KU-OU Symp., Uji Obaku Plaza, Kyoto Univ., Nov. 11, 2009

Quantitative estimation of rainfall intensity and hydrometeors mixture using C-band polarimetric radar based on validation by in-Situ campaign observation synchronized with Video-Sonde

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Introduction

Background

- In Japan, main weather radars for operational network has been the C-band radar.
- The new type polarimetric radar, which can observe K_{DP}, has not been put into operational use in Japan.
- Small number of C-band polarimetric radar in the world

One of the purposes

- Promotion of introducing the new C-band polarimetric radars to Japanese operational radar network.

Activities

- A synchronized observation by the C-band polarimetric radar, COBRA, with the video-sonde.
- Development of a new operational QPE algorithm for polarimetric with C-band radar by an improvement of existing algorithm.
- Classification as mixture of some types of hydrometeors.
- QPF with data assimilation

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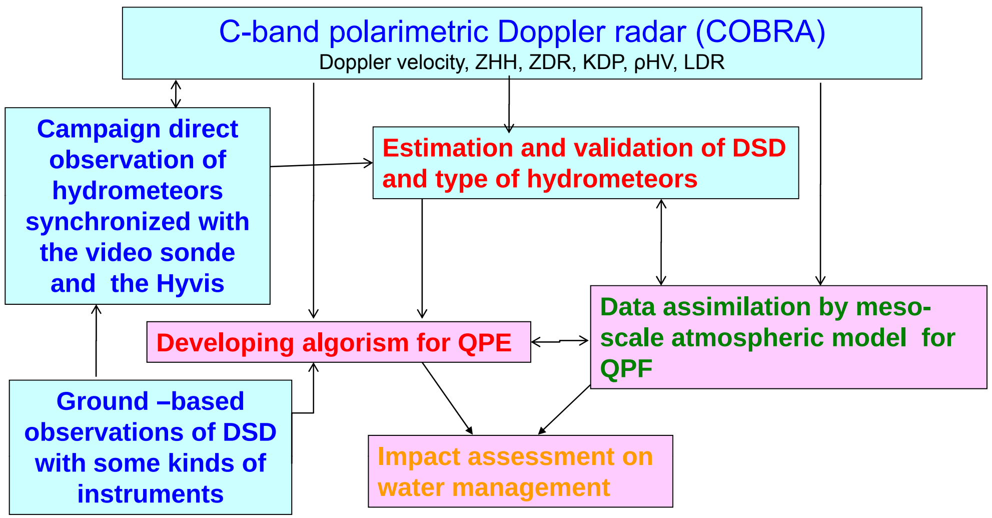
Current activities with C-band polarimetric Doppler radar

Campaign Obs.＋Analysis＋Data Assimilation＋Impact Assessment



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- **In-Situ campaign observation synchronized with Video-Sonde**
- **A new operational QPE algorithm for C-band polarimetric radar**
- **Classification of co-existing hydrometeors using a C-band polarimetric radar**
- **Operational polarimetric radars in near future by the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT), and one of an important background**

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- **In-Situ campaign observation synchronized with Video-Sonde (~ 5 min.)**
- **A new operational QPE algorithm for C-band polarimetric radar (~ 10 min.)**
- **Classification of co-existing hydrometeors using a C-band polarimetric radar (~ 14 min.)**
- **Operational polarimetric radars in near future by the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT), and one of an important background (~20 min.)**

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In-Situ campaign observation synchronized with Video-Sonde (2007~2009)

Eiichi NAKAKITA, Kosei YAMAGUCHI,
Hidenobu TAKEHATA, Yasuhiko SUMIDA, (Kyoto University)
Kenji SUZUKI (Yamaguchi University)
Katuhiro NAKAGAWA, Seiji KAWAMURA (NICT)
Satoru OISHI (University of Yamanashi)
Kazuhisa TUBOKI, Yukari SHUSSE, Tadayasu OHIGASHI (Nagoya University)
Tsutomu TAKAHASHI (University of Hawaii)

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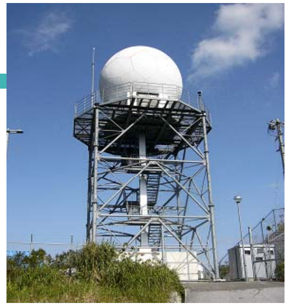
C-Band Doppler Polarimetric Radar



COBRA = CRL Okinawa Bistatic polarimetric RAdar

COBRA is operated by the National Institute of information and Communications Technology (NICT).

- **C-band** polarimetric weather radar
- COBRA's purpose is the development of the meso hydrometeorological observation for the next generation.
- Target : Typhoon, Bai-u, meso scale rainfall system
- Polarization parameters: Z_{HH}, Z_{VV}, Z_{DR}, ϕ_{DP}, K_{DP}, ρ_{HV}, L_{DR}

Peak power	> 250 kW (Dual Klystron) > 10 kW (Dual TWTA)
Pulse width	0.5 μs, 1.0 μs, 2.0 μs (Klystron) 0.5 – 100 μs (TWTA)
PRF	250 Hz - 3000 Hz, PRT 1μ s step (staggered PRF)
Antenna size	4.5m φ parabolic
Beam width	0.91deg
Radome size	8m φ
Cross pol. ratio	> 36 dB (Integrated value in a beam)
Antenna gain	45 dBi (including radome)
Sidelobe	< -27 dB (one way)
Ant. scan speed	0.5-10 rpm(PPI), 0.1-3.6 rpm(RHI), 0.1 rpm step
Polarization	H, V, +45, -45, LC, RC (pulse by pulse)

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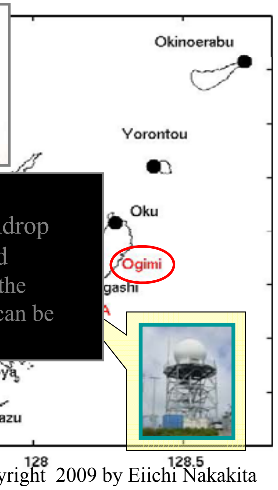
Ground-based observations

locations of COBRA and the ground observation points.

2-D Video Disdrometer (2DVD)
2DVD has two line scan cameras which are orthogonally set at different height. Therefore it can observe not only the size and shape but also the terminal velocity of precipitation particles.

Disdrometer
The momentum of raindrop particle is observed and correspond to the size of the particle. Therefore DSD can be observed.



•Disdrometers and optical rain gauge at Ogimi
•Rain gauge of AMeDAS, which stands for Automated Meteorological Data Acquision System, at Yoronjima

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Campaign Observation in Okinawa

- **Observation Periods**

  Preliminary IOP : Nov. 15th – 28th , 2007
  Main IOP (1): May 28th-June 21st, 2008
  Main IOP (2): May 21th-June 21st, 2009

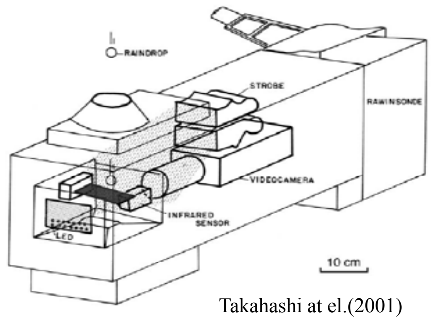
- **Collaboration**

  Kyoto University, University of Yamanashi, Yamaguchi University, Nagoya University, University of Tsukuba, Utsunomiya University, National Institute of Information and Communications Technology, Central Research Institute of Electric Power Industry, University of Hawaii (more than 30 researchers and students)

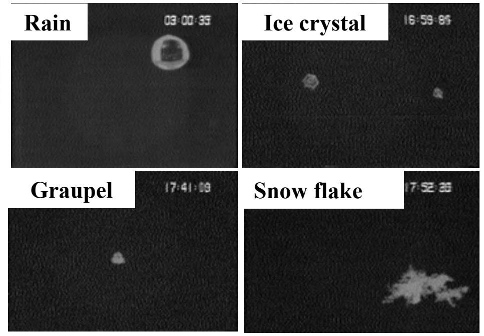
- **Observation instruments**

  ・Polarimetric Doppler radar (COBRA)
  ・Video-Sonde, Hyvis
  ・2-D video distrometer, Impact type disdrometer, Micro rain radar, Laser drop-sizing gauge, Optical rain gauge, etc.

Video-Sonde and Hydrometeor types



Takahashi at el.(2001)



- Video-sonde is the radiosonde with a video camera.
- The video-sonde records images of particles larger than 0.5mm diameter.
- The video-sonde is launched with the balloon, and can directly observe hydrometeors below and in the cloud.

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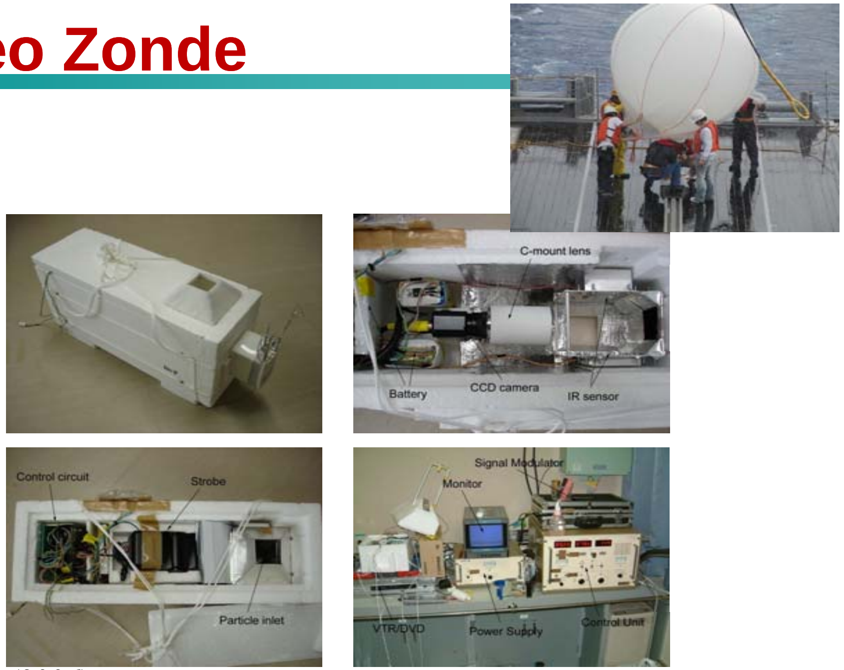
Video Zonde



Suzuki et al. (2006)

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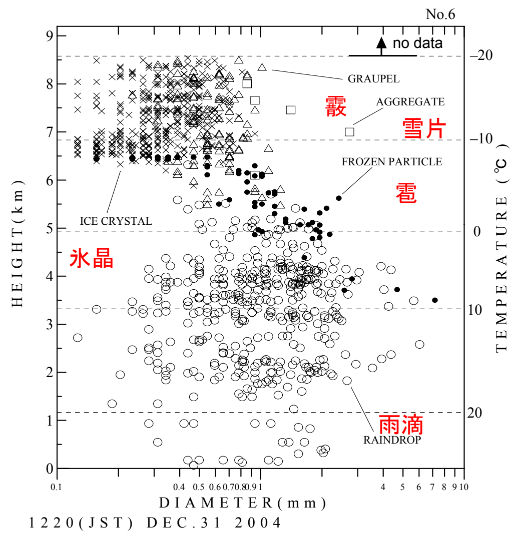
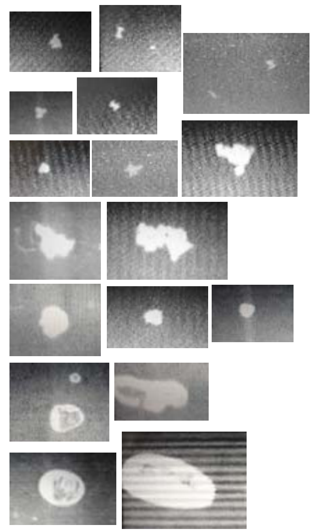
Example of observations





Suzuki et al. (2006)

