Dual-polarization radar application

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Contents

- Rainfall rate estimation
  - Including the overview of JMA's Quantity Precipitation Estimate(QPE)

- Hydrometeor classification(HC)
  -Including a severe storm with hail, and lightning

Rainfall rate estimation

- Overview of JMA's QPE : Radar/rain-gauge Analyzed Precipitation (R/A)
- Attenuation correction： R(Zc)
- Estimation for heavy rain: R(K_{DP})
- Development of high-resolution K_{DP}
- Limitations and potential for estimation
- Operational use of advanced Estimation

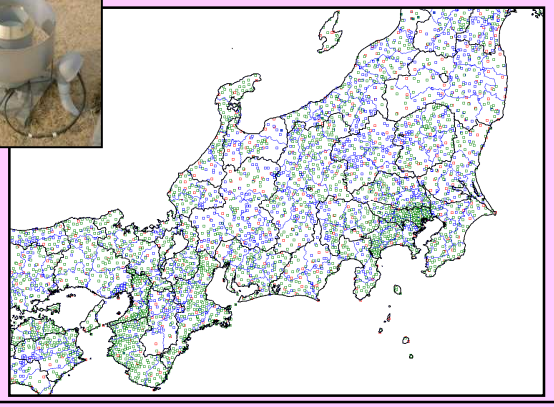
*quantitative precipitation estimation (QPE)

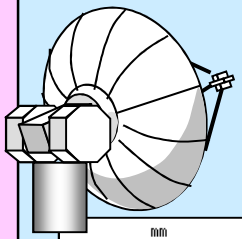
JMA QPE products

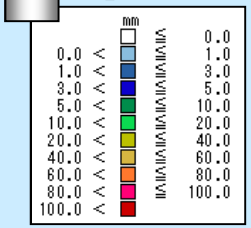
The JMA's QPE product uses
radar precipitation and rain gauge-data.

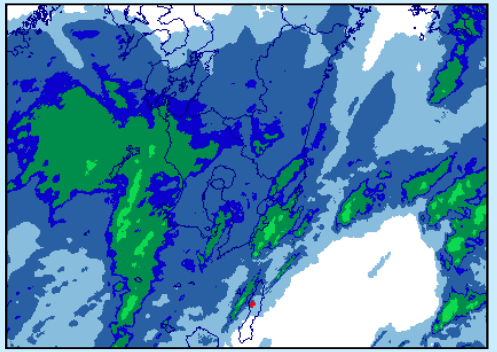
Very high density

- JMA **1,300** points
- Ministry of Land, Infrastructure, Transport and Tourism (MLIT) 3,400 points
- Local government 5,700 points





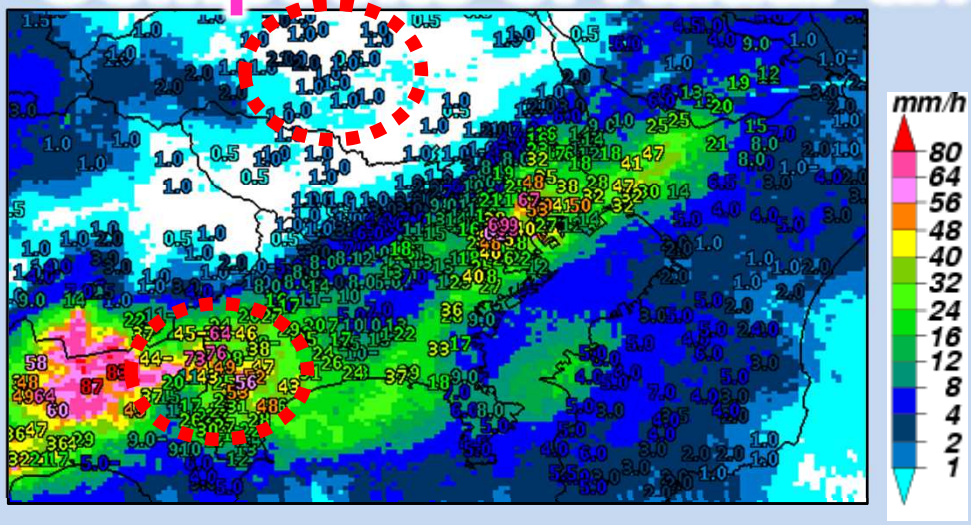




	Rain gauge	Radar
Advantage	High accuracy	Wide area coverage
Disadvantage	Local	Lower accuracy (than rain gauge)

JMA QPE products

Composite of Radar and rain gauge



Wide coverage of Radar

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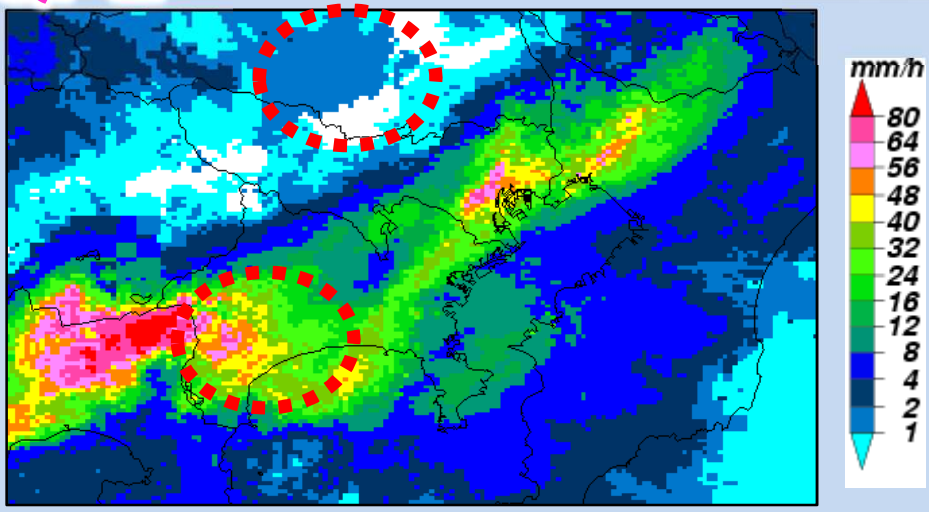
High accuracy of rain gauge

QPE

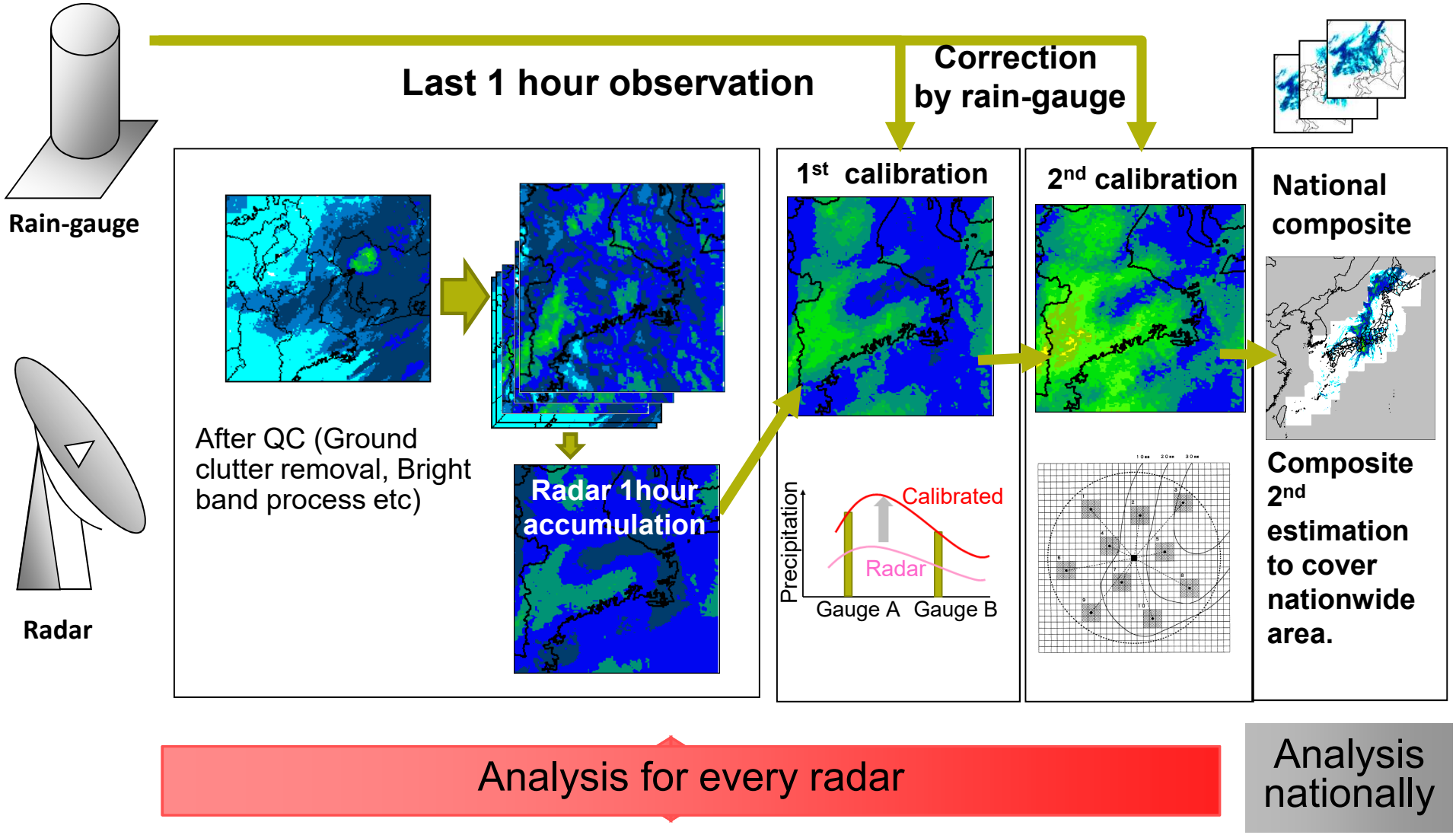
Combination of advantages



Wide cover with accuracy

Overview of making JMA QPE products

R/A : Radar/raingauge-Analized precipitation

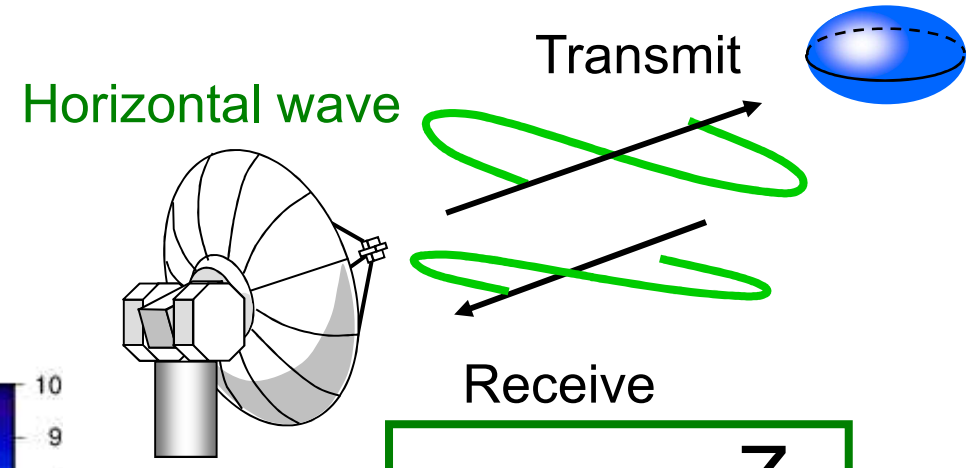


Analysis for every radar

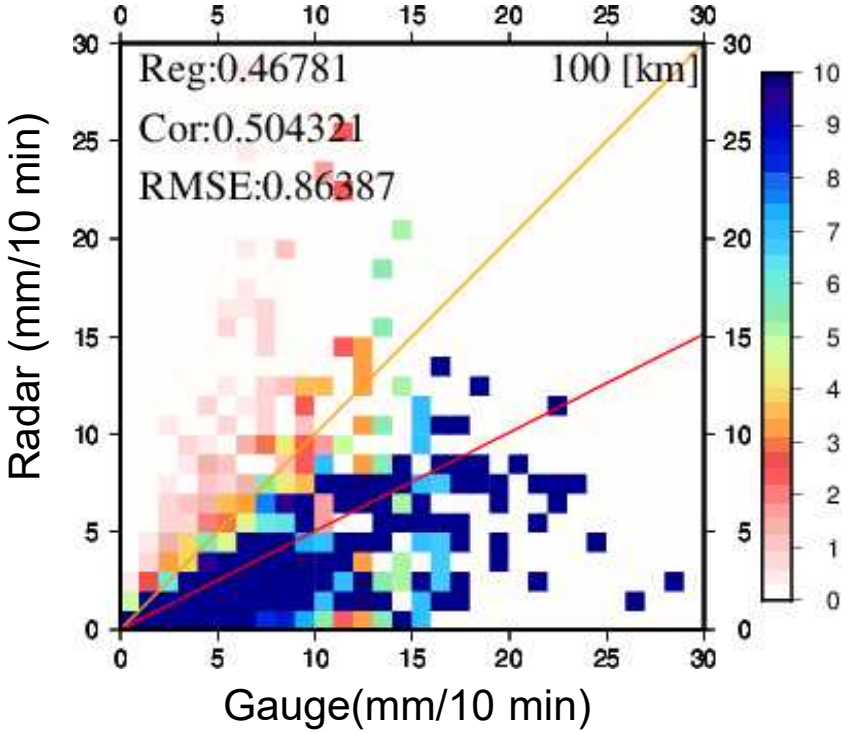
Analysis nationally

Why Dual-pol radar?

