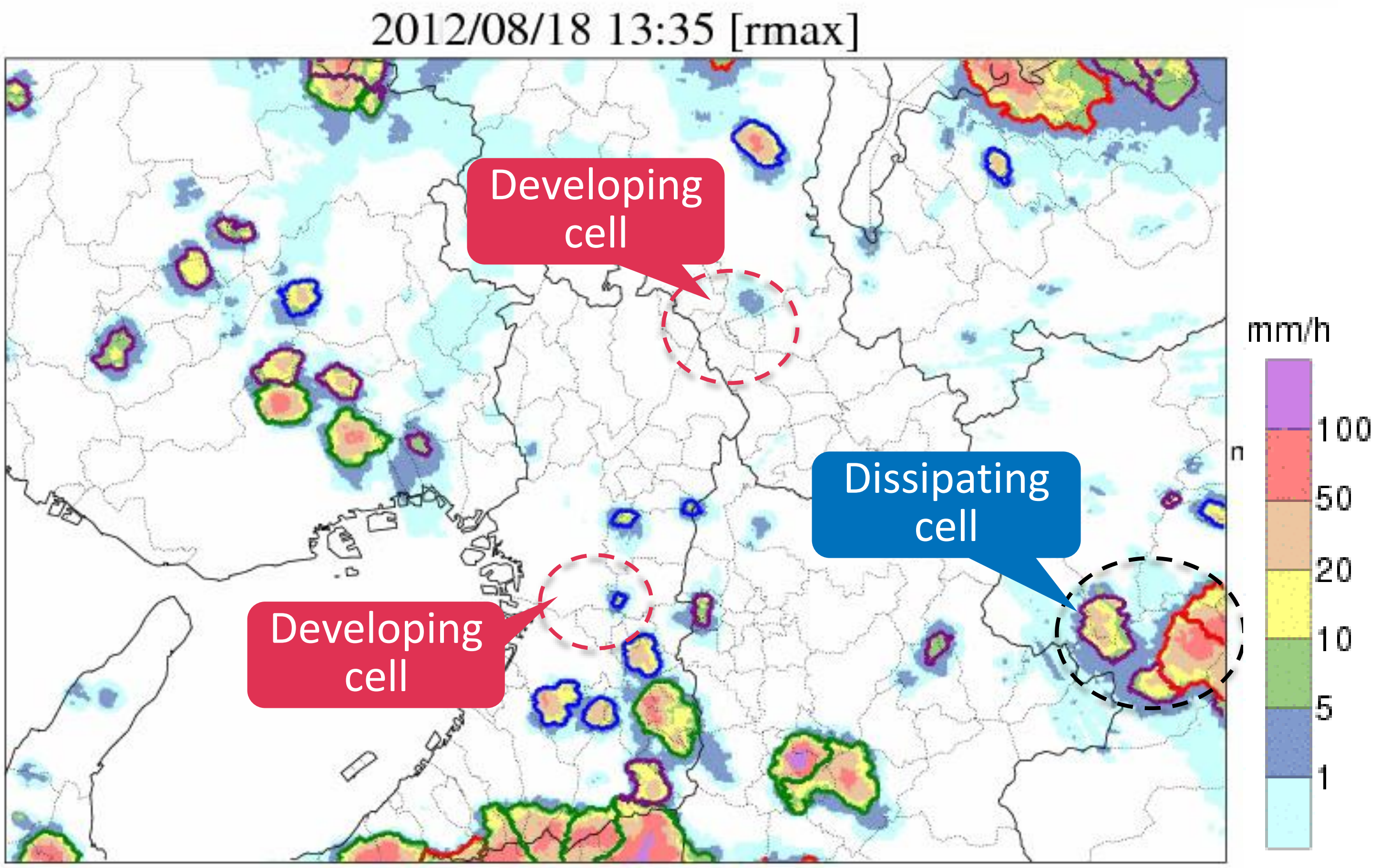
Since 2007

Okinawa campaign observation with professors from Korea and Taiwan (June, 2012)

Installation of Okinawa phased array radar （June, 2014)