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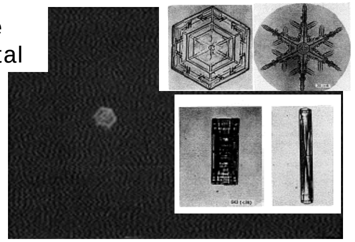
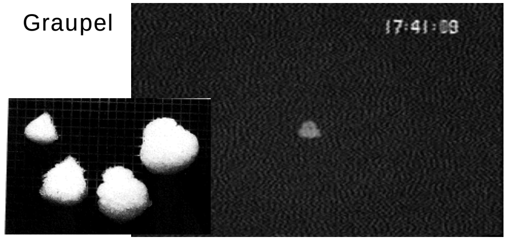
Hydrometeor types

Rain

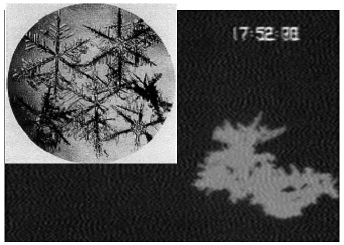
Ice crystal



Graupel



Snow flake



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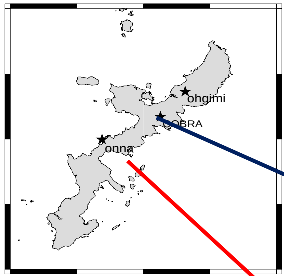
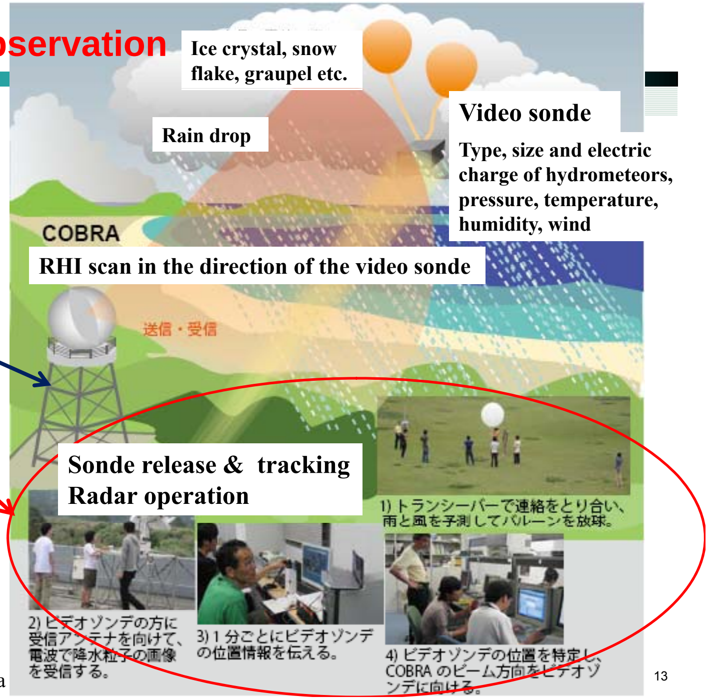
Synchronized Observation





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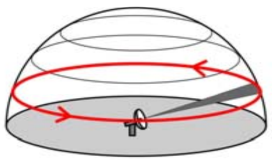
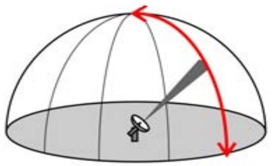
Scanning of Whether Radar



Volume scan



RHI scan

before and after synchronization

During synchronization

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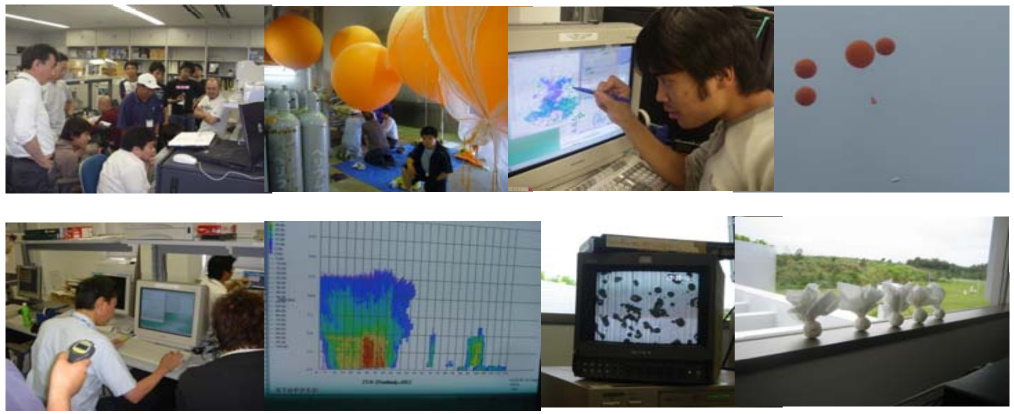
Scenes in the campaign observation



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A new operational QPE algorithm for C-band polarimetric radar (2008)

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In short ……

➢Mass –weighted diameter D_m will be introduced into estimators $R(Z_{HH})$ and $R(K_{DP})$, as $R(Z_{HH}, D_m)$ and $R(K_{DP}, D_m)$.

➢D_m will be used also in the selection of $R(Z_{HH}, D_m)$ or $R(K_{DP}, D_m)$.

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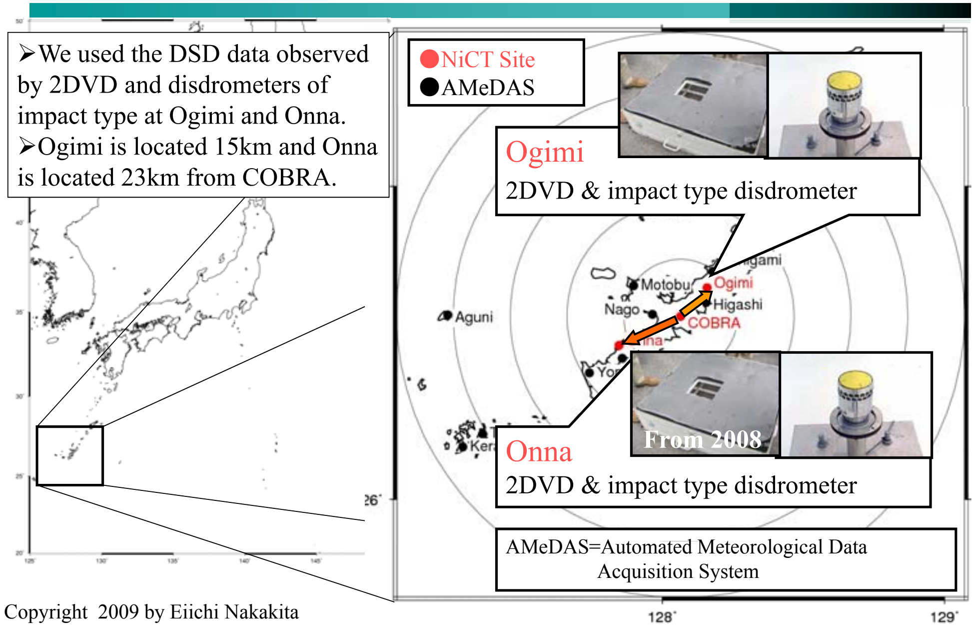
Data set (Ground)

➢We used the DSD data observed by 2DVD and disdrometers of impact type at Ogimi and Onna.
➢Ogimi is located 15km and Onna is located 23km from COBRA.



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Data set

No.	Start Time (UTC)	End Time (UTC)
1	2006. 5.30 23:00	2006. 5.31 11:00
2	2006. 6. 1 15:00	2006. 6. 2 4:00
3	2006. 6. 4 8:00	2006. 6. 5 8:00
4	2006. 6.10 0:00	2006. 6.10 13:00
5	2006. 6.11 6:00	2006. 6.11 12:00
6	2006. 7. 8 15:00	2006. 7. 9 10:00
7	2006. 8. 5 10:00	2006. 8. 6 12:00
8	2006. 8. 9 0:00	2006. 8. 9 5:00
9	2006.12. 7 2:00	2006.12. 7 9:00
10	2007. 5.25 18:00	2007. 5.25 24:00
11	2007. 6. 5 4:00	2007. 6. 5 15:00
12	2007. 6. 7 0:00	2007. 6. 7 13:00
13	2007. 6.11 12:00	2007. 6.12 22:00
14	2007. 6.16 8:00	2007. 6.16 23:00
15	2007. 6.18 20:00	2007. 6.19 5:00

Radar
- COBRA
  Z_{HH}, Z_{VV}, Z_{DR}, ϕ_{DP}, ρ_{hv}, LDR,
- Time step every 6 minutes
- 14PPI(0.5, 1.1, 1.8, 2.5, 3.3, 4.2, 5.3, 6.5, 8.1, 10.0, 12.3, 14.8, 17.4, 20.5° elevation angle)
- Pulse width 2μs (300m)
- Beam width 0.9°

Ground data
- Impact type disdrometer (2006-2007)
- 2DVD (4-11 June. 2006)
- AMeDAS (2006-2007)

AMeDAS=Automated Meteorological Data Acquisition System

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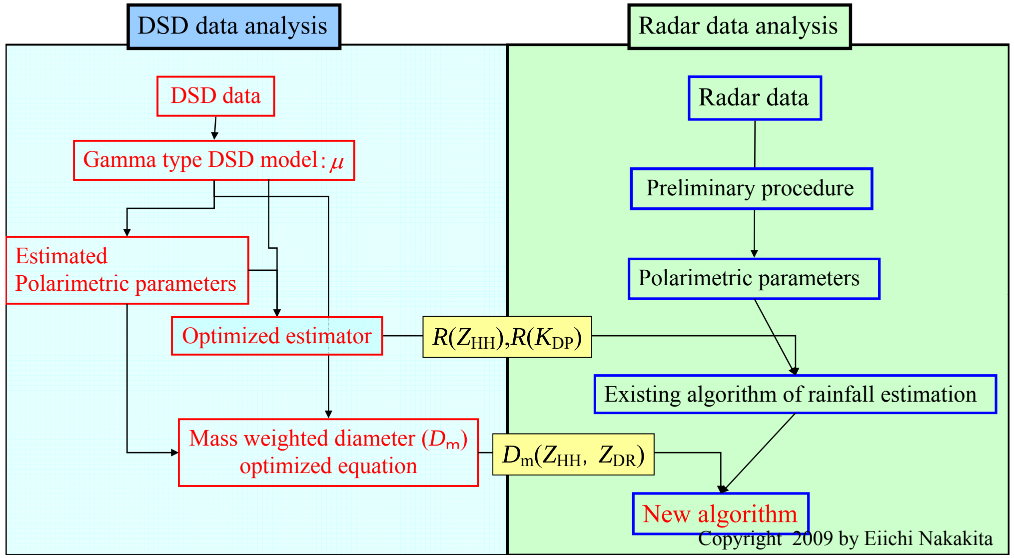
Strategy of developing the new algorism with Dm



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Preliminary procedure (1)

- Removing of the radar echoes by nonmeteorological factor (such as ground clutter) using ρ_{HV} (ρ_{HV}<0.9)
- Calibration of the system offset of Z_{DR} using 2DVD and impact type disdrometers measurements.
- Attenuation correction with K_{DP} using the self-consistent method by Bringi *et al* (2001)
- Finally, the radar data was converted into 100m mesh data, and the mesh data was spatially averaged over 1km × 1km mesh.