Single-pol



R(Z)



✓These radars allow **accurate estimation of heavy rainfall characteristics**.
Especially, we cannot use rain-gauge correction area:
on the sea, localized heavy rain.

Data: Tokyo radar and Gauge (< 100 km from radar)
Period: 2022/06/01 – 2022/08/31
Frequency: Percentage of radar estimation for each 1 mm/10 min bin gauge data

* abt. 2km AGL data

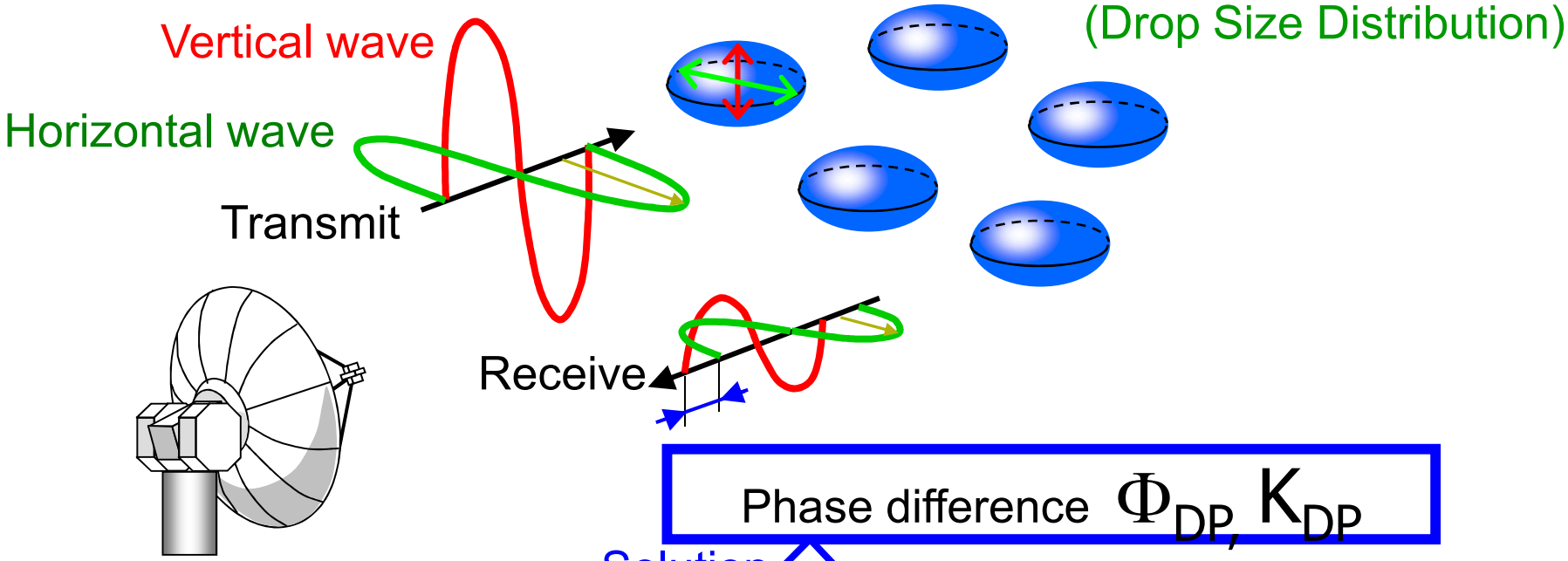
Why Dual-pol radar?

Dual-pol

in terms of rainfall rain estimation

Reflectivity Z_H

Problem: Attenuation by raindrops, assumption of DSD (Drop Size Distribution)



Phase difference Φ_{DP}, K_{DP}

Solution

Non-attenuation

Dependency on water content

Corrected of reflectivity: Z_C

K_{DP}-R relation

Attenuation correction: R(Zc)

Attenuation correction using K_{DP}

$$Zc\,(r) = Z(r) + 2\sum_{i=1}^{r} \mathrm{A_h}(r)$$

Bringi and Chandrasekar (2001), Jameson (1992)

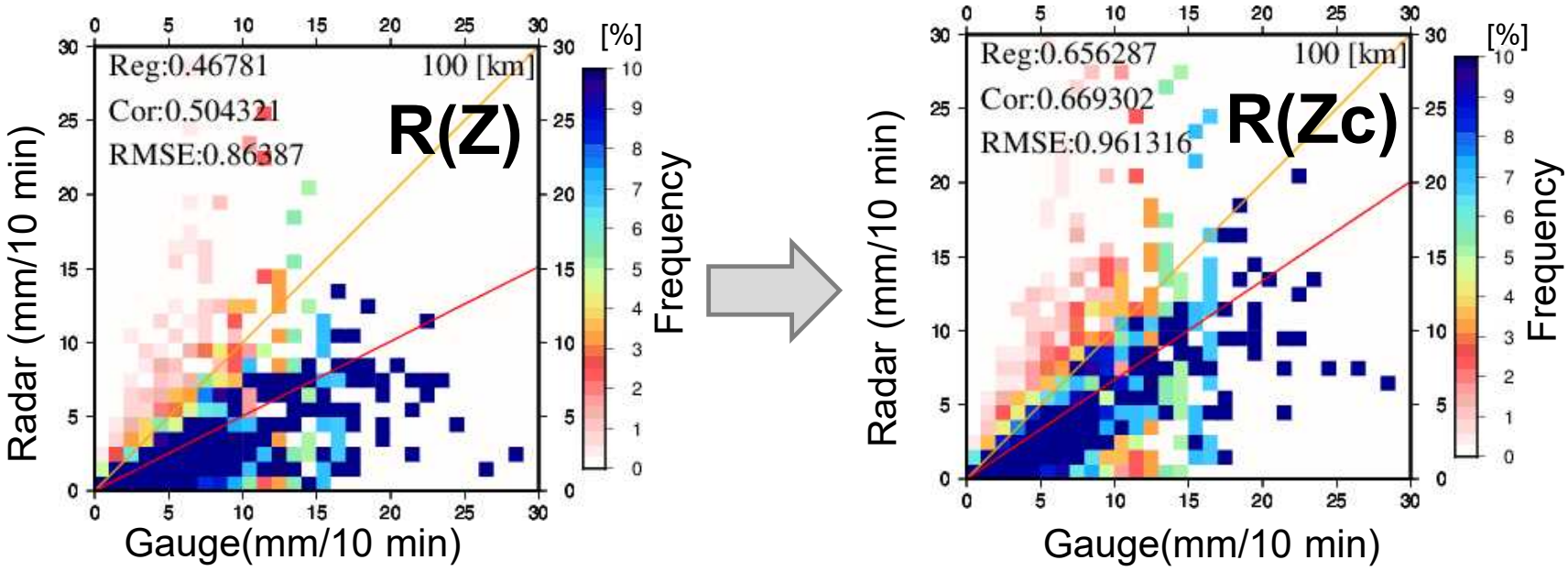
$$A_h(r) = \alpha \mathrm{K_{DP}}(r)^b$$

	S-band (2.8 GHz)	C-band (5.5 GHz)	X-band (9.3 GHz)
A_h	$0.017\mathrm{K_{DP}}^{0.84}$	$0.073\mathrm{K_{DP}}^{0.99}$	$0.233\mathrm{K_{DP}}^{1.02}$

$Z = 200\ R^{1.6}$

Single-pol

Dual-pol



Same data **without** attenuation correction

Same data **with** attenuation correction

Estimation for heavy rain: $R(K_{DP})$

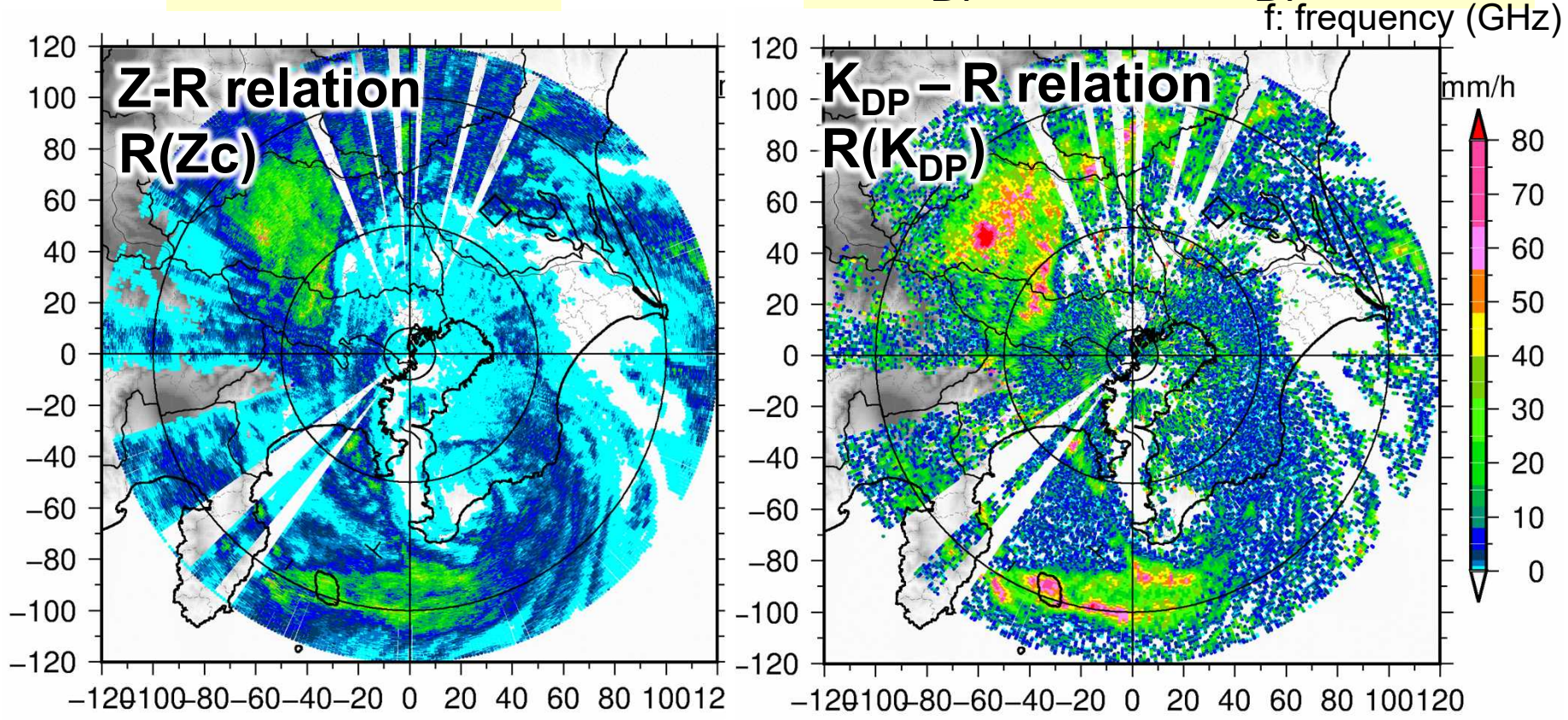
Improved estimation for heavy rain region using K_{DP}