Identification of the stage of storm life cycle

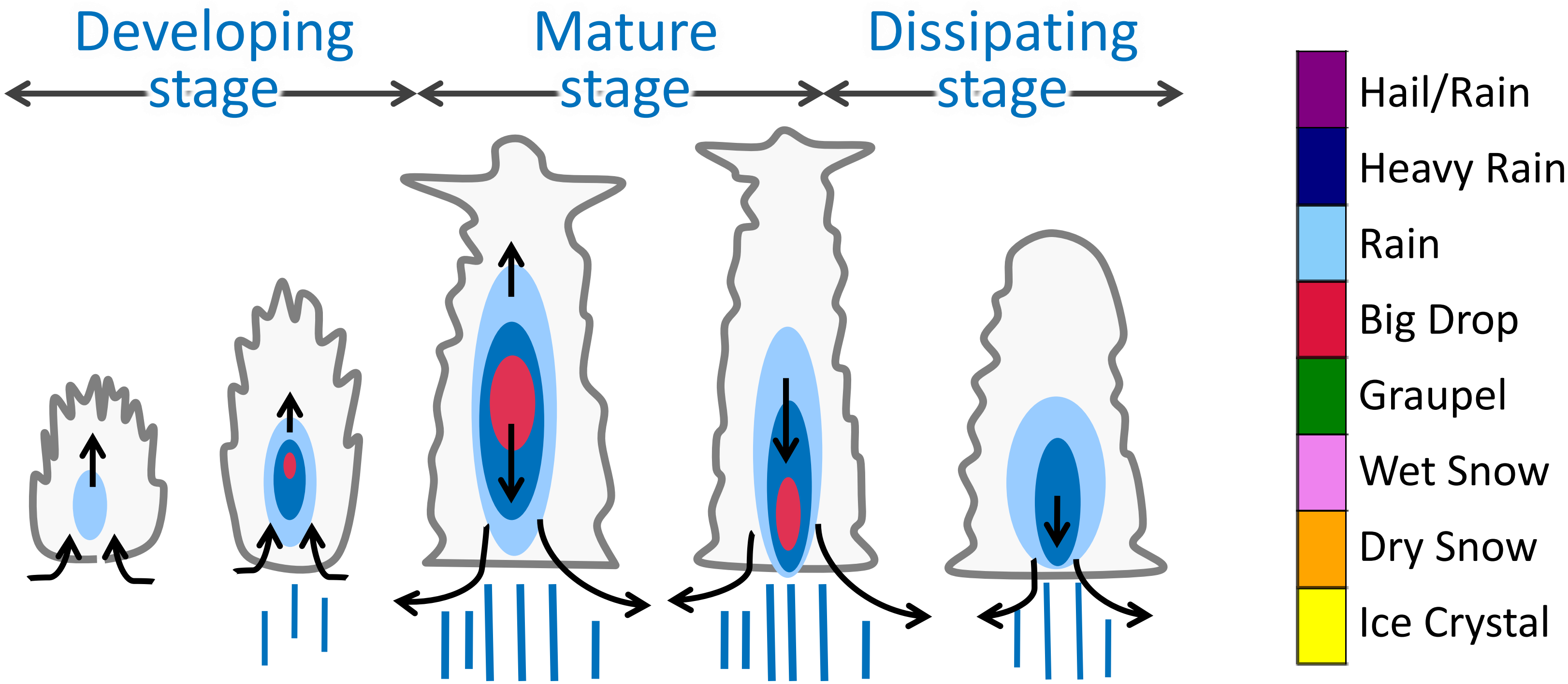
Developing stage | Mature first stage | Mature last stage | Dissipating stage



Masuda and Nakakita (2014)

Identification of the stage of storm life cycle

☐ Existing ratio of hydrometeor in a storm cell



Calculate the existing ratio of hydrometer in a storm cell

→ Investigate the relationship between the existing ratio of hydrometer and the stage.