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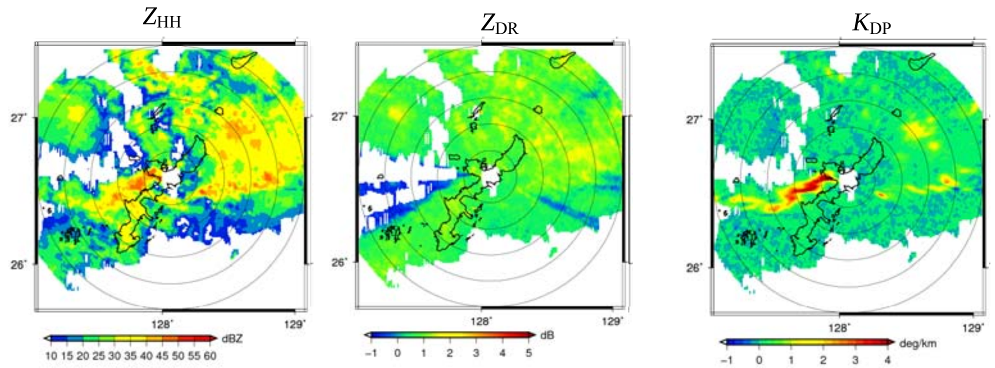
Preliminary procedure (2)



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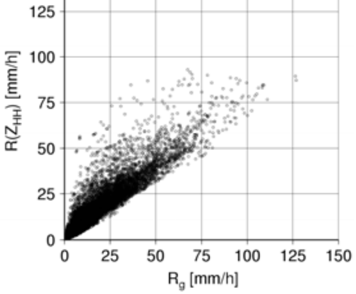
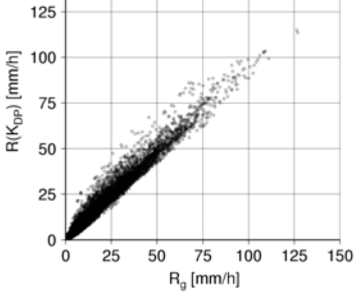
Optimization of basic estimators using observed DSD

$R(Z_{HH}) = 3.94\times10^{-2} Z_{HH}^{0.650}$ $R(K_{DP}) = 30.56 K_{DP}^{0.813}$





Assumption

- Data: impact type disdrometer at Okinawa in Japan (2006-2007)
- DSD is Gamma distribution
- Axis ratio model of raindrop

$$r(D) = 1.0048 + 5.7\times10^{-4} D - 2.628\times10^{-2} D^2 + 3.682\times10^{-3} D^3 - 1.677\times10^{-4} D^4$$

- Type of basic estimators:

$$R(Z_{HH}) = a_0 Z_{HH}^{b_0}, \quad R(K_{DP}) = a_1 K_{DP}^{b_1}$$

$$Z_{HHg} = \int_0^{D_{max}} D^6 N(D) dD$$

$$Z_{DRg} = 10\log_{10} \frac{\int_0^{D_{max}} D^6 N(D) dD}{\int_0^{D_{max}} r(D)^{7/3} D^6 N(D) dD}$$

$$K_{DPg} = \frac{180}{\lambda} 10^{-3} C_k W_g \left(1 - \frac{\int_0^{D_{max}} r(D) D^3 N(D) dD}{\int_0^{D_{max}} D^3 N(D) dD}\right)$$

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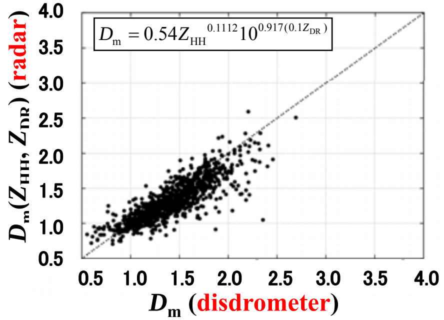
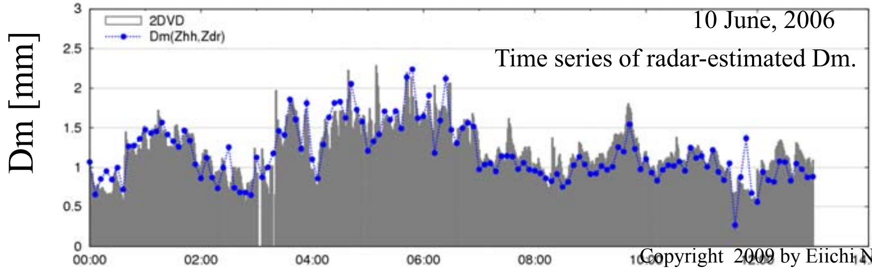
Estimation of mass-weighted diameter (Dm)

- This fig. shows the comparison between the observations D_m and the estimations D_m by radar observations.
- Time series of radar-estimated D_m (blue line) well explain that of observed D_m (bar).





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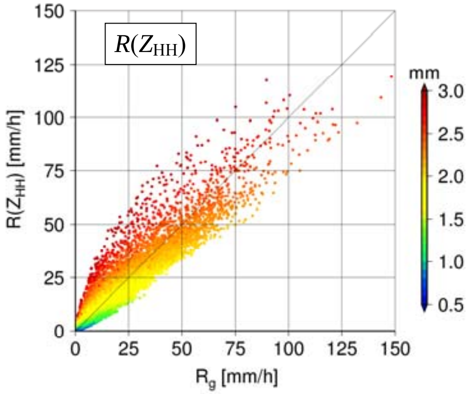
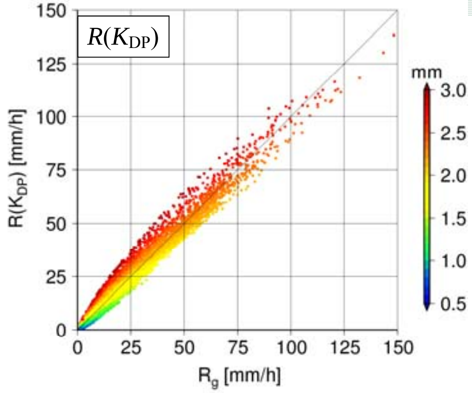
Optimization of estimators depending on class of *D*m (1)





$R(Z_{HH}) = 3.59\times10^{-2} Z_{HH}^{0.634}$ $R(K_{DP}) = 30.56 K_{DP}^{0.814}$

$R(Z_{HH})$ .VS. Rg and $R(K_{DP})$ .VS. Rg depend on the size of D_m.

These relations can be further sophisticated using D_m.

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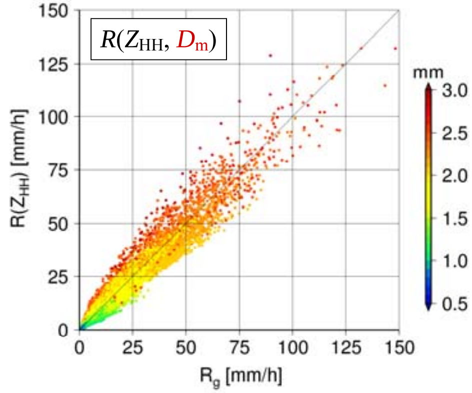
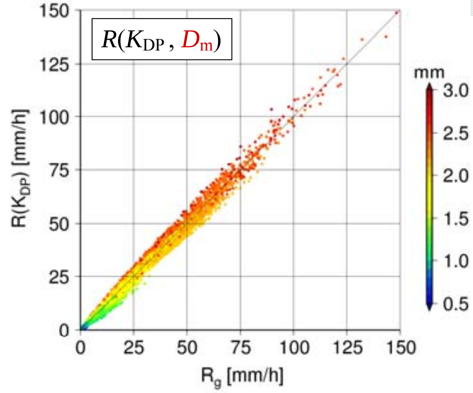
Optimization of estimators depending on class of *D*m (2)





$$R(Z_{HH}, D_m) = \begin{cases} 3.49\times10^{-2} Z_{HH}^{0.724} & 0.0 \le D_m < 1.0 \\ 7.72\times10^{-3} Z_{HH}^{0.852} & 1.0 \le D_m < 1.5 \\ 3.39\times10^{-3} Z_{HH}^{0.878} & 1.5 \le D_m < 2.0 \\ 3.13\times10^{-3} Z_{HH}^{0.867} & 2.0 \le D_m < 2.5 \\ 1.60\times10^{-4} Z_{HH}^{1.083} & 2.5 \le D_m < 3.0 \end{cases}$$

$$R(K_{DP}, D_m) = \begin{cases} 45.62 K_{DP}^{0.776} & 0.0 \le D_m < 1.0 \\ 44.63 K_{DP}^{0.903} & 1.0 \le D_m < 1.5 \\ 35.00 K_{DP}^{0.911} & 1.5 \le D_m < 2.0 \\ 29.52 K_{DP}^{0.935} & 2.0 \le D_m < 2.5 \\ 22.57 K_{DP}^{1.031} & 2.5 \le D_m < 3.0 \end{cases}$$

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Developed algorithm for switching between $R(Z_{DR})$ and $R(K_{DP})$

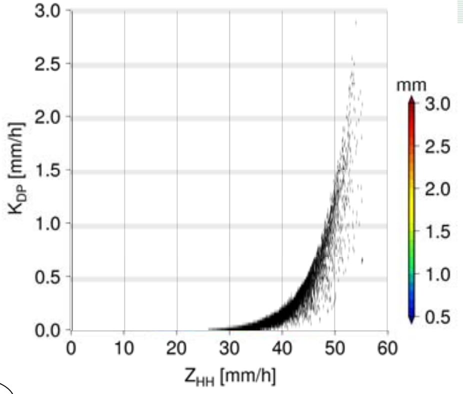
- Basic algorithm

$$R_{alg} = \begin{cases} R(K_{DP}) & \text{if } Z_{HH} \geq T_{h,z} \text{ and } K_{DP} \geq T_{h,k}, \\ R(Z_{HH}) & \text{otherwise.} \end{cases}$$

$$D_m = 0.54 Z_{HH}^{0.1112} 10^{0.917(0.1 Z_{DR})}$$

- Developed algorithm

$$R_{alg} = \begin{cases} R(K_{DP}, D_m) & \text{if } ((Z_{HH} \geq T_{h,z} \text{ or } D_m \geq T_{h,}) \text{ and } K_{DP} \geq T_{h,kdp}) \\ R(Z_{HH}, D_m) & \text{otherwise.} \end{cases}$$



D_m is used also for judging which should be used, $R(Z_{HH}, D_m)$ or $R(K_{DP}, D_m)$

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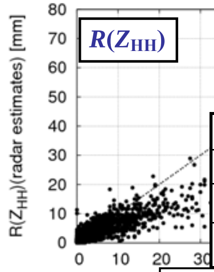
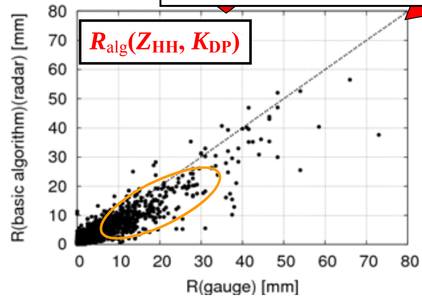
Validation using radar (1) comparison between algorithms

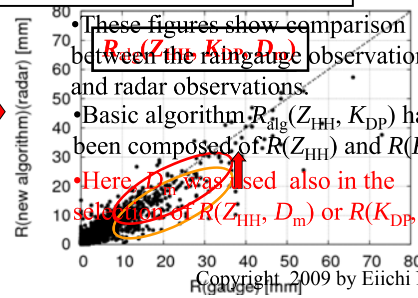


	Mean Bias [mm]	RMSE[mm]	CC	Ratio of rain total [%]
$R(Z_{HH})$	-1.245	4.42	0.873	75.60
$R(K_{DP})$	-1.101	2.91	0.922	94.04
$R_{alg}(Z_{HH}, K_{DP})$	-0.543	3.25	0.901	89.39

Introducing Dm improved both bias and correlation coefficient !!



D_m



- These figures show comparison between the raingauge observations and radar observations.
- Basic algorithm $R_{alg}(Z_{HH}, K_{DP})$ have been composed of $R(Z_{HH})$ and $R(K_{DP})$.
- Here, D_m was used also in the selection of $R(Z_{HH}, D_m)$ or $R(K_{DP}, D_m)$.