Bringi and Chandrasekar (2001)

$Z = 200\ R^{1.6}$

$R(K_{DP}) = 129(K_{DP} / f)^{0.85}$

f: frequency (GHz)

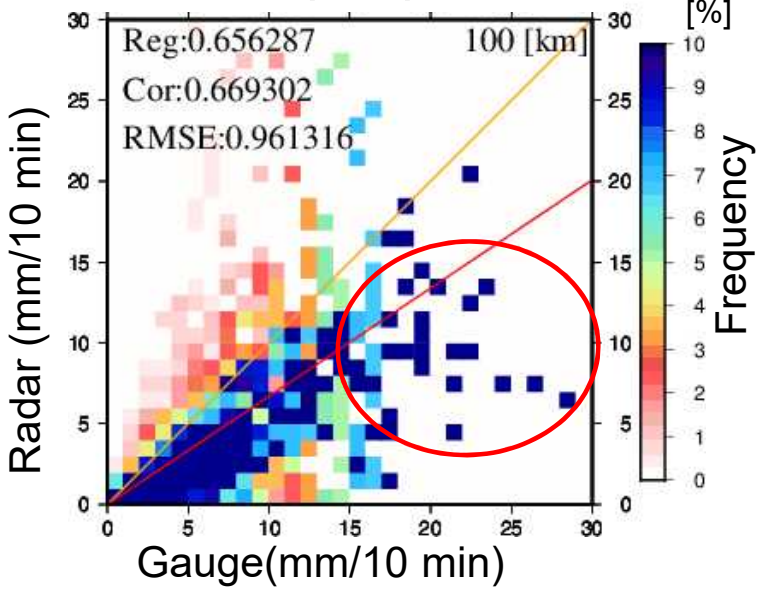


Estimation for heavy rain: $R(K_{DP})$

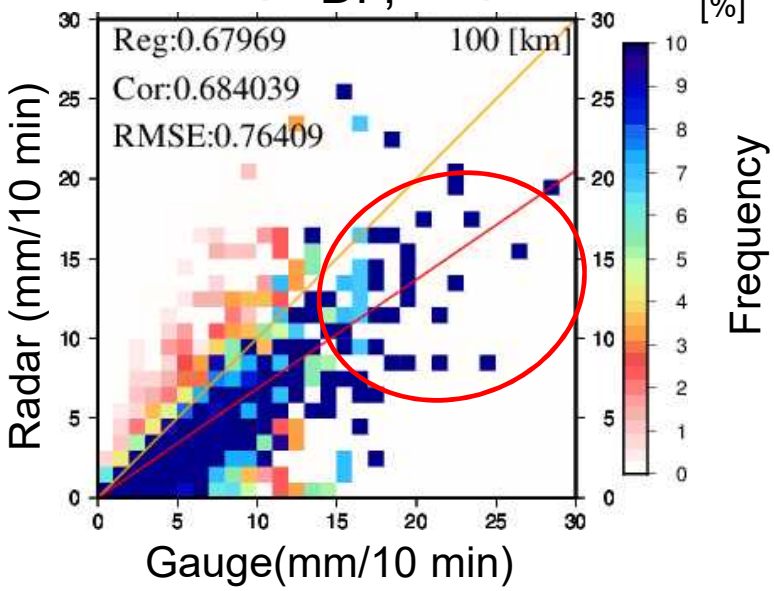
Dual-pol

$R(K_{DP})$ or R(Zc)

R(Zc)



$R(K_{DP},Zc)$



Improved radar rain estimation

R(Z)	slope of regression line:	0.47
R(Zc)	〃	: **0.66**
$R(K_{DP},Zc)$	〃	: **0.76**

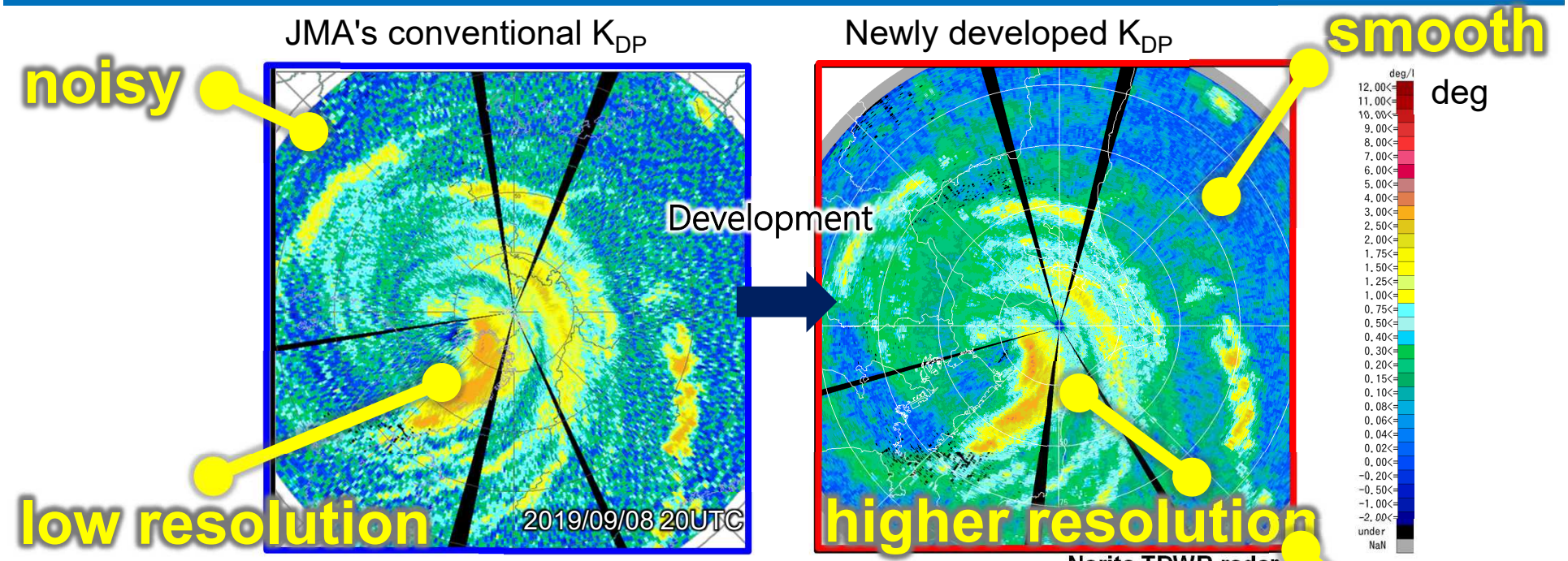
K_{DP}: conventional method based on Hubbert and Bringi (1995)

$R(K_{DP})$: Threshold
K_{DP}> 0.65 deg/km
Zc > 38 dBZ

Development of high-resolution K_{DP}

JMA's conventional K_{DP}

Newly developed K_{DP}



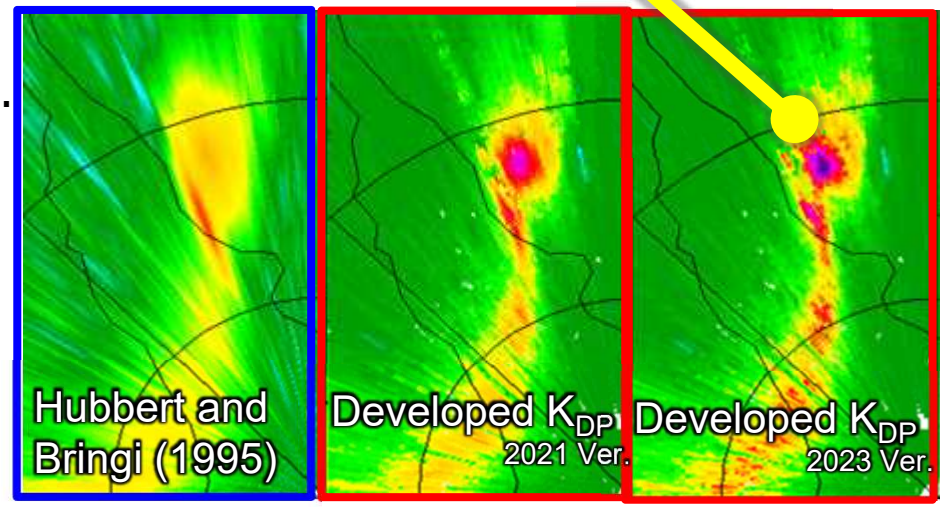
Hubbert and Bringi (1995)

JMA's conventional K_{DP} was noisy and low resolution.

We focused our efforts on developing a resolution that would be suitable for operational use.

SG-method (Savitzky and Golay 1964)

$$K_{DP}(j) = \frac{\sum_{k=-(m-1)}^{(m-1)} \left(k \times \Phi_{DP}(j+k)\right)}{\sum_{k=-(m-1)}^{(m-1)} (k^2)}$$



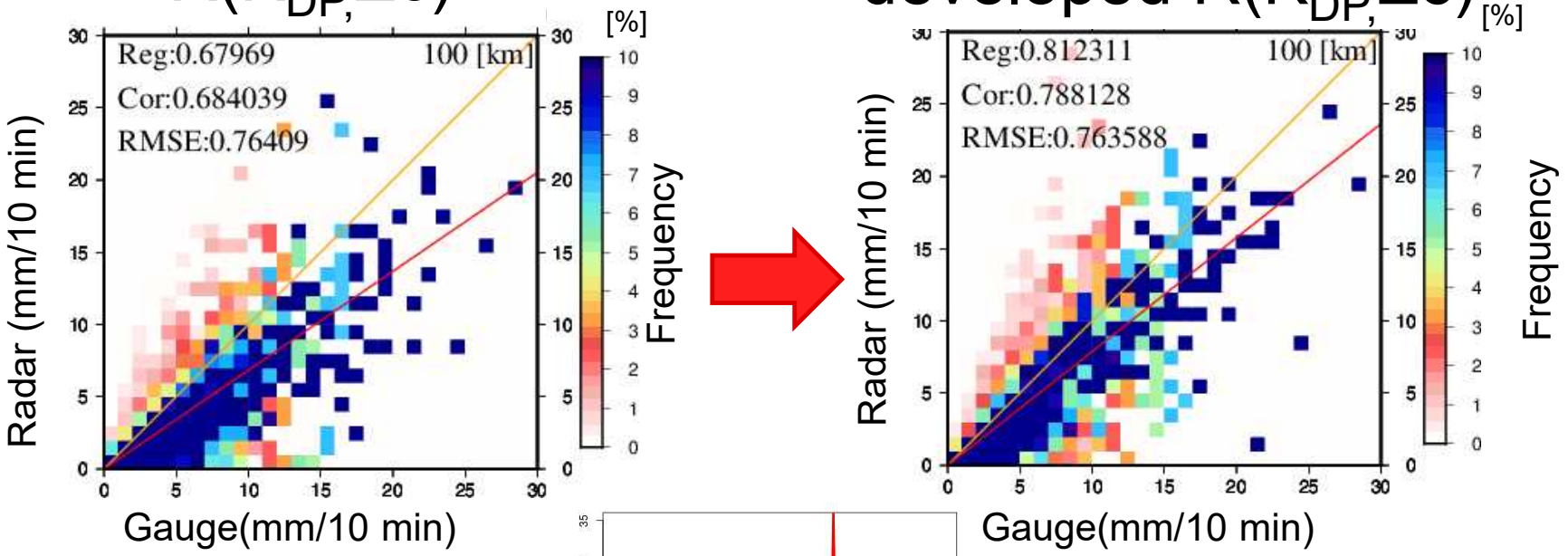
Dynamically change the calculation range depends on precipitation intensity.