Masuda and Nakakita (2014)

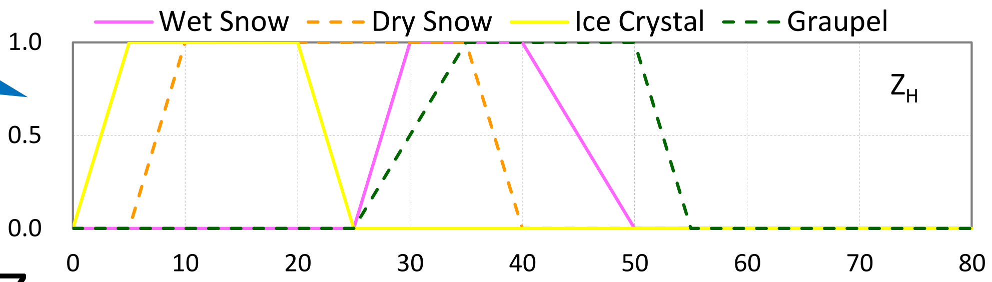
Hydrometeor Classification

Fuzzy logic

- fuzzy logic classification scheme (Park et al. 2009)
  8 categories : Rain, Heavy rain, Rain & Hail, **Big drop**, Graupel, Wet snow, Dry snow, Ice crystal
- Modified membership functions about K_{DP} for X-band

1.0 : large potential
0.0 : small potential

Example of membership function

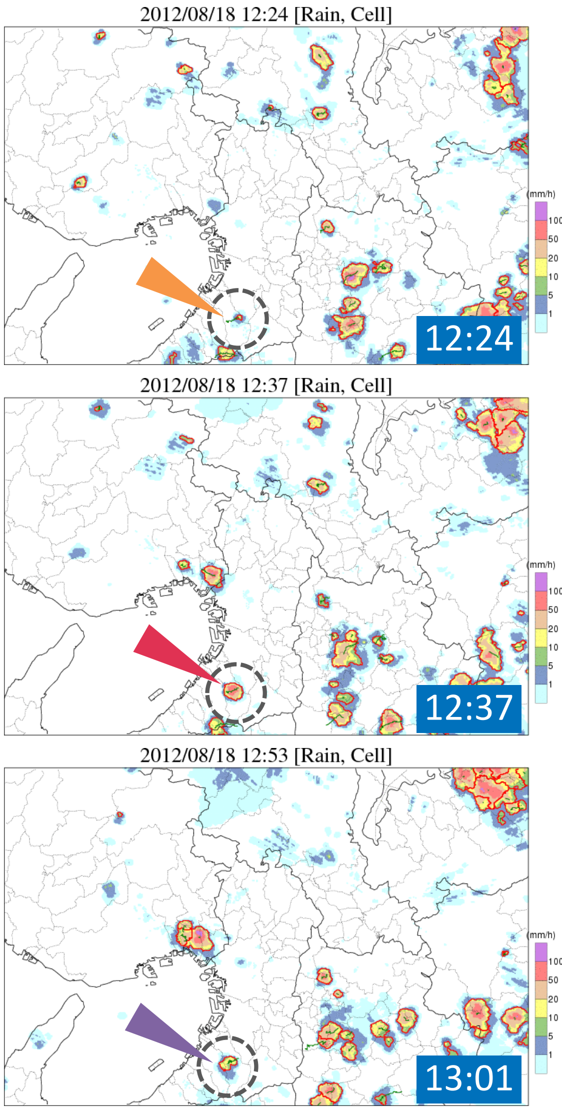


Preprocessing

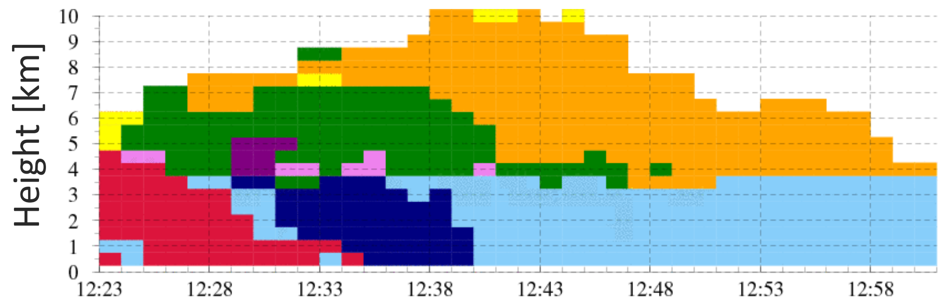
- Bias correction for Z_H and Z_{DR}
- S/N calibration for ρ_{HV}
- Identification of melting layer
- Exclude mesh affected by ground clutter

Masuda and Nakakita (2014)