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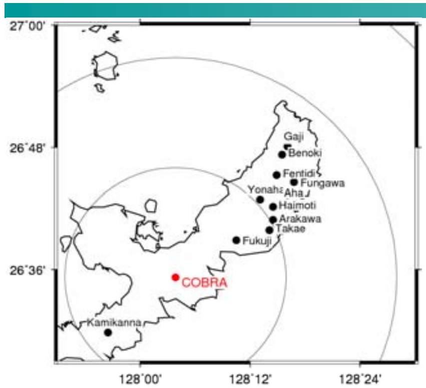
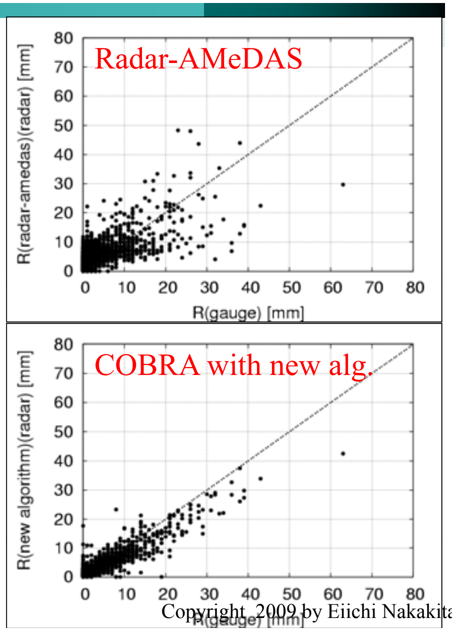
Validation(2) comparison with current operational QPE (Radar-AMeDAS)





➢Comparisons of 1-h rainfall between COBRA's estimates using proposed the new algorithm and the Radar-AMeDAS precipitation data

➢Radar-AMeDAS precipitation data is the data which is calibrated with ground rain-gauges and synthesized using the conventional radars in Japan.

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Classification of co-existing hydrometeors using a C-band polarimetric radar (2009)

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Katsuhiro NAKAGAWA
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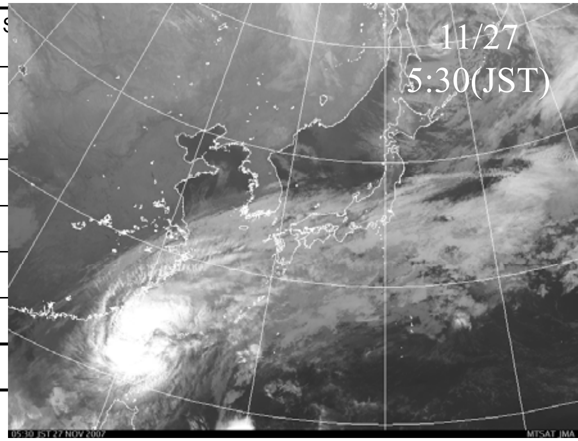
Datasets

- When the typhoon 0723 approached on 27th Nov. , six Video-sondes were launched.

Observation time 27th Nov.(JTC)

The number of particles

	S…	…upel	Ice crystal	Snow flake	Sum
No.1		25	107	5	254
No.2		47	1487	16	1960
No.3		8	45	6	131
No.4		2	1	0	24
No.5		3	7	0	106
No.6		8	64	0	274
		98	1711	27	2749



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Hydrometeor Classification

- Hydrometeor is classified into four types; rain, graupel, ice crystal and snow flake.
- The video-sonde observed the mixture of some types of particles over melting layer.
- In previous many researches they usually classified just one type of hydrometeor at each point.
- We consider that two types of hydrometeors mixed-exist, when the difference in values of evaluation index between the highest and second highest hydrometeors is small.
- Graupel+Ice crystal, Graupel+Snow flake and Ice crystal+Snow flake, are set in addition to each types.

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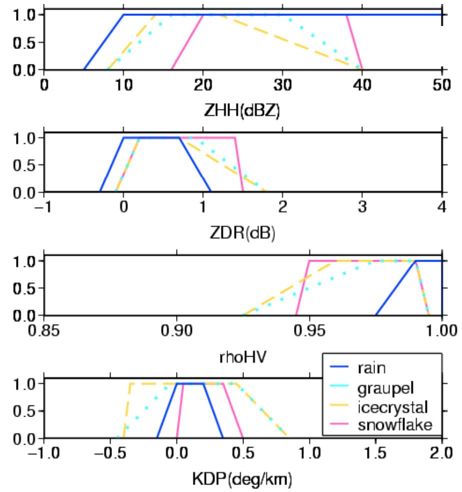
Hydrometeor Classification

Membership Function

Rain	$j = 1$
Graupel	$j = 2$
Ice crystal	$j = 3$
Snow flake	$j = 4$



Z_{HH} Membership Function μ_j^{ZHH}

Z_{DR} Membership Function μ_j^{ZDR}

ρ_{HV} Membership Function $\mu_j^{\rho_{HV}}$

K_{DP} Membership Function $\mu_j^{K_{DP}}$

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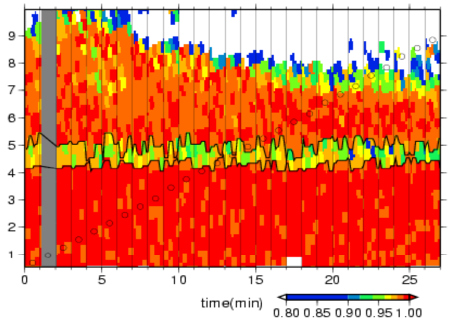
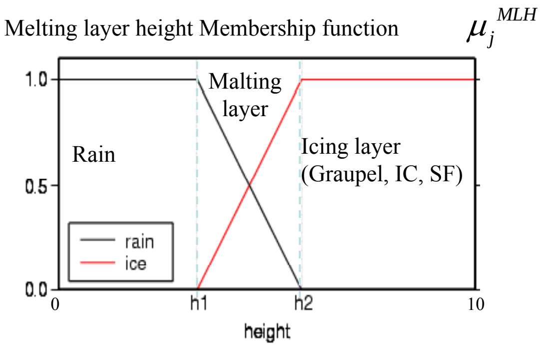
Malting Layer Detection by ρ_{HV}





- It is important to distinguish between rain and icing layer.
- Melting layer height is detected by ρ_{HV}.
- We make the Melting Layer Height (MLH) membership function

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Hydrometeor classification Method (mixture)

Membership function

$\mu_j^{Z_{HH}}, \mu_j^{Z_{DR}}, \mu_j^{\rho_{HV}}, \mu_j^{K_{DP}}, \mu_j^{MLH}$ （***j*** **: Particle type index**）

⇩

Hydrometeor Evaluation index

$$Q_j = \mu_j^{MLH}(h) \times \left(\mu_j^{Z_{HH}}(Z_{HH}) + \mu_j^{Z_{DR}}(Z_{DR}) + \mu_j^{\rho_{HV}}(\rho_{HV}) + \mu_j^{K_{DP}}(K_{DP}) \right)$$

⇩

Decide Particle Types(j)

Mixture of hydrometeors

max{ Q_j ; j = 1, 4 } = Q_{jmax}

if $Q_{jmax} - Q_{jsec} \leqq 0.1$ then particle type : jmax and jsec

else particle type : jmax

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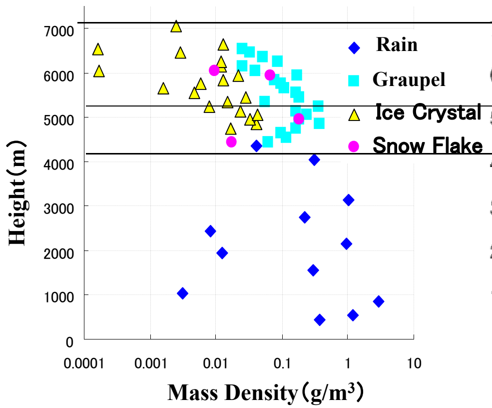
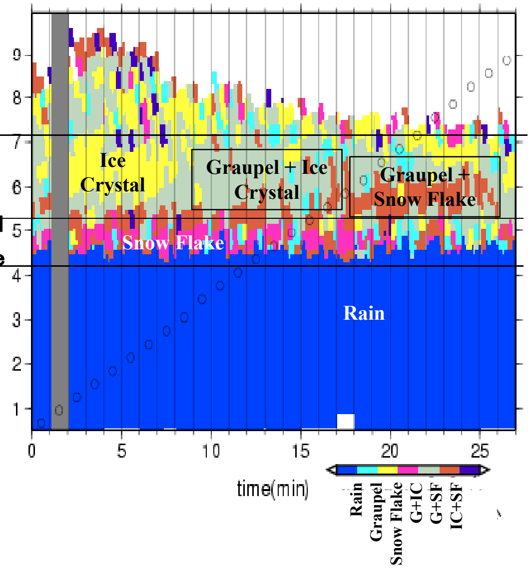
Hydrometeor Classification (mixture) (1)





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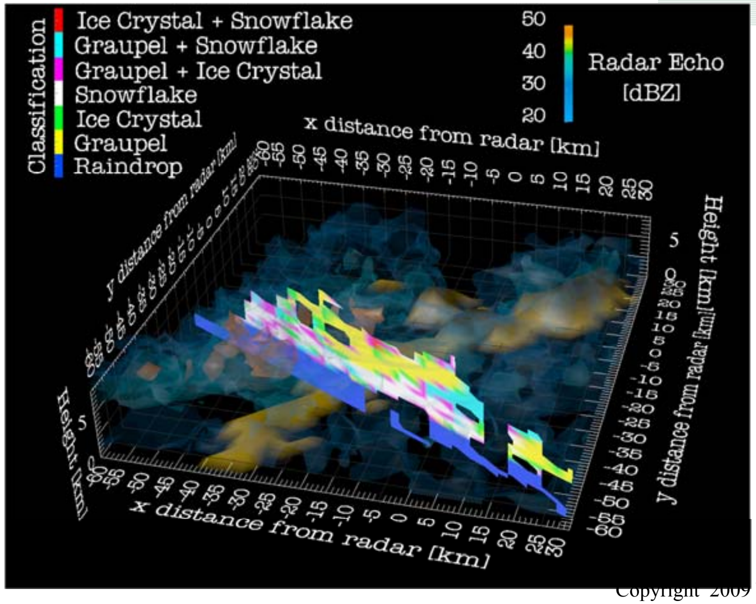
Hydrometeor Classification (mixture) (2)



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Contents

- In-Situ campaign observation synchronized with Video-Sonde (~ 5 min.)
- A new operational QPE algorithm for C-band polarimetric radar (~ 10 min.)
- Classification of co-existing hydrometeors using a C-band polarimetric radar (~ 14 min.)
- Operational polarimetric radars in near future by the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT), and one of an important background (~20 min.)

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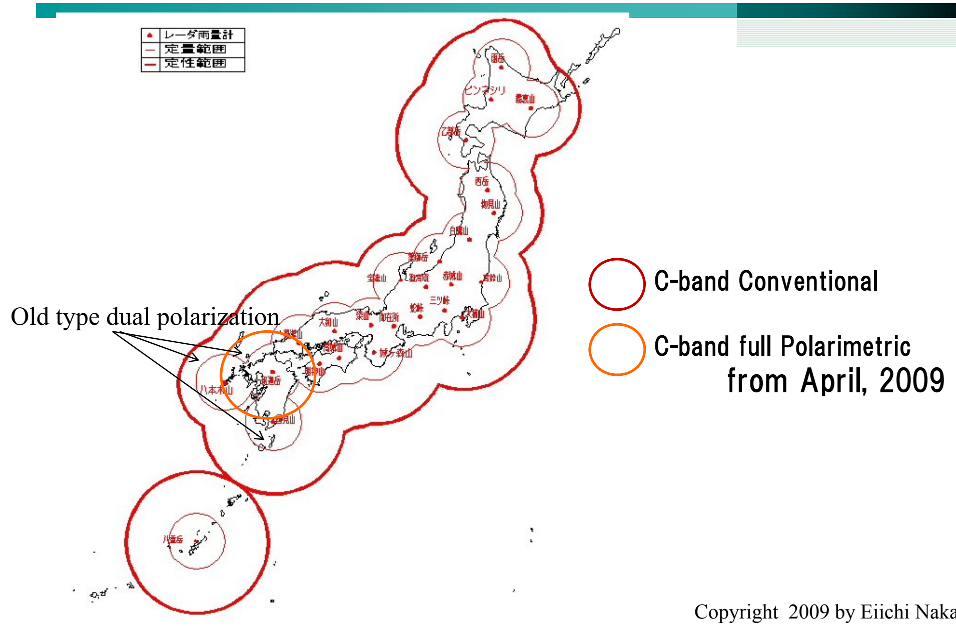
Current Radar network by MLIT in Japan