Development of high-resolution K_{DP}

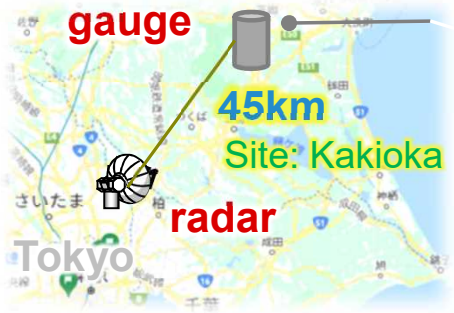
Comparison with rain gauge

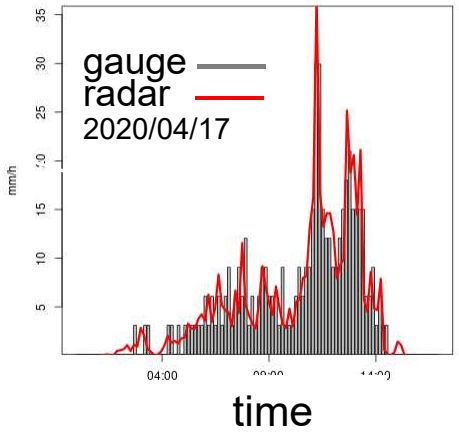
Conventional

SG-method



Best example



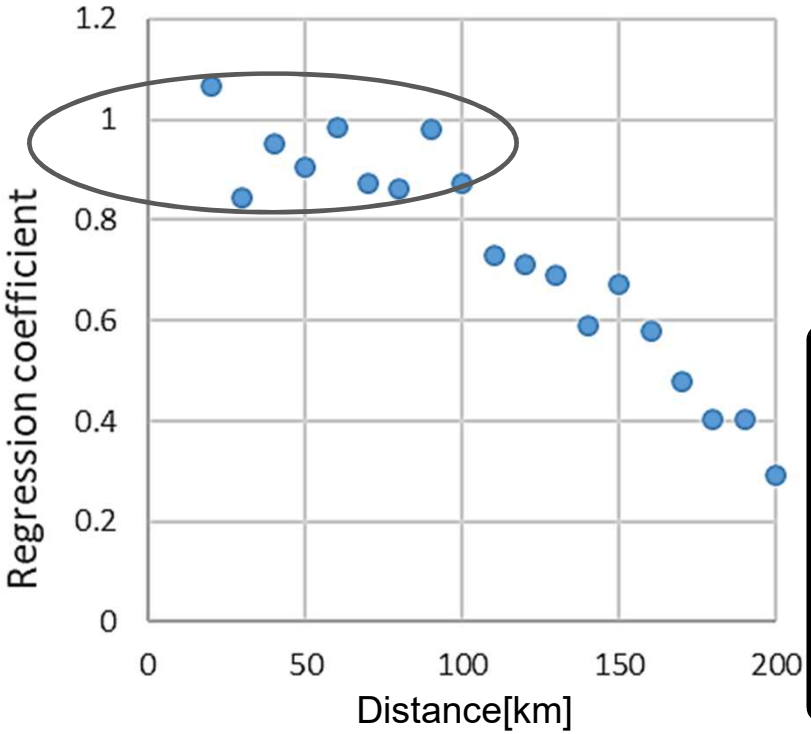


$R(K_{DP})$: Threshold
K_{DP} > 0.6 deg/km
Zc : Depends on conditions

*Dynamic selection of elevation angles

Limitations and potential for estimation

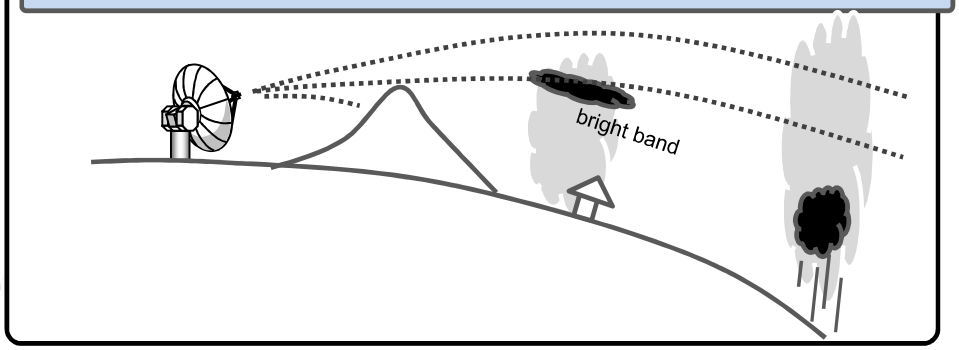
Regression coefficient compared to rain gauge (x-axis shows distance from radar)



Site: Tokyo radar
time: 2022/06/01 – 2022/08/31

High accuracy: Up to 100 km

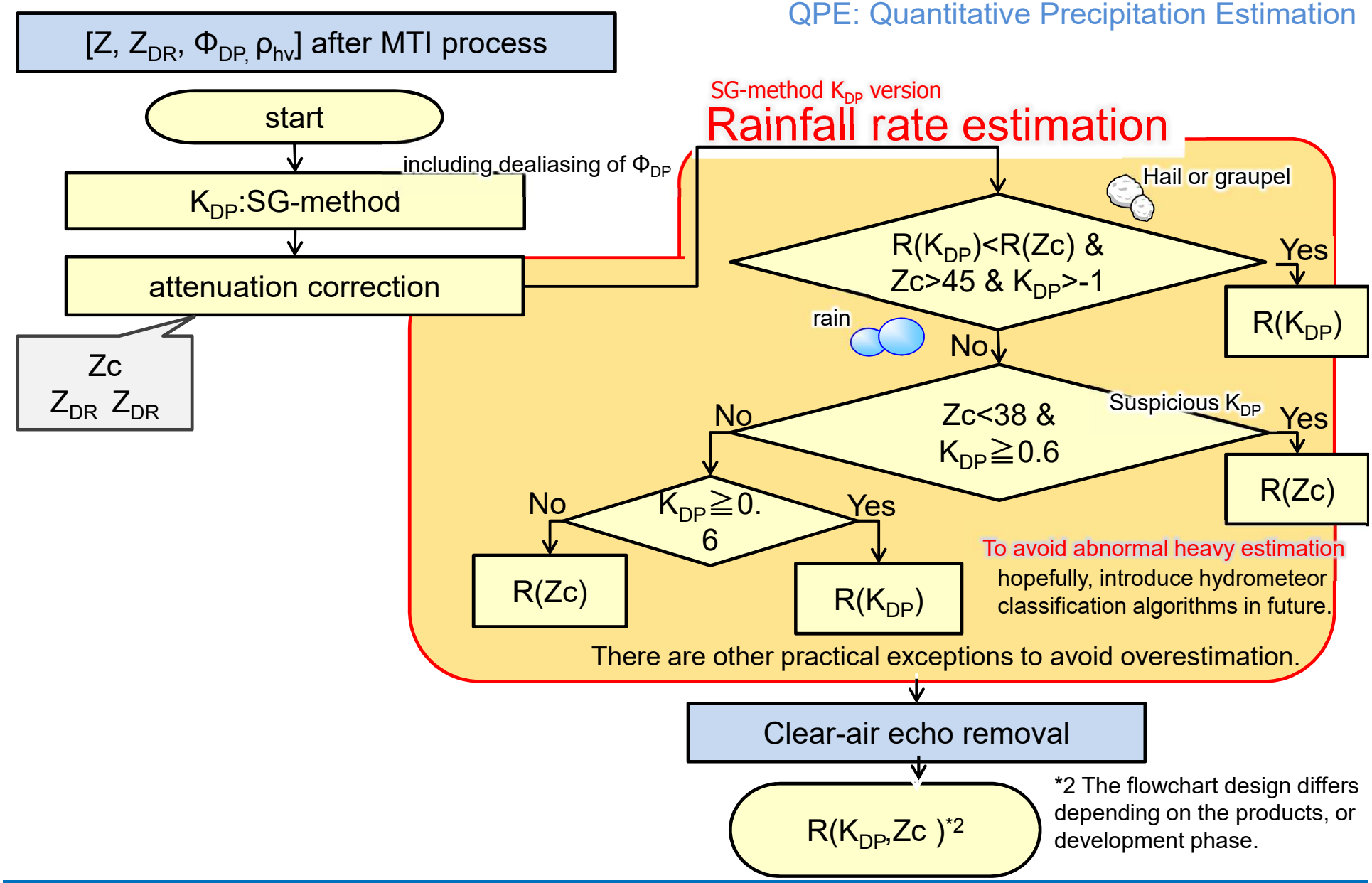
Cause: Shielding, observation altitude,
bright band, beam broadening, etc.



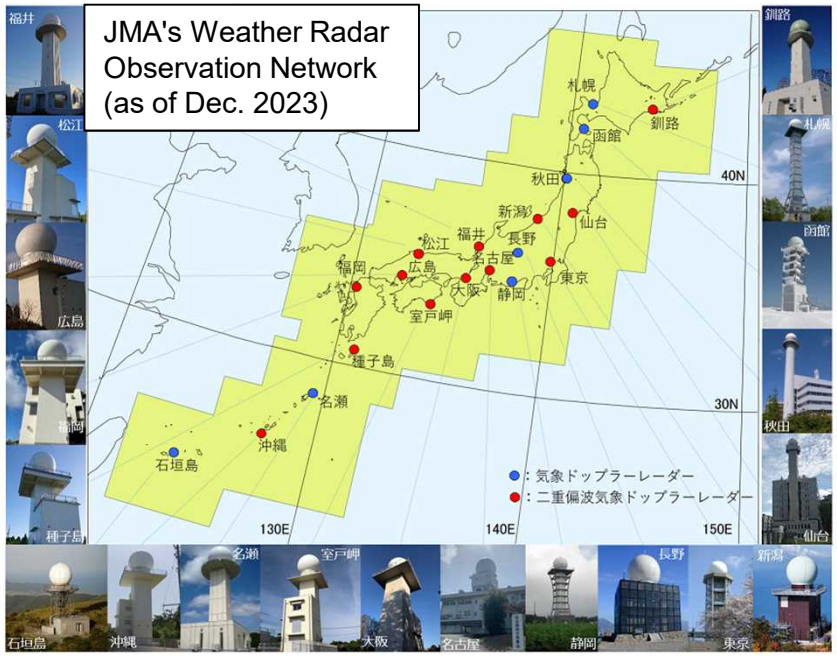
Future works:
Advancement of R(K_{DP},Zc) estimation algorithm
Optimization of the selection of elevation angles
Combinational use of rain gauge correction for operational

Operational use of advanced QPE

QPE: Quantitative Precipitation Estimation



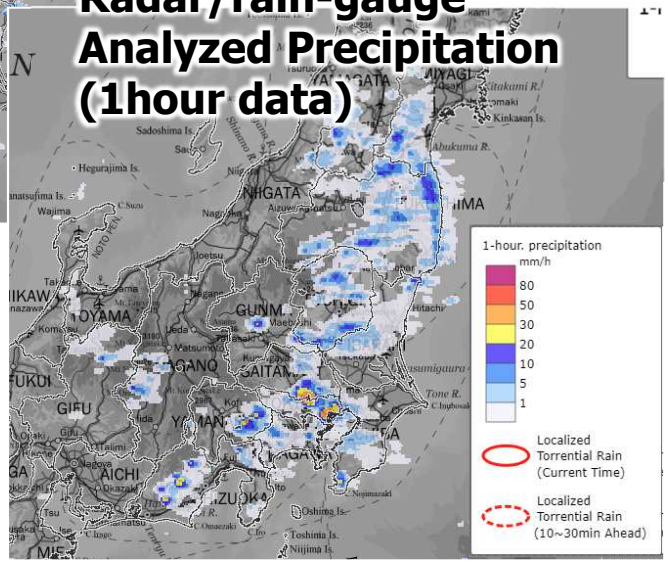
Operational use of advanced QPE



Dual polarization Weather Radar ●13 site

High-resolution Precipitation Nowcasts (5min data)

Radar/rain-gauge Analyzed Precipitation (1hour data)



1. Attenuation correction of Z is introduced at installation.

2. QPE using K_{DP} has been implemented limitedly since 2022.

   ・**High-resolution Precipitation Nowcasts** https://www.jma.go.jp/en/highresorad/

   ・**Radar/rain-gauge Analyzed Precipitation (R/A)**

   *K_{DP} is used limitedly. Expansion of K_{DP} usage sites and times is under consideration.
   https://www.jma.go.jp/bosai/en_kaikotan

First content summary: rain fall estimation

JMA Quantitative Precipitation Estimation(QPE) Radar/Rain gauge-Analyzed Precipitation(R/A) data enable

Highly accurate estimation of rainfall rates and distribution

・Deficient radar rainfall datasets are corrected using coefficients created from rain gauge information.