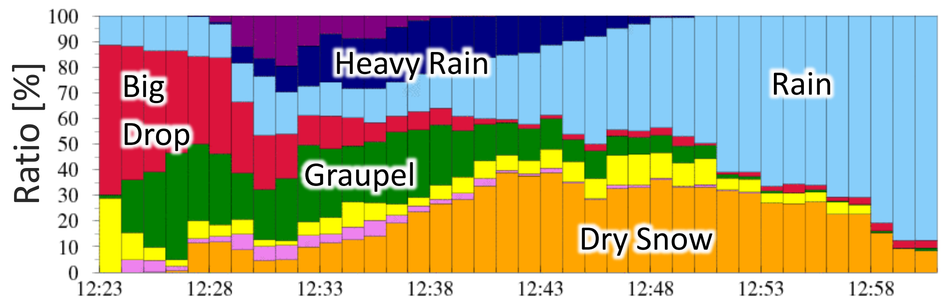
Tracking cell and Hydrometeor classification



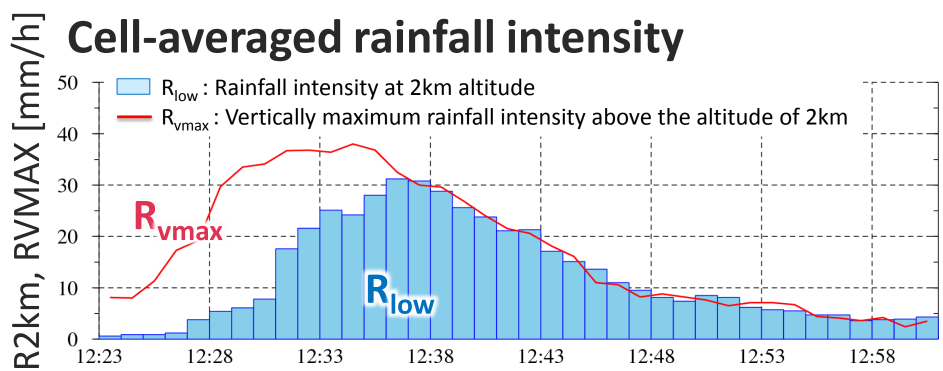
Dominant Hydrometeor at each altitudes



Existing ratio of hydrometeor in the cell