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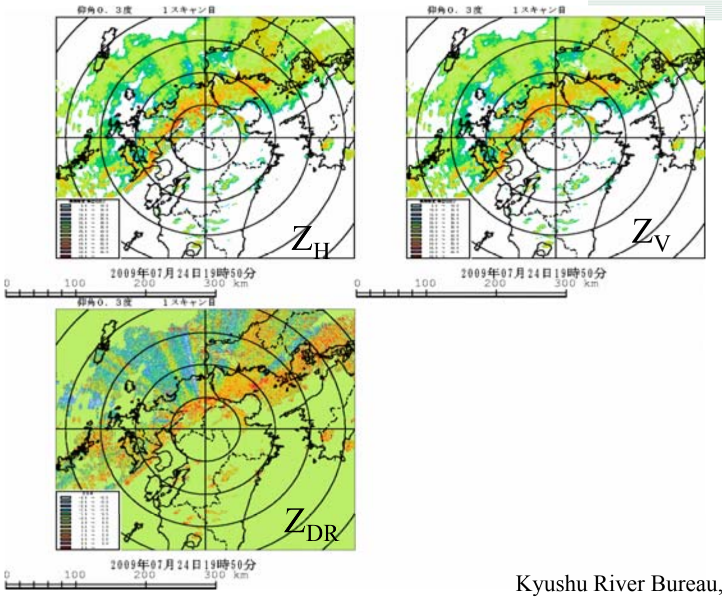
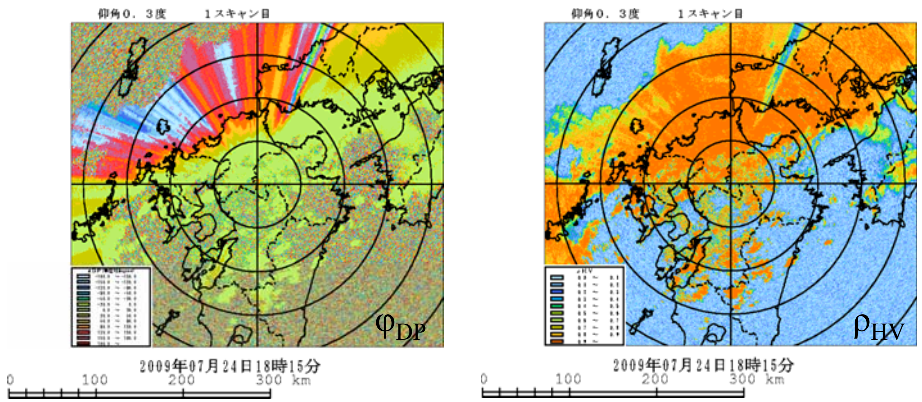
Observed example by the new C-band full polerimetric radar (July 24, 2009)



Kyushu River Bureau, MLIT, 2009

Observed example by the new C-band full polerimetric radar (July 24, 2009)



偏波間位相差φ_{DP}　　偏波間相関係数ρ_{HV}

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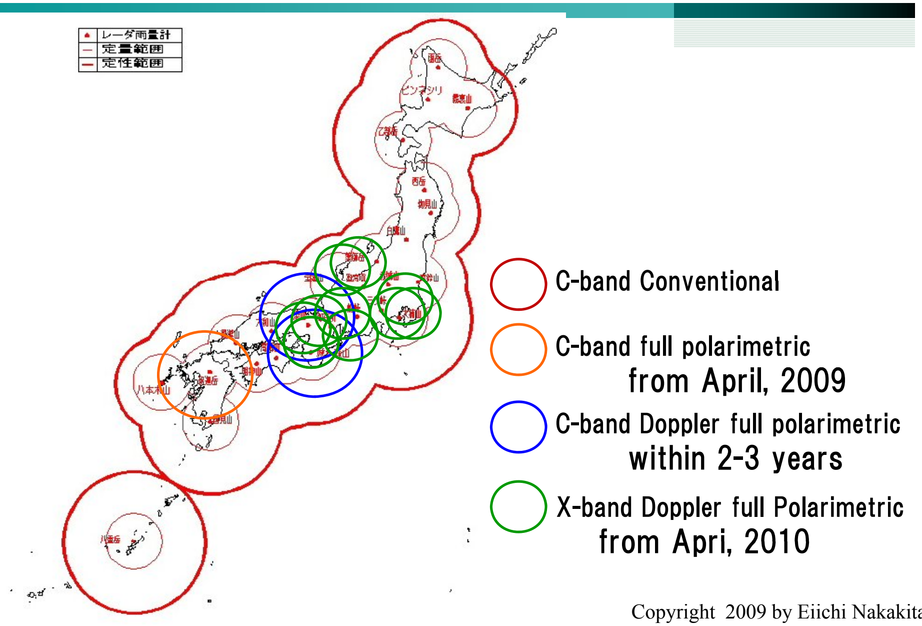
Kyushu River Bureau, MLIT, 2009

Radar networks by MLIT in Japan in near future



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One of the important background for installing operational X-band polarimetric radar (2009)

Eiichi NAKAKITA
Disaster Prevention Research Institute (DPRI), Kyoto University
Hiroyuki YAMABE
Graduate School of Engineering, Kyoto University
Kosei YAMAGUCHI
Institute for Sustainability Science (ISS), Kyoto University

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Background

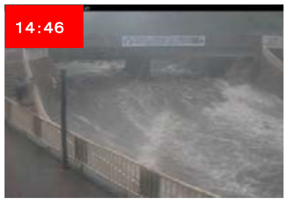
On July 28 （Toga River, Kobe)

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

In this case, many people were playing in the river side. 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 disaster could occur in the any urban small rivers.

10 min. later



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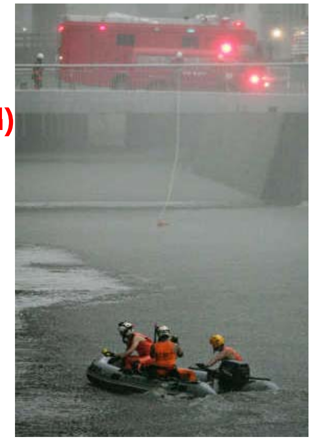
Background

On August 5 (Zoshigaya, Tokyo)

Six people, working in an underground sewage pipe system in Toshima ward, Tokyo, were swept away and five people were died.

These disasters were occurred by isolated cumulonimbus (isolated convective rainfall)



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Images from monitored movie managed by Kobe City

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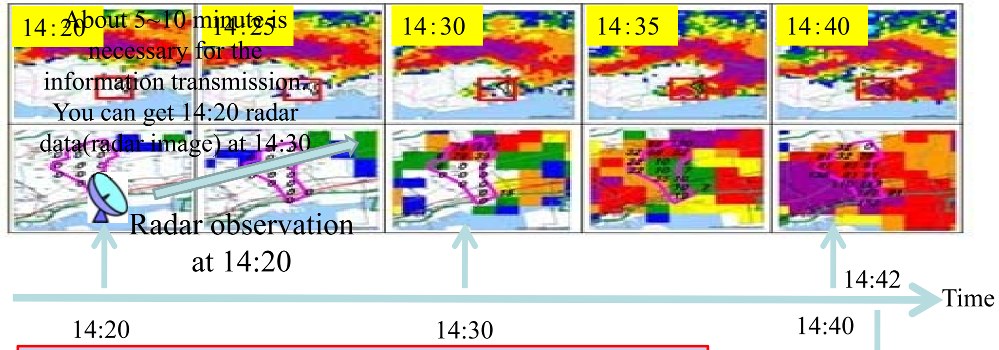
Operationally distributed radar image



✓The rain area covered all the small river at 14:35:
✓Flush flood occurred at 14:42.
✓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 shows us that the rain area covered all the small river base is after flash occurred.

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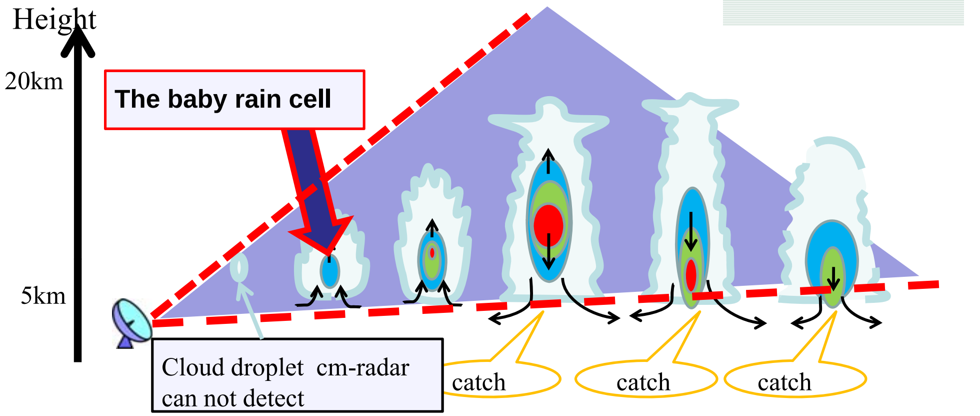
The advantage of operational 3D scan



✓**Low** elevation scan detect raindrops after the cumulonimbus growing up.
✓The baby rain cell cannot be detected by a low elevation observation.
✓The volume scan radar monitoring can detect the baby stage of the rainfall.

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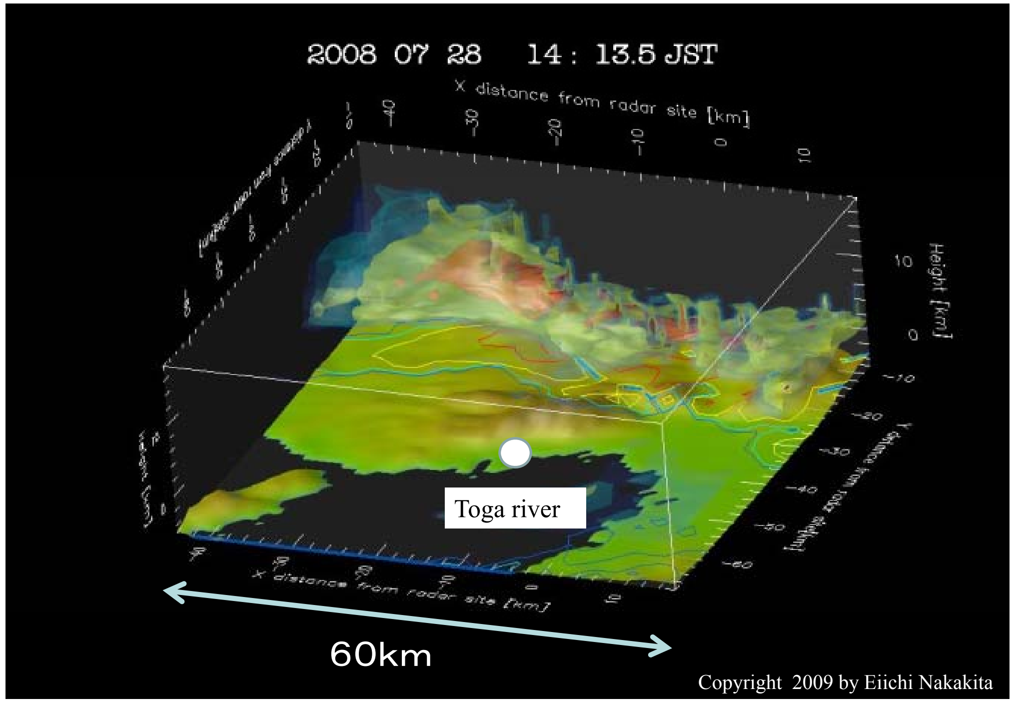