Dual-polarization radar enables

Highly accurate rainfall rate estimation

・JMA uses attenuation correction in Z-R estimation, and is in the process of introducing advanced K_{DP}-R estimation.

・Advanced QPE has been implemented for selected precipitation products since 2022.

・Expansion of the time scale and range using advanced QPE/QPF is expected in the near future.

Hydrometeor Classification (under development)

- Basics of JMA's hydrometeor classification algorithm (HCA)
- JMA's hydrometeor classification (HC) results and evaluation
- Concept of JMA's HCA application
- Applying JMA’s HC to melting layer and severe storm

Single-Pol radar and Dual-pol radar in HC

Hydrometeor Classification (HC)

Single-pol

- It is almost impossible to determine the characteristics of precipitation particles.
  - Because only the Z is used.

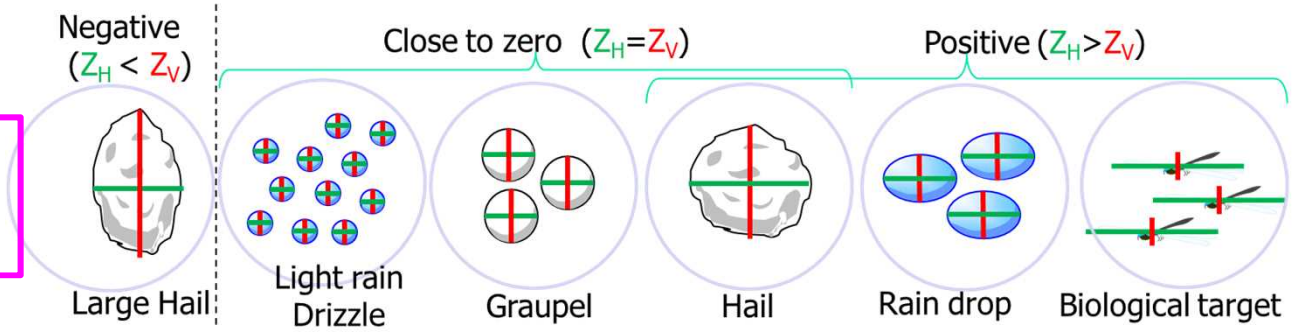
To better estimate rainfall and enable detection of melting layers.

Dual-pol

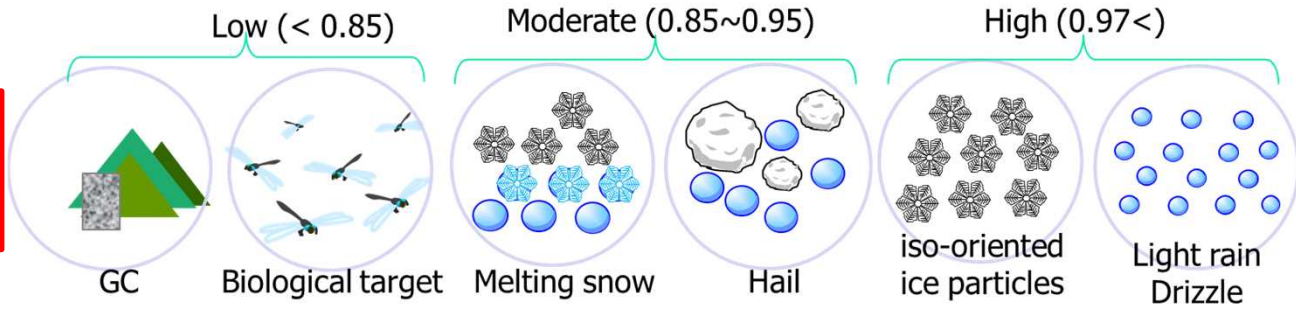
- Precipitation particles can be identified or discriminated.
  - Using of dual-polarization variables

Dual-polarization variables used in HCA

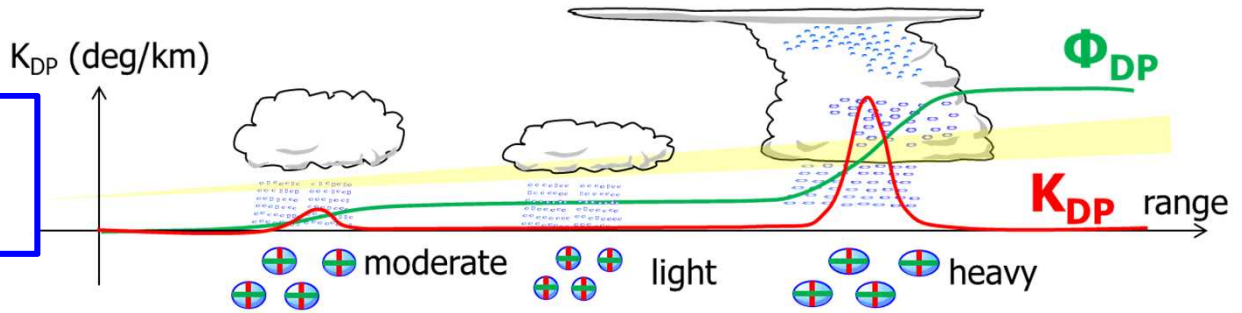
Z_{DR}: Differential reflectivity
→Particle shape



ρ_{hv}: Correlation coefficient
→Shape diversity



K_{DP}: Specific differential phase
→Rain rate/water content

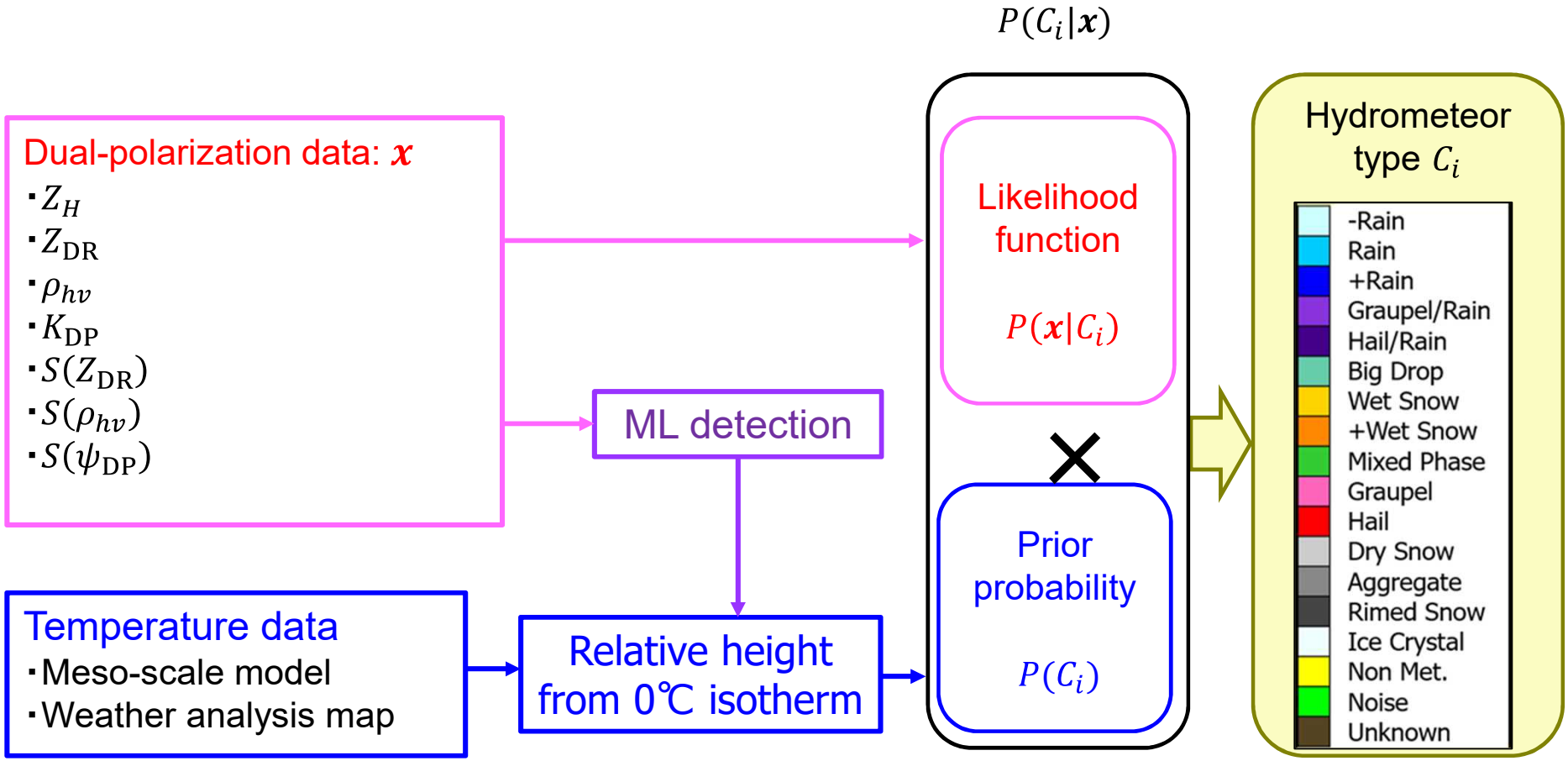


Textures of Z_{DR}, ρ_{hv}, Φ_{DP} (differential phase)

JMA Hydrometeor Classification Algorithm (HCA)

Hydrometeor Classification (HC)