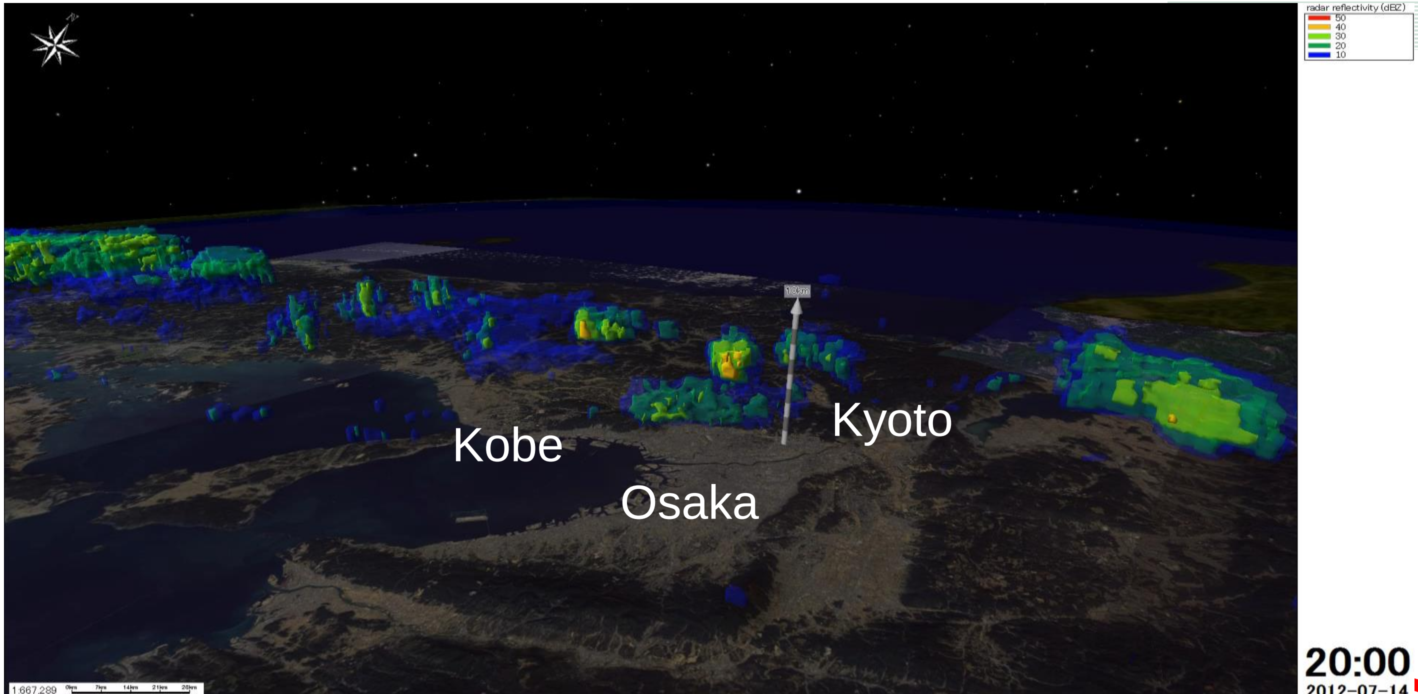


Cell-averaged rainfall intensity

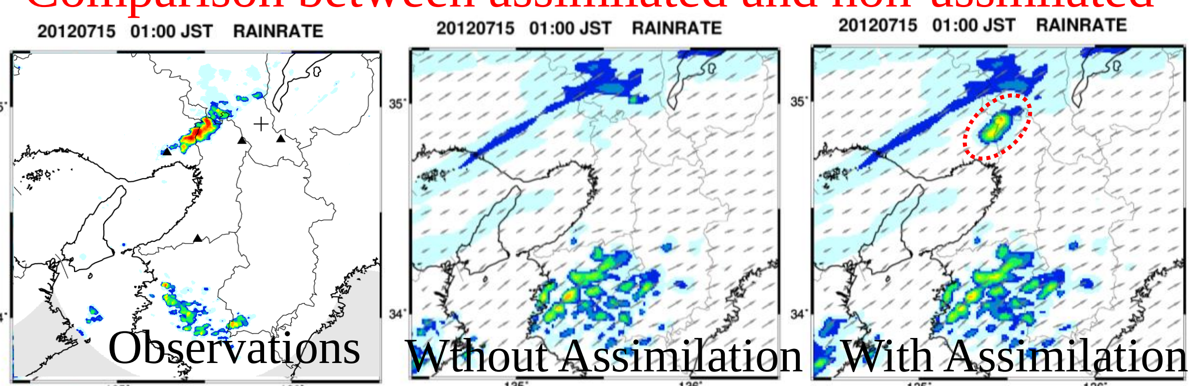


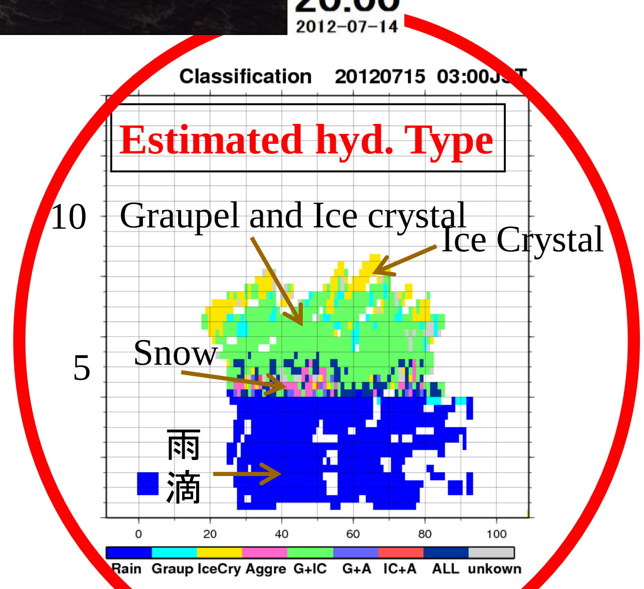
Masuda and Nakakita (2014)