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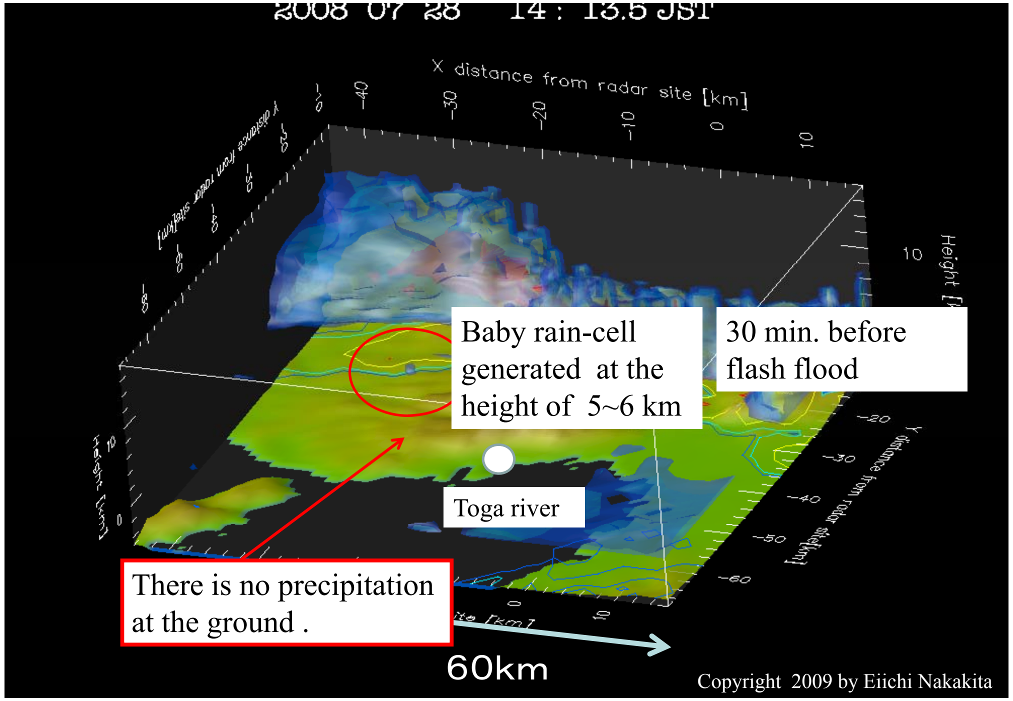
2008 07 28 14 : 13.5 JST
X distance from radar site [km]
Baby rain-cell generated at the height of 5~6 km
30 min. before flash flood
Toga river
There is no precipitation at the ground .
60km
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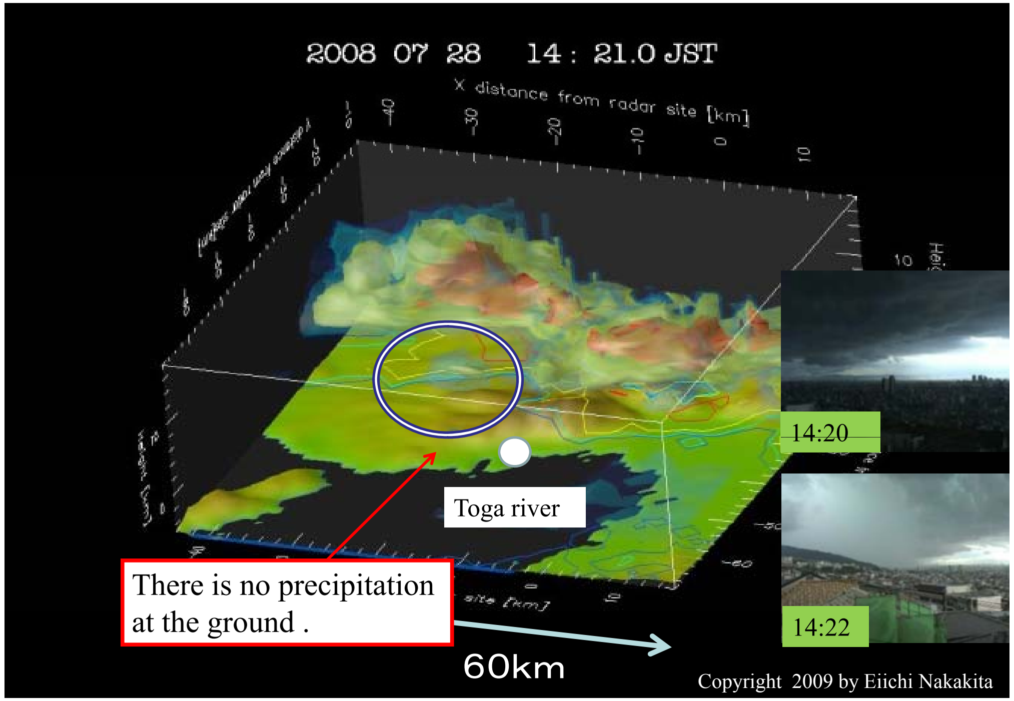
2008 07 28 14 : 21.0 JST
X distance from radar site [km]
14:20
14:22
Toga river
There is no precipitation at the ground .
60km
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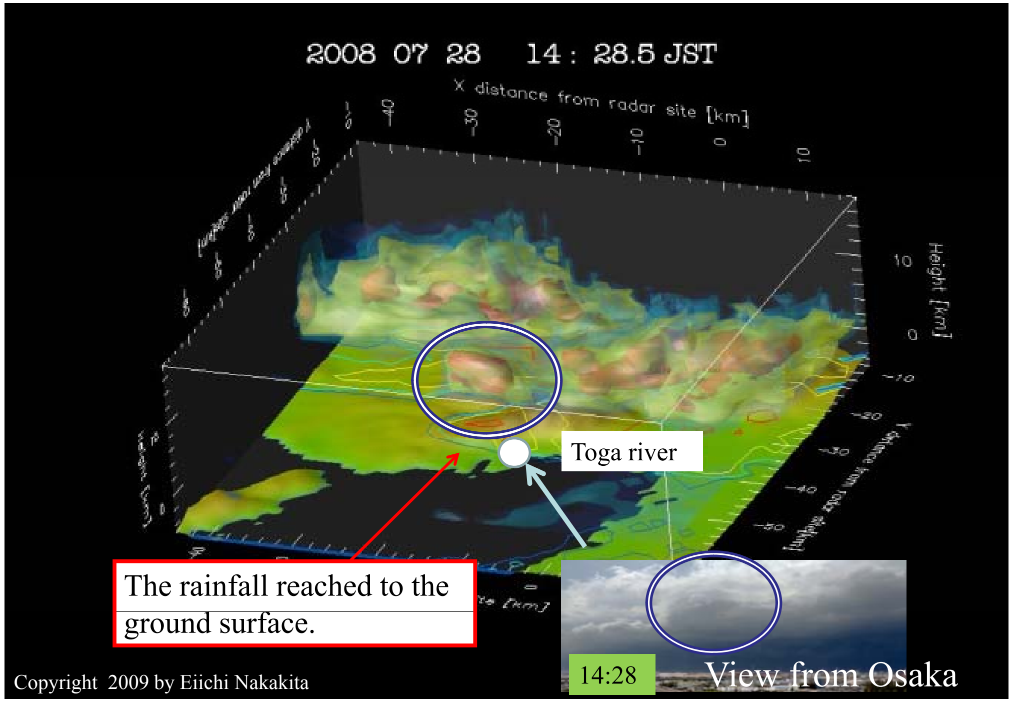
2008 07 28 14 : 28.5 JST
X distance from radar site [km]
Height [km]
Toga river
The rainfall reached to the ground surface.
14:28
View from Osaka
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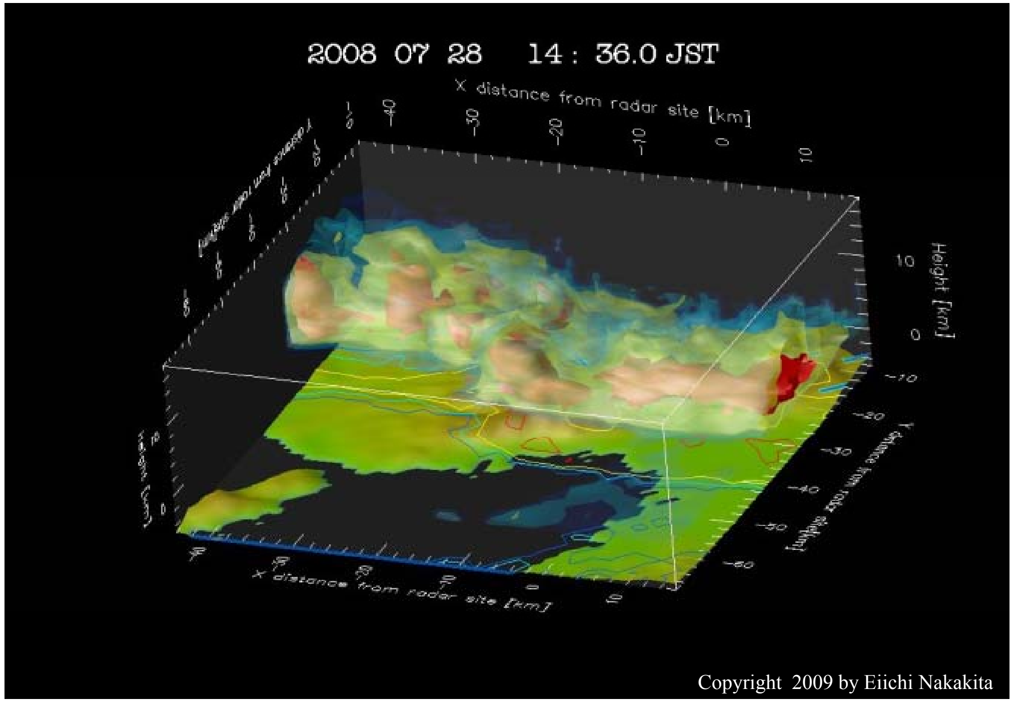
2008 07 28 14 : 36.0 JST
X distance from radar site [km]
Height [km]
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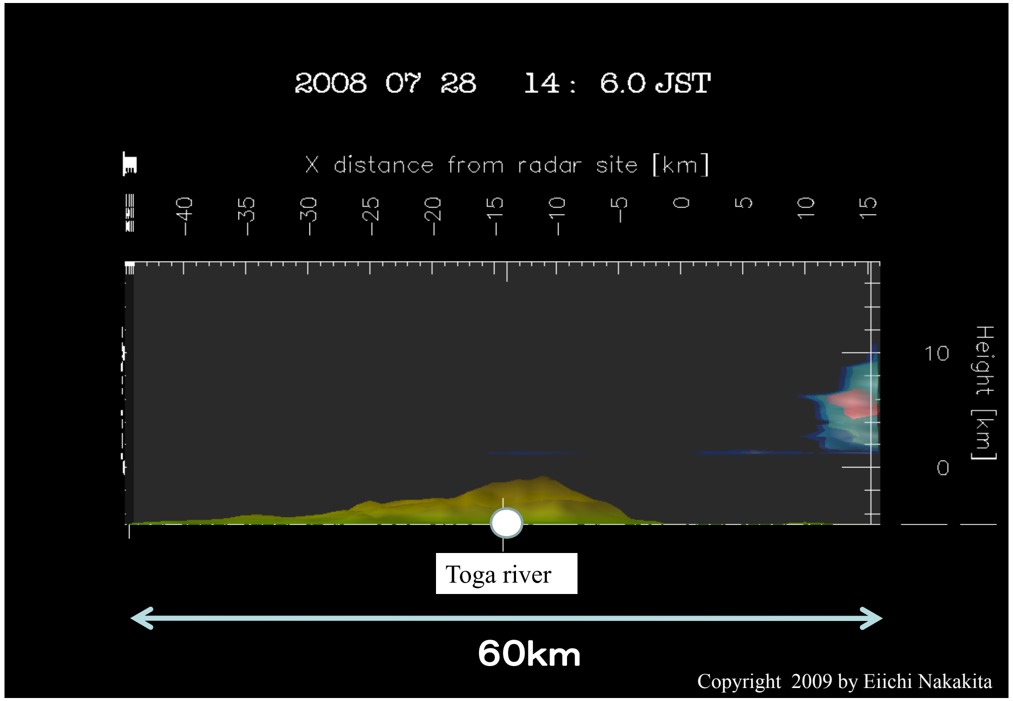
2008 07 28 14 : 6.0 JST
X distance from radar site [km]
−40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15
10
0
Height [km]
Toga river
60km
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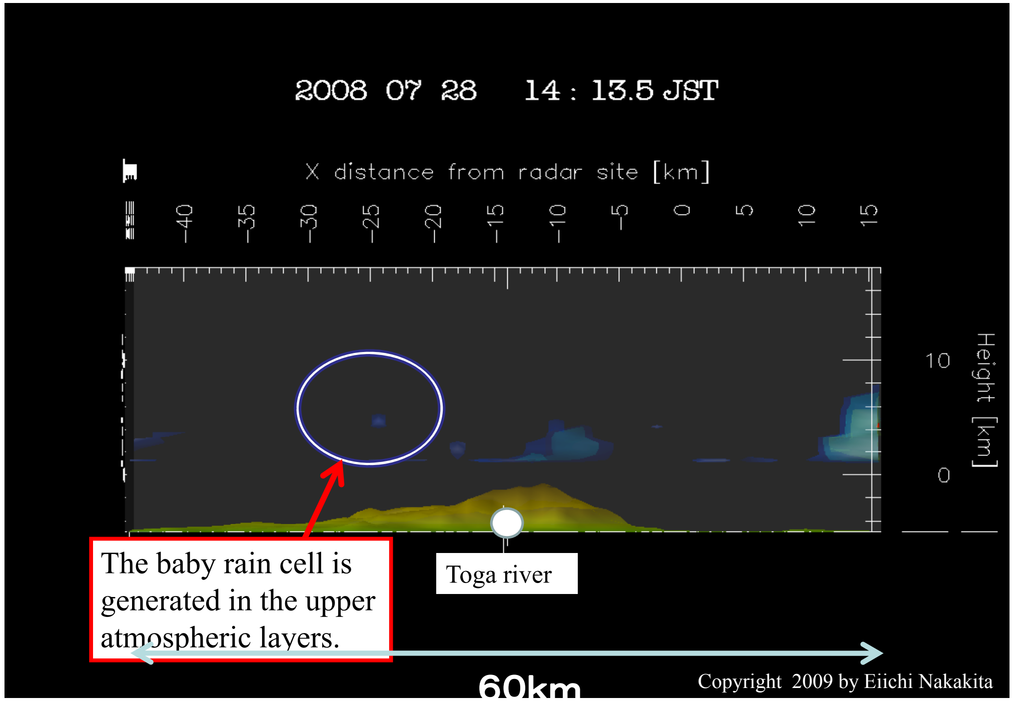
2008 07 28 14 : 13.5 JST
X distance from radar site [km]
−40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15
10
0
Height [km]
The baby rain cell is generated in the upper atmospheric layers.
Toga river
60km
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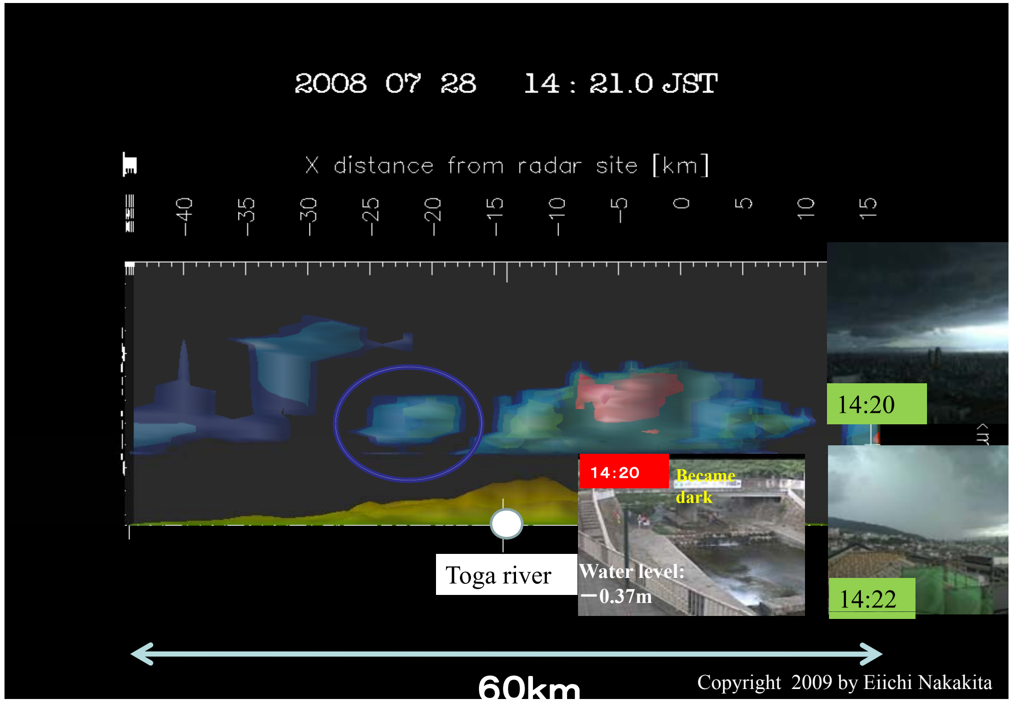
2008 07 28 14 : 21.0 JST
X distance from radar site [km]
−40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15
14:20
14:20
Became dark
Water level: −0.37m
14:22
Toga river
60km
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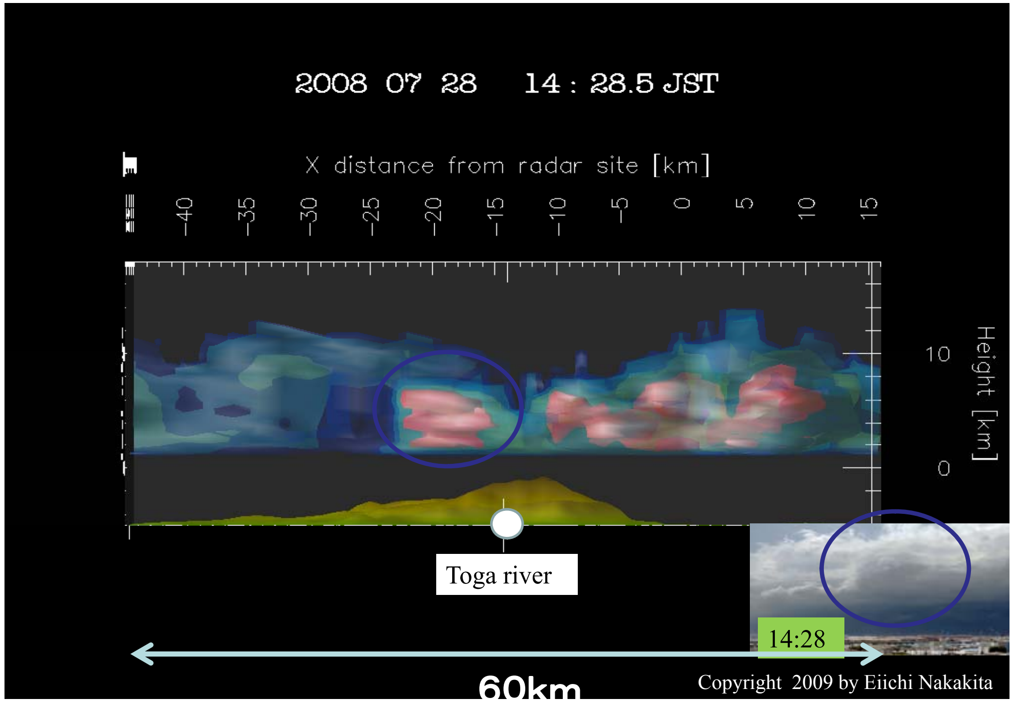
2008 07 28 14 : 28.5 JST
X distance from radar site [km]
−40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15
10
0
Height [km]
Toga river
14:28
60km
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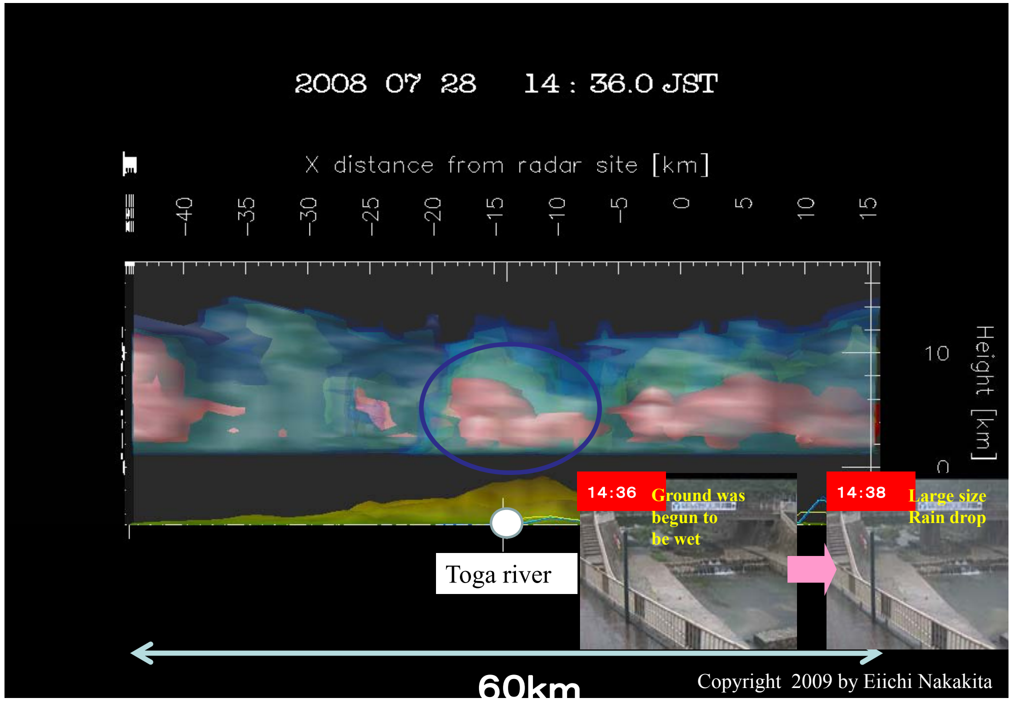
2008 07 28 14 : 36.0 JST
X distance from radar site [km]
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15
10
0
Height [km]
14:36
Ground was begun to be wet
14:38
Large size Rain drop
Toga river
60km
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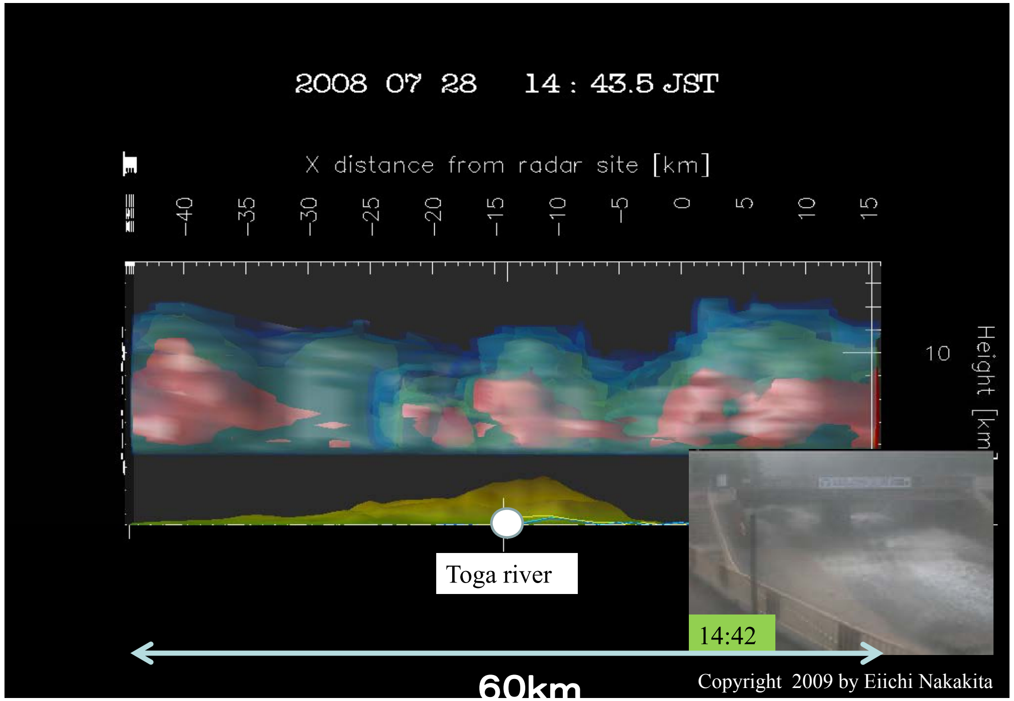
2008 07 28 14 : 43.5 JST
X distance from radar site [km]
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15
10
Height [km]
14:42
Toga river
60km
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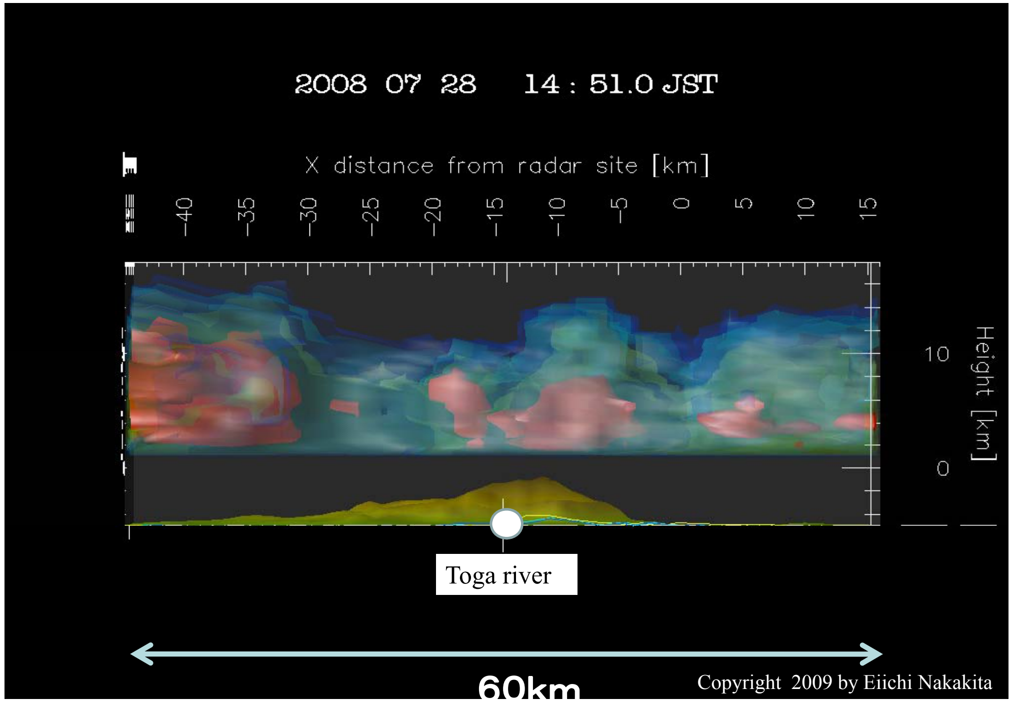
2008 07 28 14 : 51.0 JST
X distance from radar site [km]
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15
10
0
Height [km]
Toga river
60km
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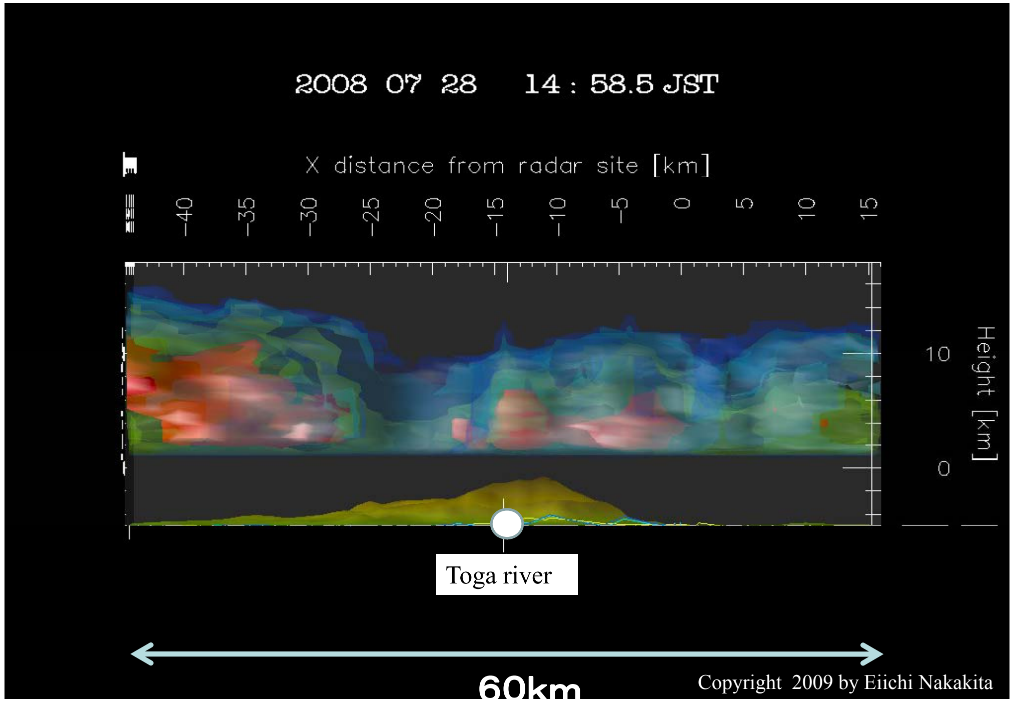
2008 07 28 14 : 58.5 JST
X distance from radar site [km]
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15
10
0
Height [km]
Toga river
60km
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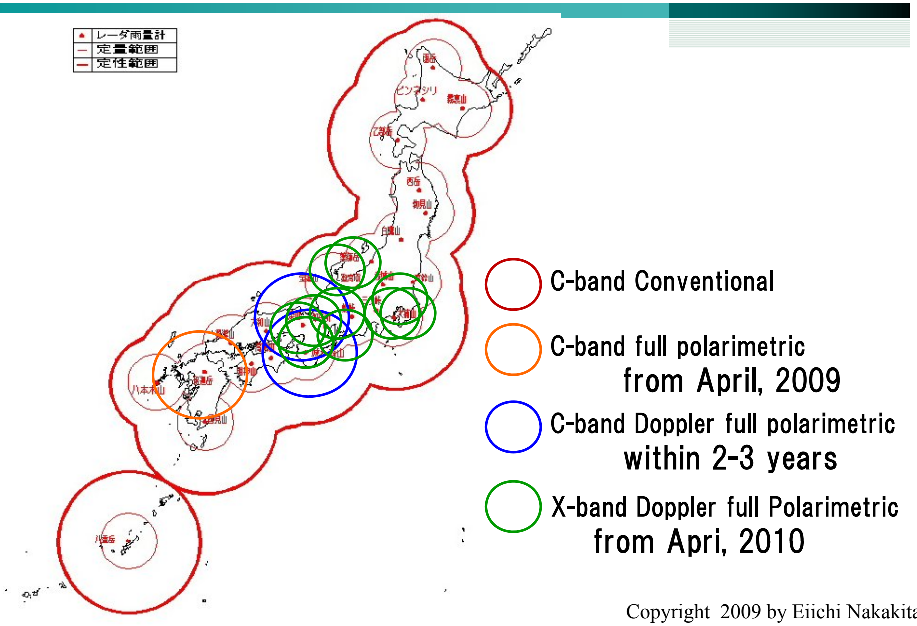
Radar networks by MLIT in Japan in near future