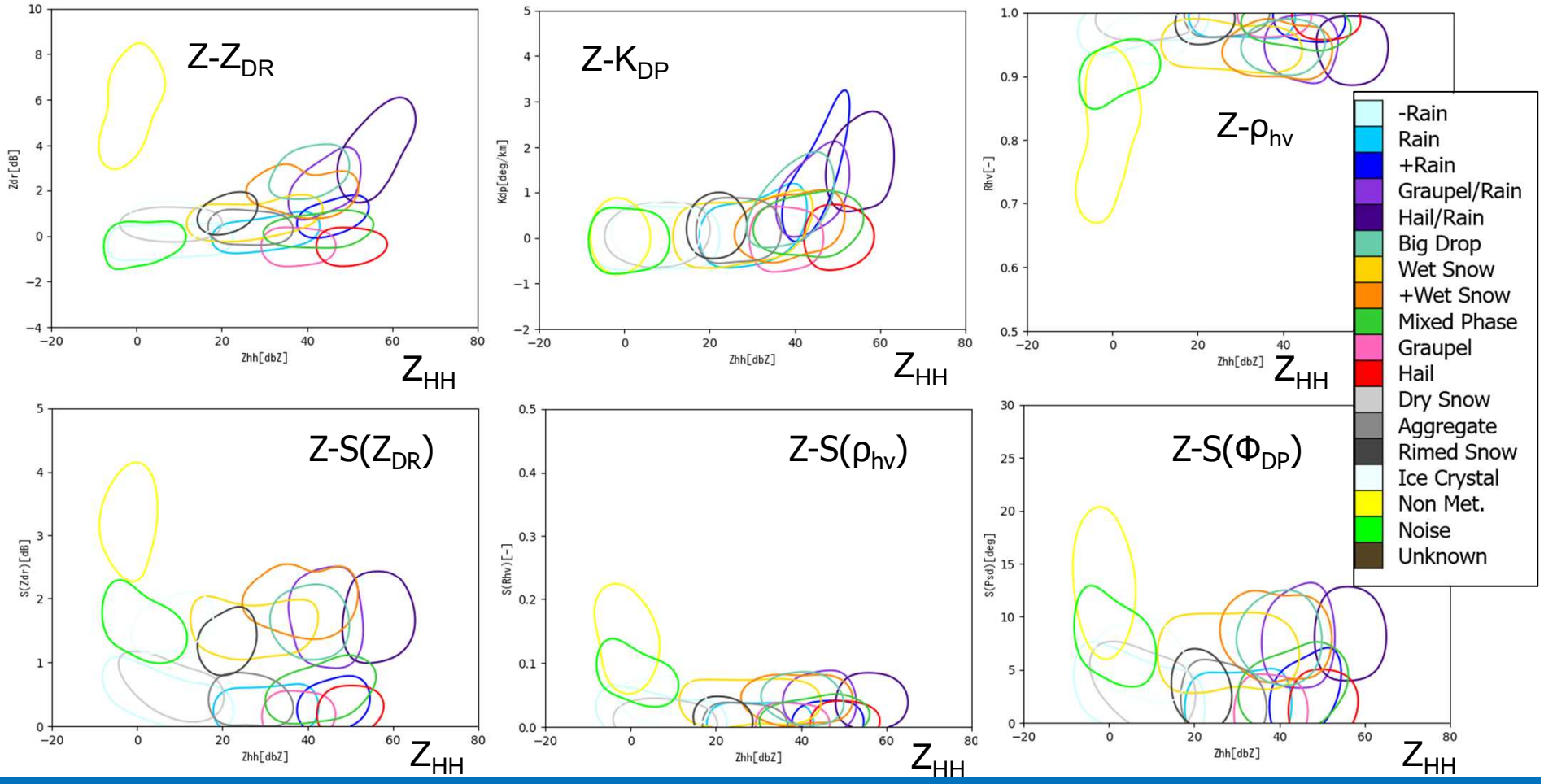
- Hydrometeor type is determined from the highest posterior probability based on Bayesian estimation
  - posterior probability $P(C_i|\boldsymbol{x}) \propto P(\boldsymbol{x}|C_i)P(C_i)$



JMA hydrometeor classification algorithm

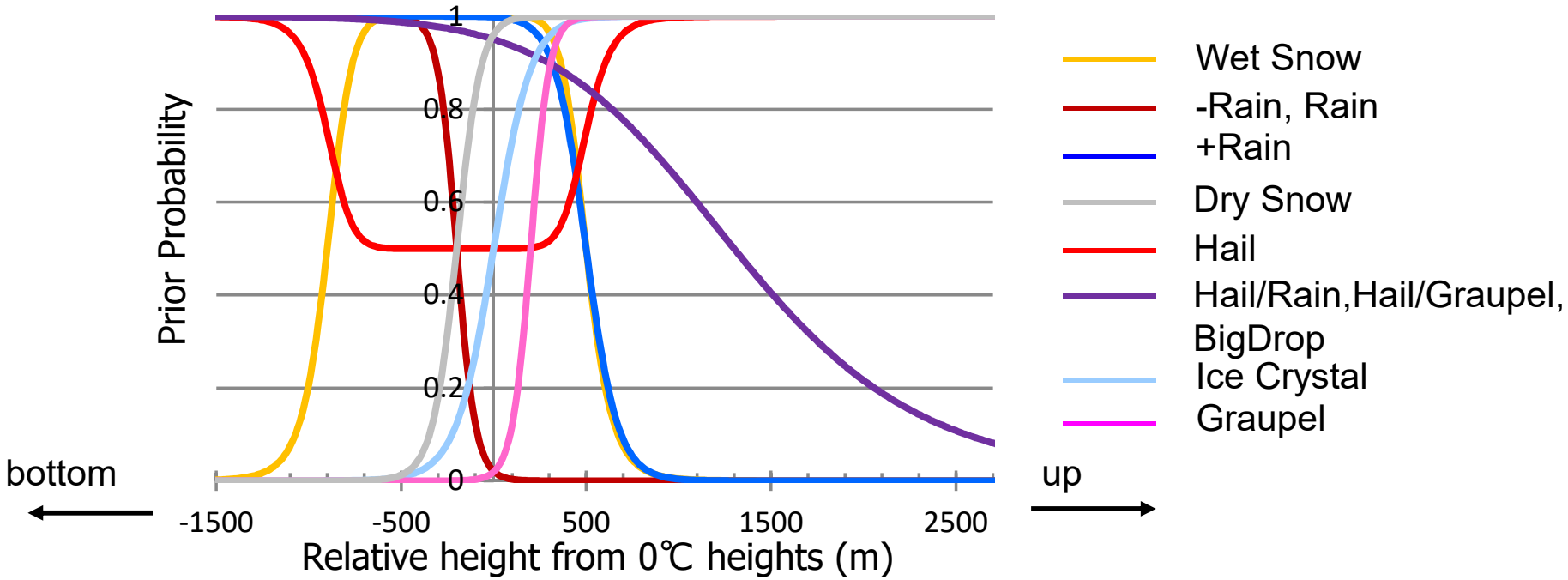
Hydrometeor Classification (HC)

- Likelihood function $P(\boldsymbol{x}|C_i)$
  - created by clustering techniques & kernel density estimation



JMA hydrometeor classification algorithm

- Prior probability $P(C_i)$

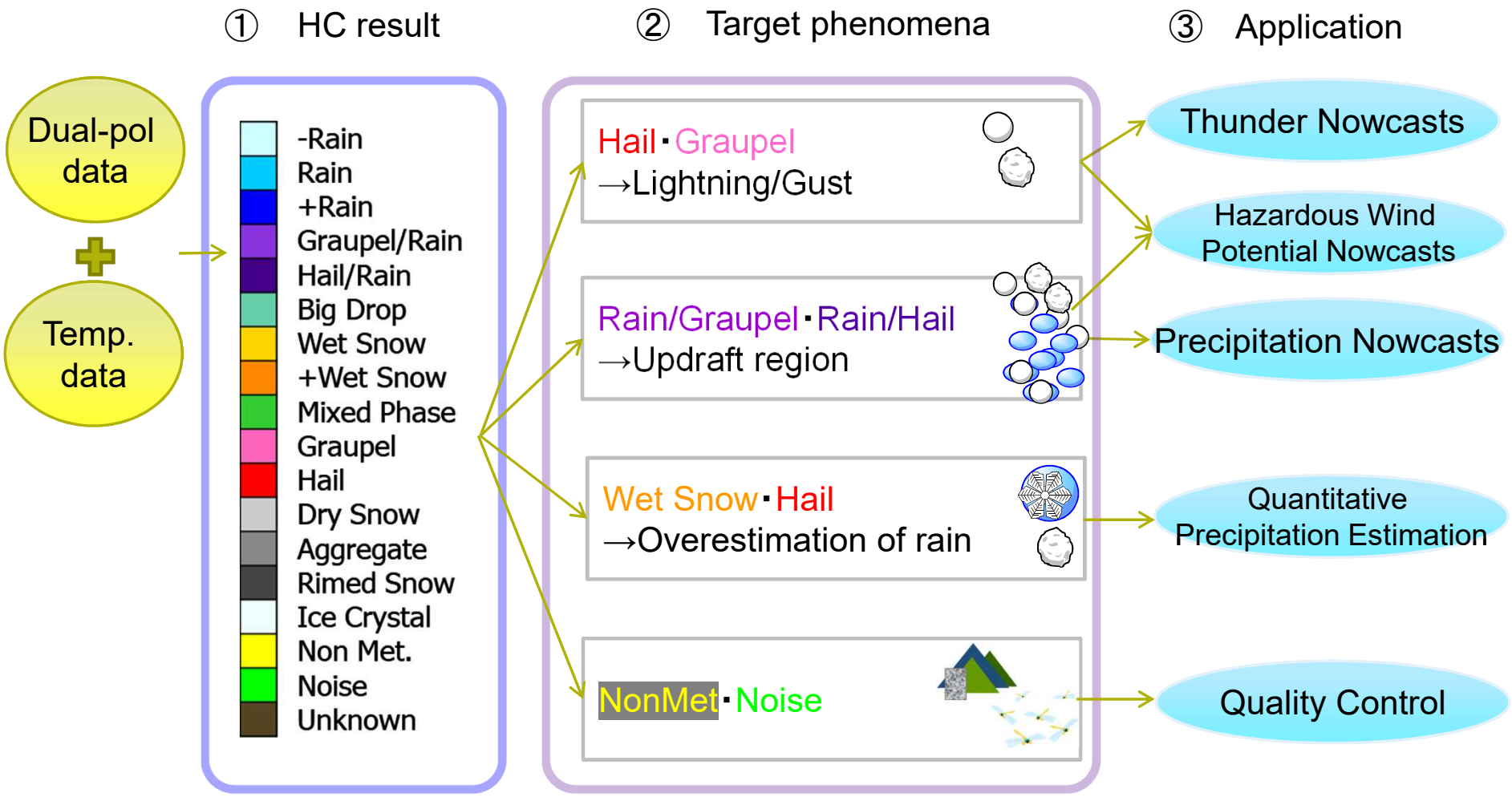


– Function of distance from 0℃ heights

(0℃ heights ← melting layer height & temperature data)

Umehara et al. (2019), 39th Radar conf.

Concept of JMA HCA application



JMA hydrometeor classification results

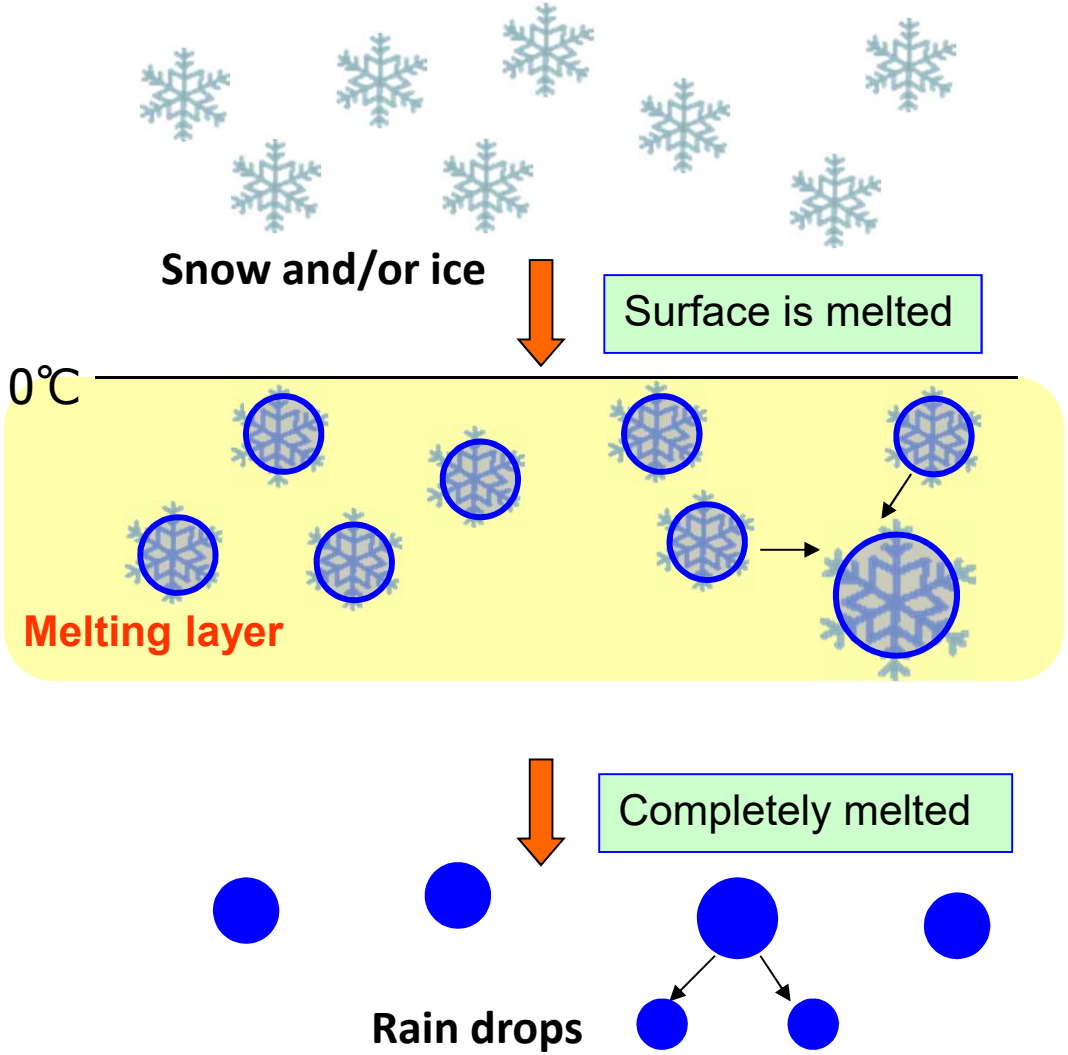
- Application of JMA hydrometer classification