NWP assimilated by hydrometeor type



Comparison between assimilated and non-assmilated

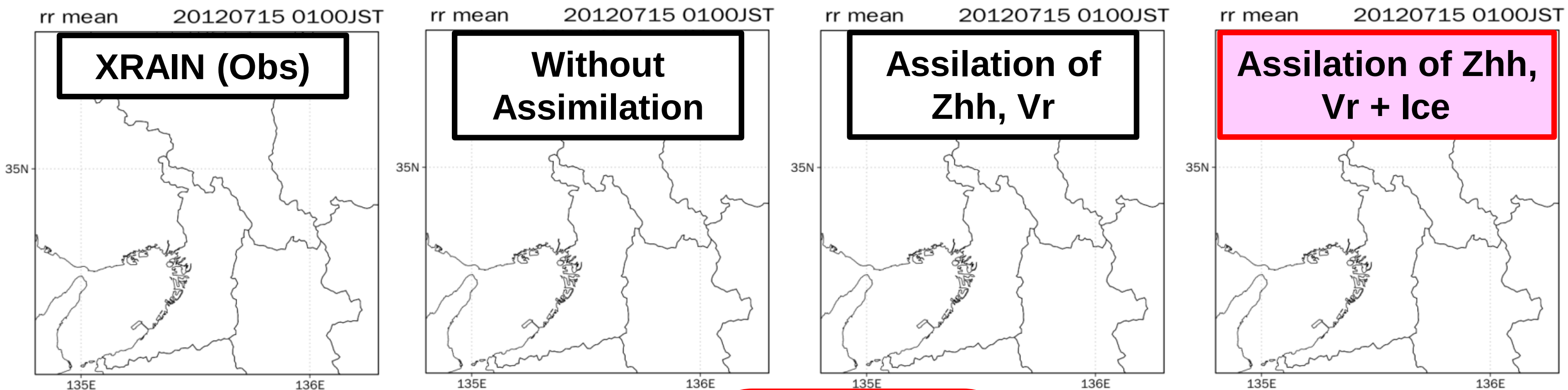


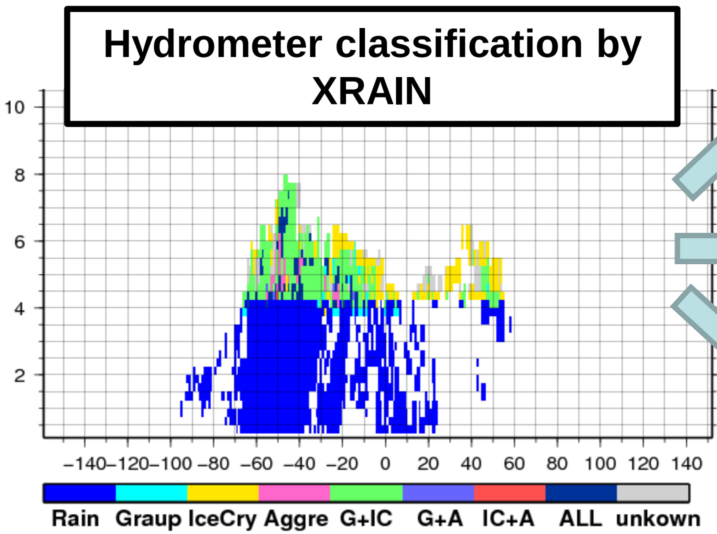


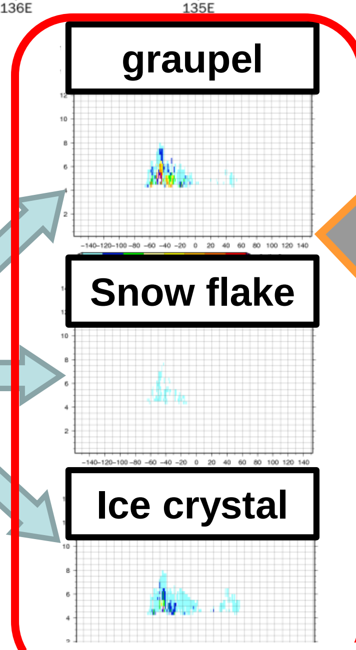
Yamaguchi・Furuta・Nakakita(2013)