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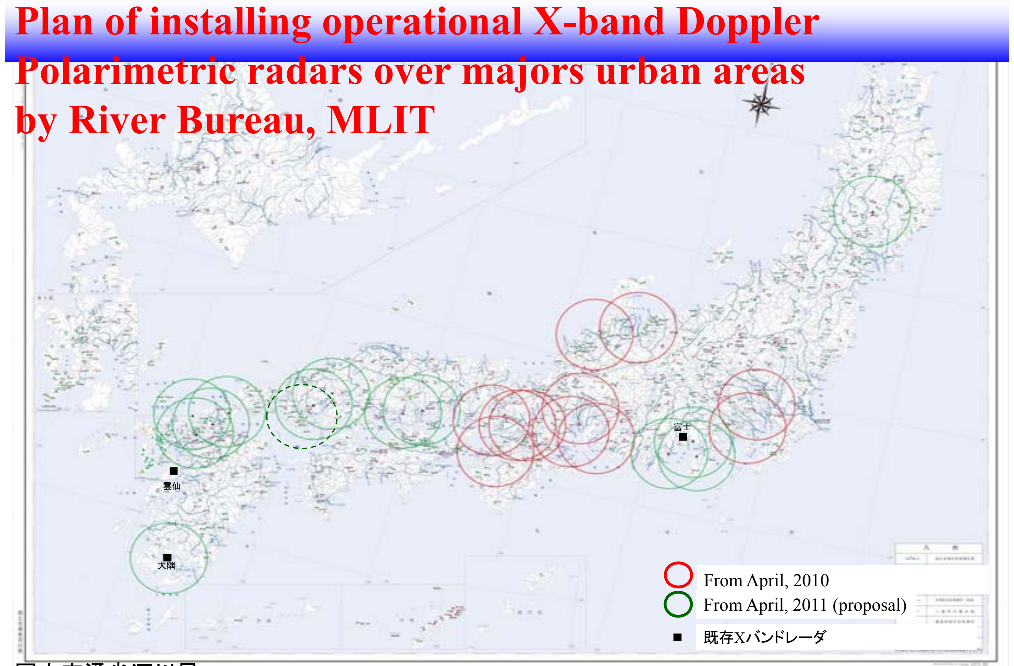
Plan of installing operational X-band Doppler Polarimetric radars over majors urban areas by River Bureau, MLIT