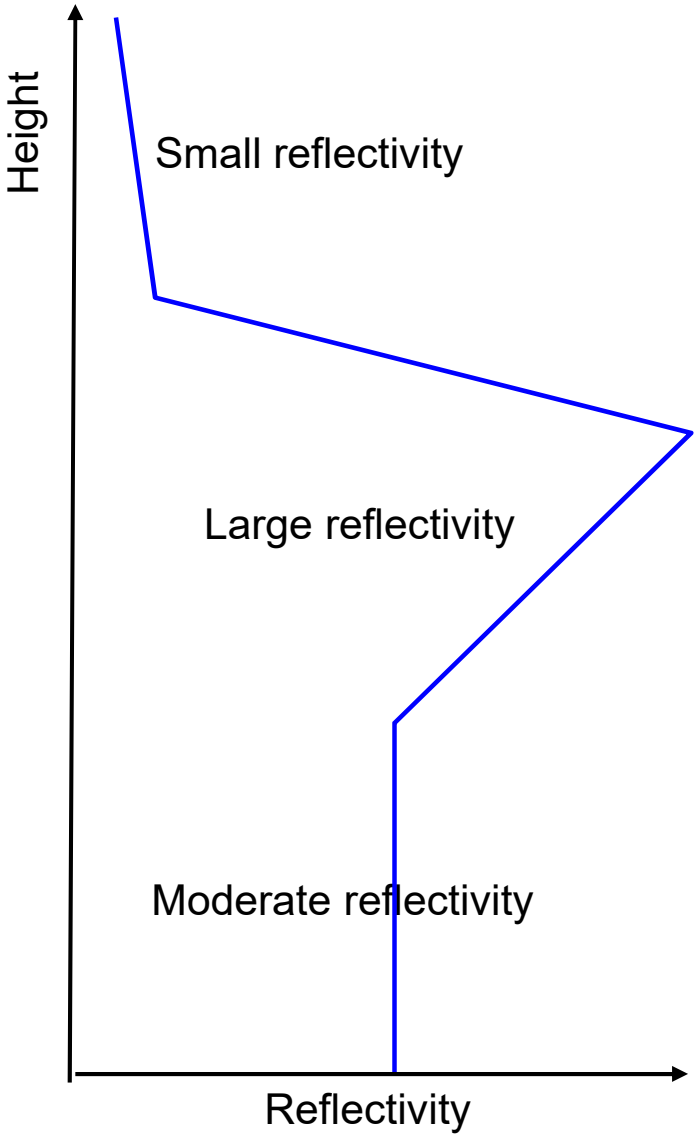
  -Melting layer detection

  -Severe weather detection
  (hailstorm, thunderstorm)

Melting layer and bright band relationship

Bright band: Echo of enhanced reflectivity by melting precipitation in the zero-degree Celsius layer (melting layer).

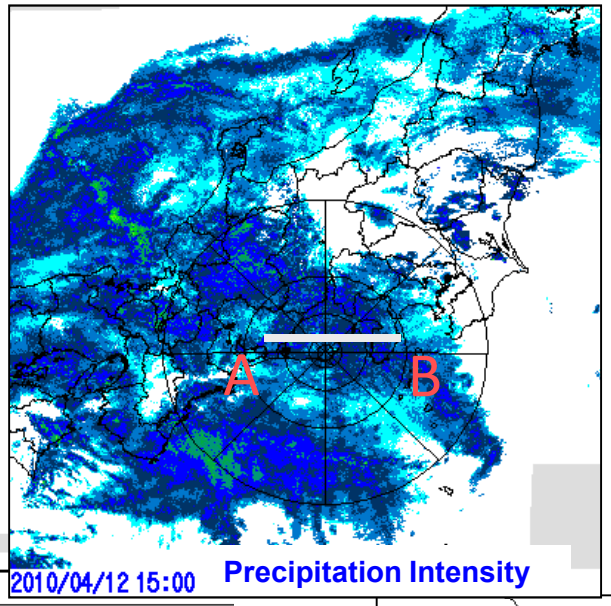


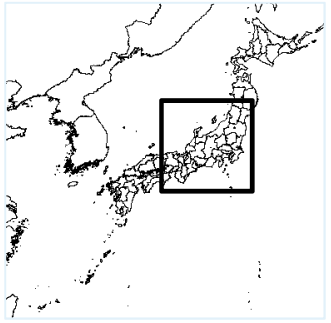


The Bright band case in Japan

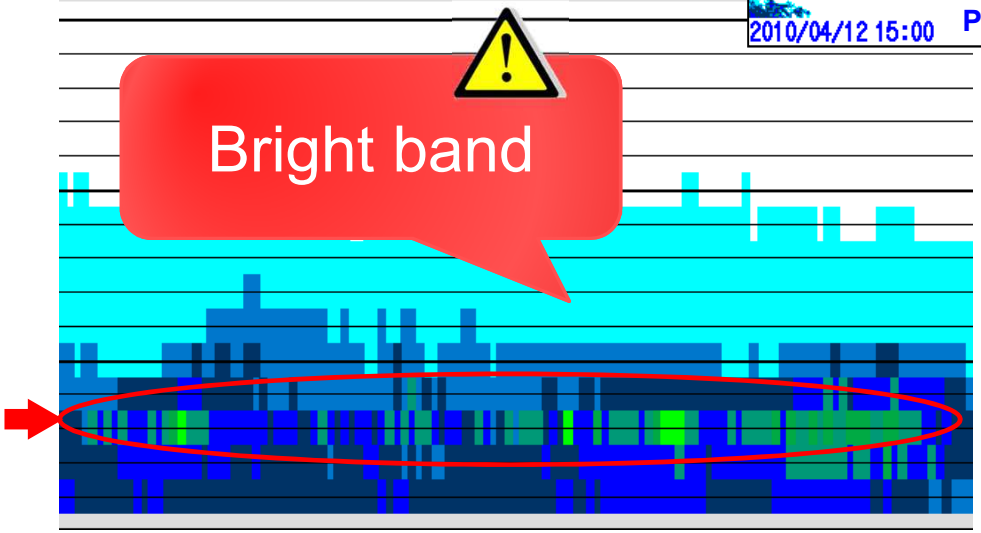
Single-pol

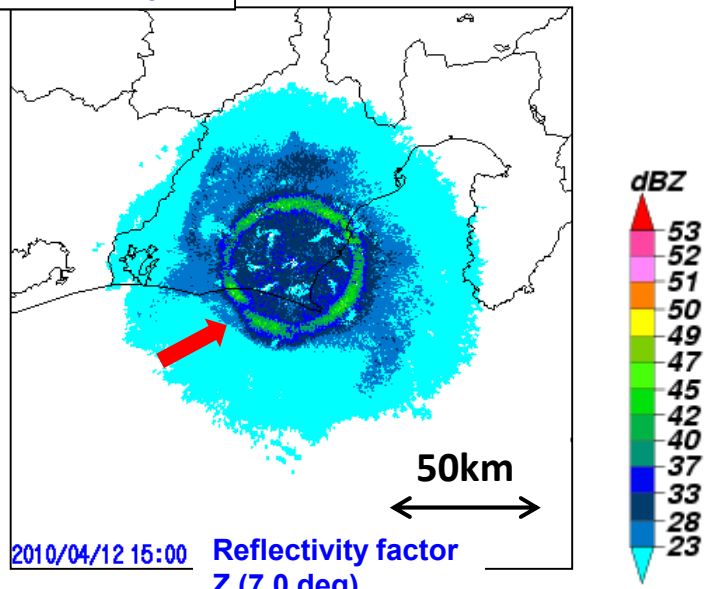
2010/04/12
Extratropical cyclone





Vertical cross-section



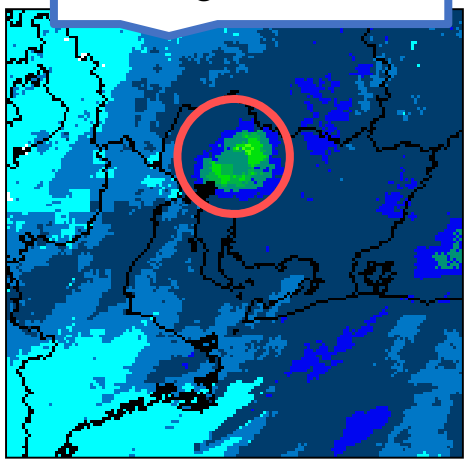


The bright band is shown as light green color in cross-section of Z

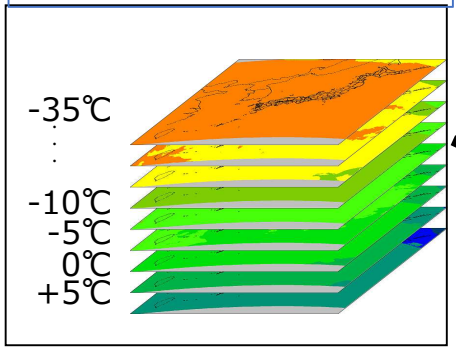
Detection of melting layer used by JMA's QPE

Single-pol
(operational)

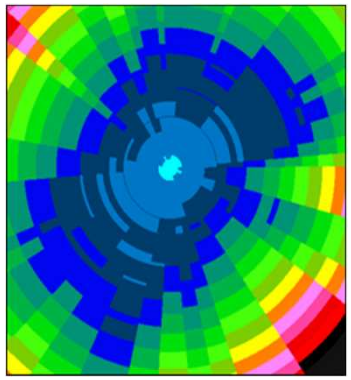
Bright-band



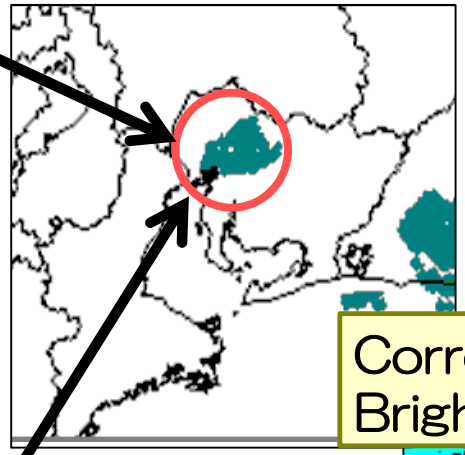
Use of temperature data from **meso-scale** NWP