NWP assimilated by hydrometeor type

Observed and predicted accumulated rainfallamout



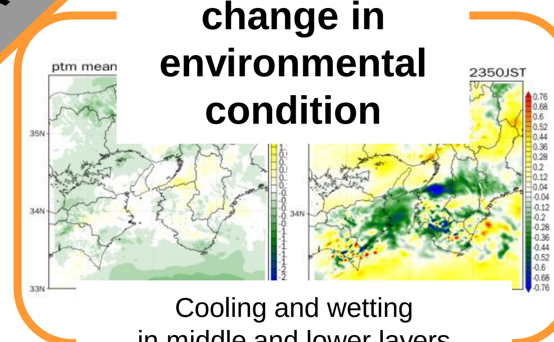




Mixing ratio

Assimilation

Improvement of accuracy in 1 to 2 hours lead time



Yamaguchi・Furuta・Nakakita(2015)

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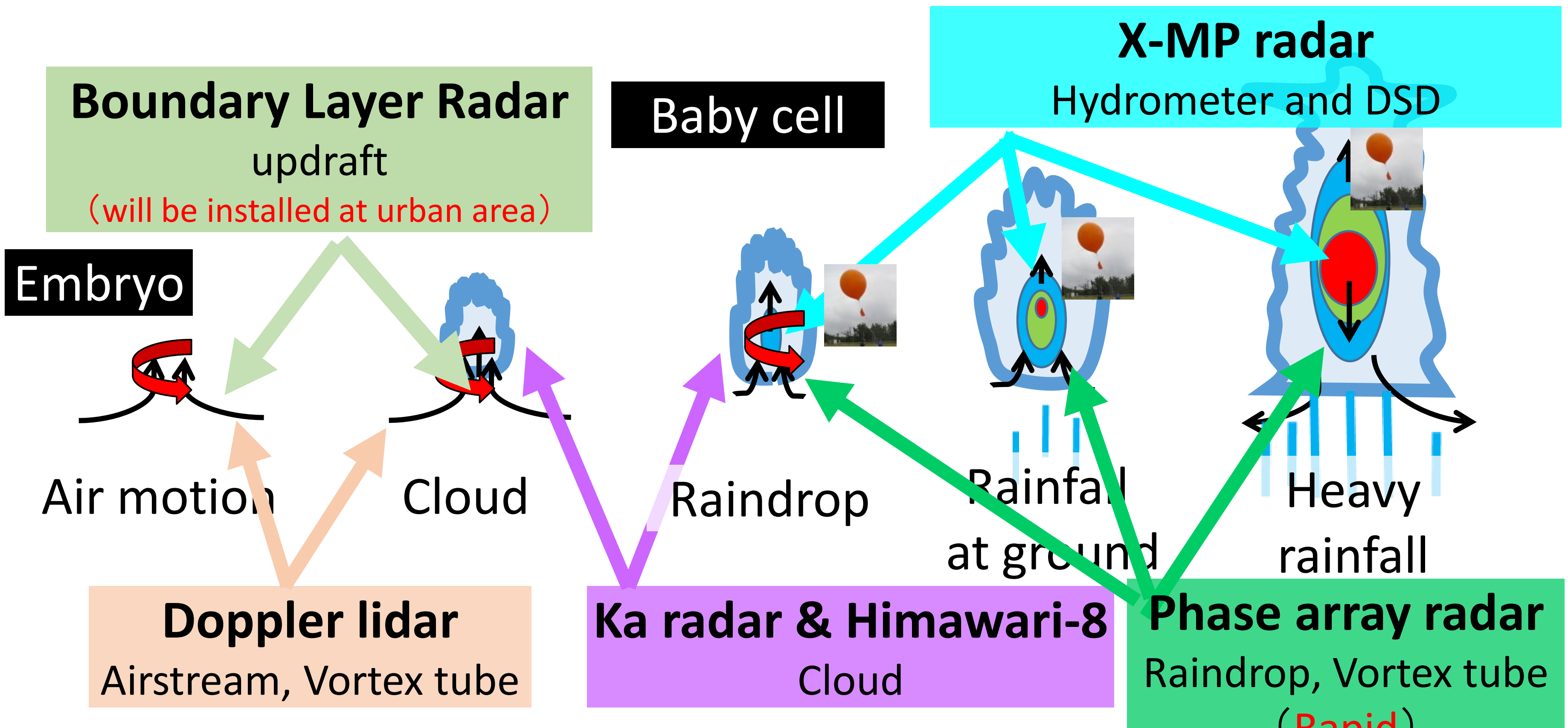
- **Utilization of polarimetric information**
- **Campaign observations by radars and lider with multi-frequencies and multi-types**