国土交通省河川局

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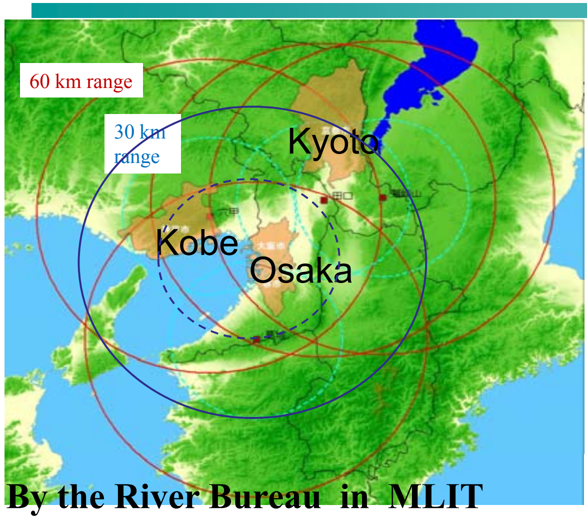
New operational network by X-band radars



By the River Bureau in MLIT

- Higher sensitivity by :
  X band radar
- Higher spatial resolution by :
  X band radar (250~500 m)
  Dense network
- Free from attenuation by :
  Polarimetric function (KDP)
  Dense network together with C-band
- Higher accuracy by :
  Polarimetric function (ZDR, KDP)
- Shorter scan interval with low elevation :
  1 minutes
- Shorter transmission time :
  2 minute
- 3D image :
  Volume scan

New operational networks by X band polarimetric Doppler radars are scheduled to be in operation in various urban areas in Japan before next April.

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Concluding remarks

- **In-Situ campaign observations synchronized with Video-Sonde have been carried out.**
- **A new operational QPE algorithm for C-band polarimetric radar was developed.**
- **Algorithm for classifying the co-exising hydrometeors using a C-band polarimetric Radar was developed**
- **Plan for introducing operational polarimetric radars by MLIT is introduced with an important background.**

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