Targets of each sensors



Understanding of vortex tube which can not be detected by X-MP radar

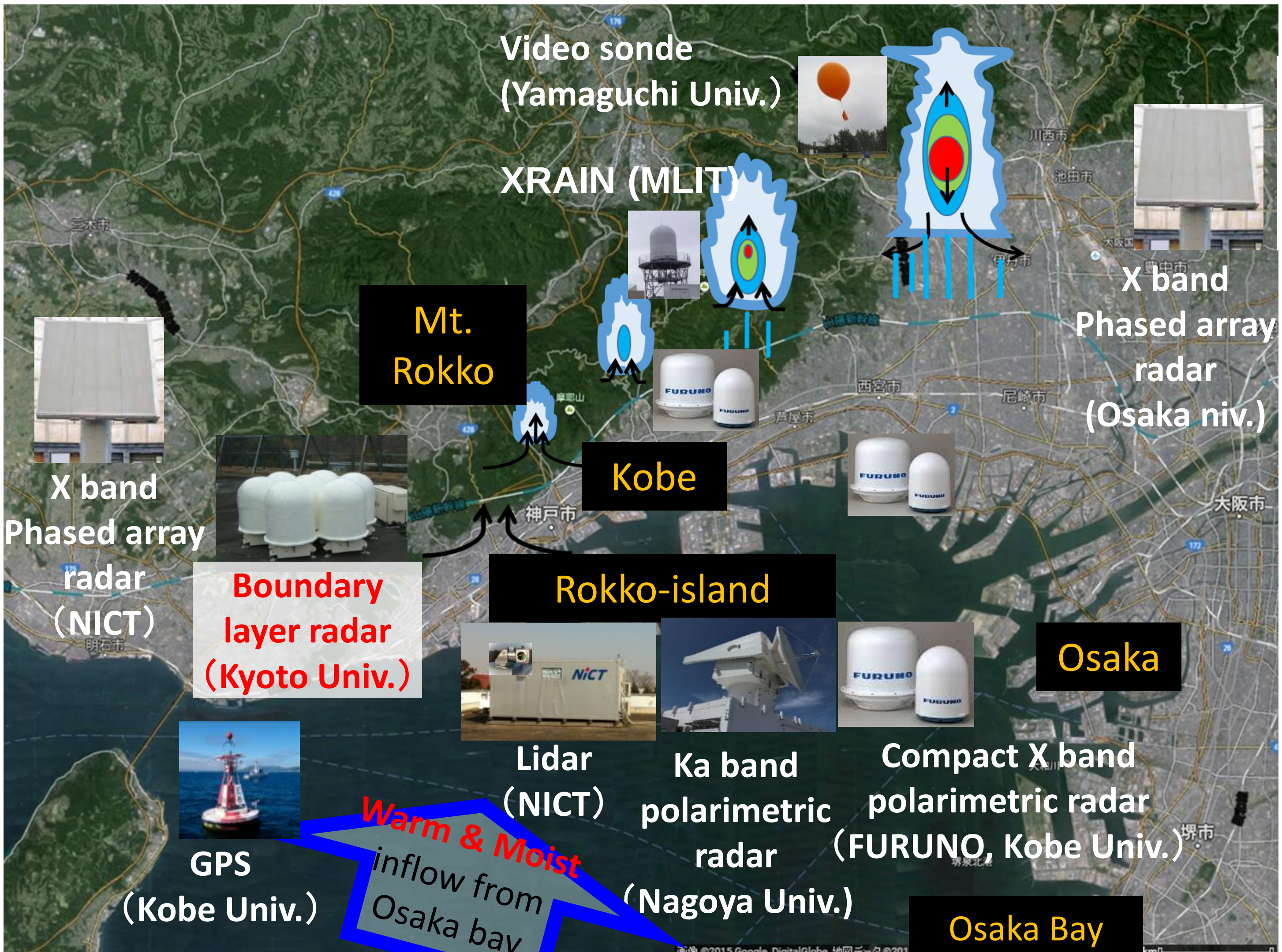
Generation of baby cell

updraft (airplume)→vortex formulation

Developing of baby cell

vortex formulation→precipitation formulation

new multi-sensors observation of storm-genesis, Kobe (2017-2019)



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