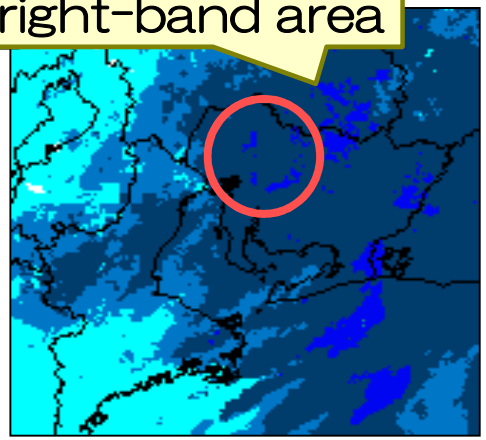
Elevation data from radar



Detection of the area



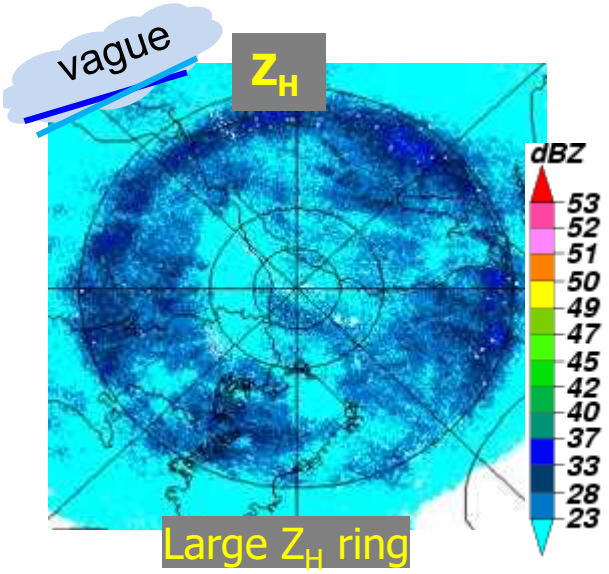
Corrected the Bright-band area

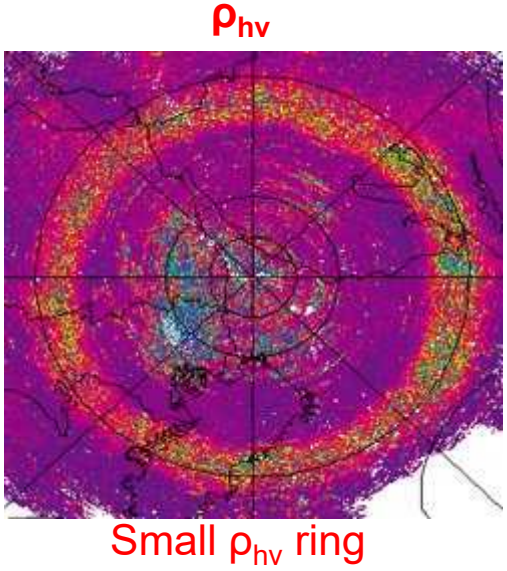


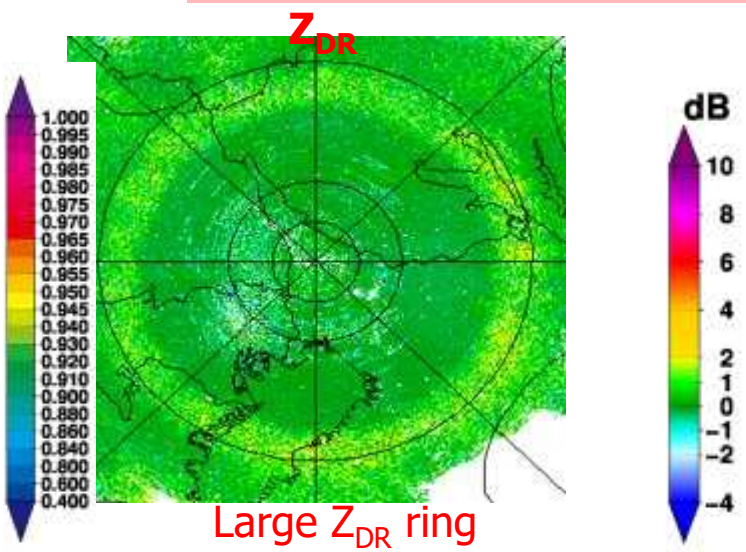
Detection of melting layer by HC

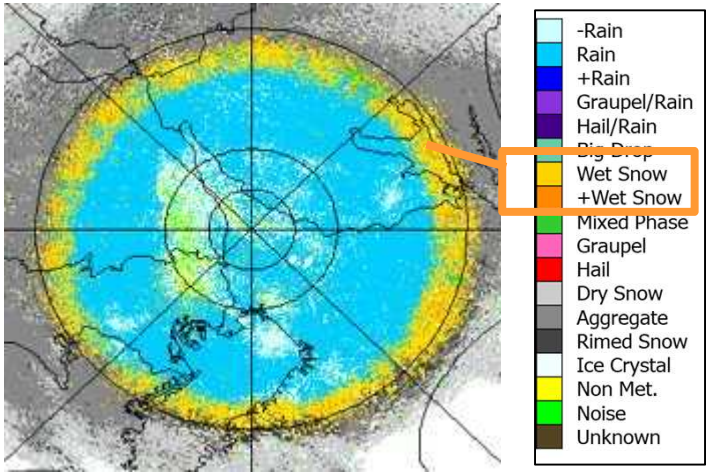
Hydrometeor Classification (HC)

Dual-pol
(under development)









Wet snow regions (Melting layer) are well identified.

Evaluation：Melting layer (ML)

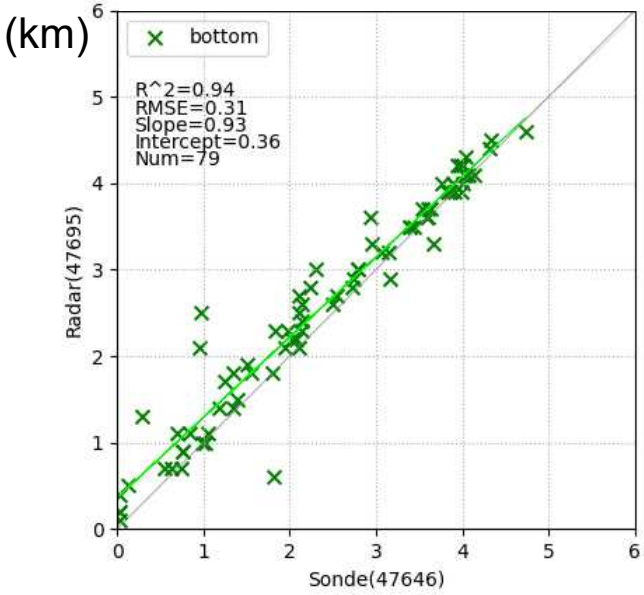
Dual-pol
(under development)

Hydrometeor Classification (HC)

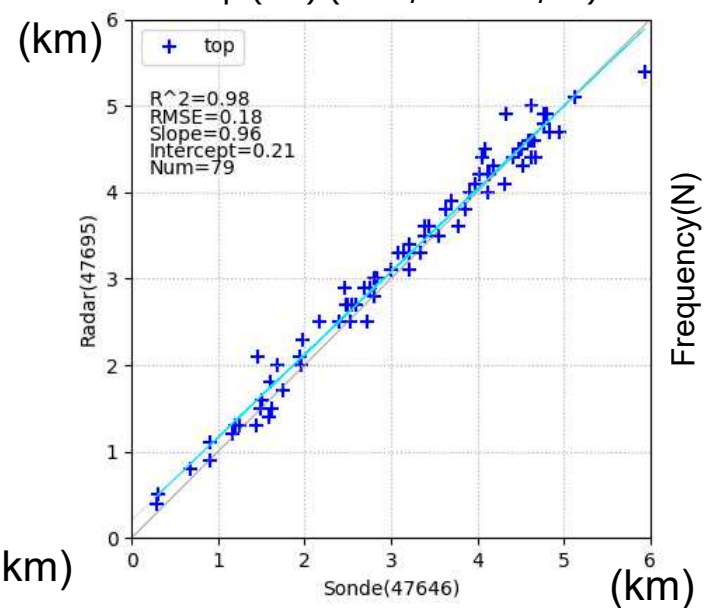
- Wet snow regions (melting layer) are evaluated using comparisons with radiosonde observations.

	ML bottom	ML Top
Radiosonde (Tateno)	4℃ heights	0℃ heights
HC (JMA Tokyo radar), el>1.1 deg Wet snow region	20 percentile height from bottom	80 percentile height from bottom

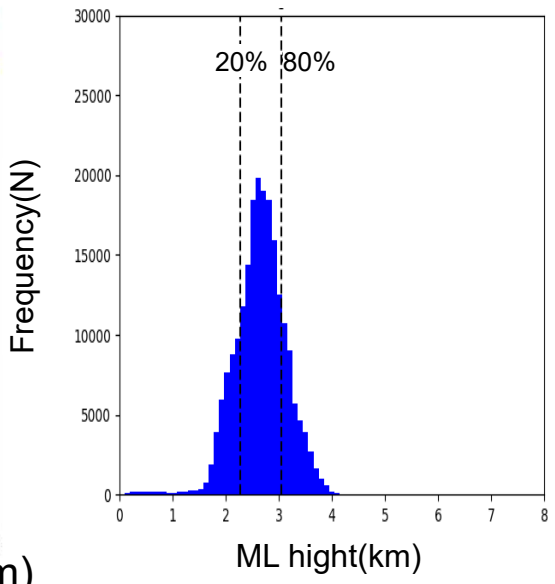
ML bottom (2021/09-2022/08)



ML top (km) (2021/09-2022/08)



Frequency distribution of wet snow

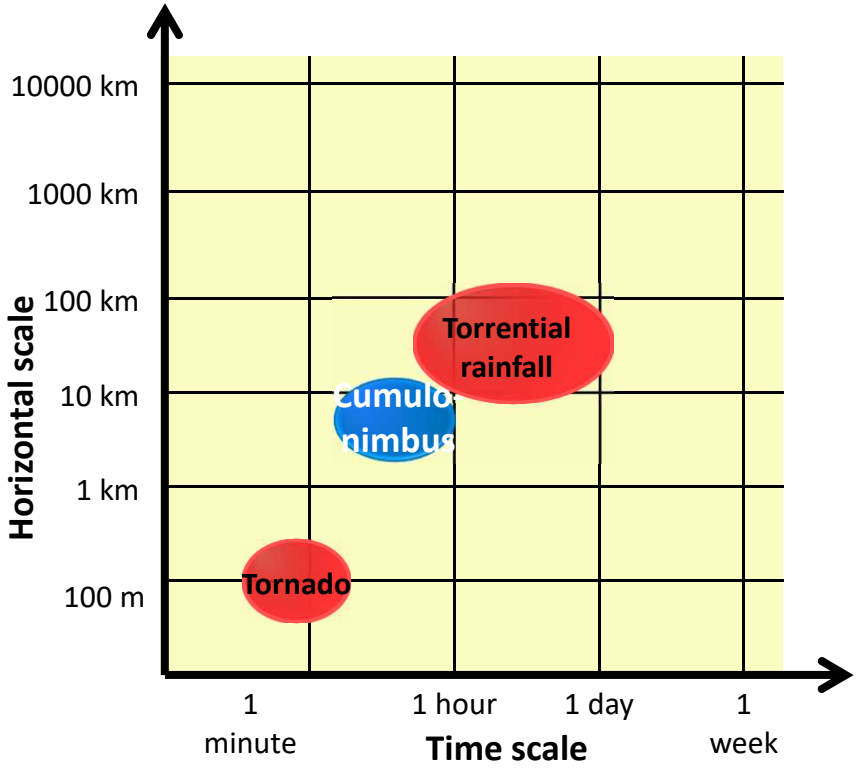


The classification results showed good agreement with the radiosonde observations.

The Hail-storm

1-yen coin
The diameter is 20mm

The hailstones fell in Chiba prefecture, May 24, 2000



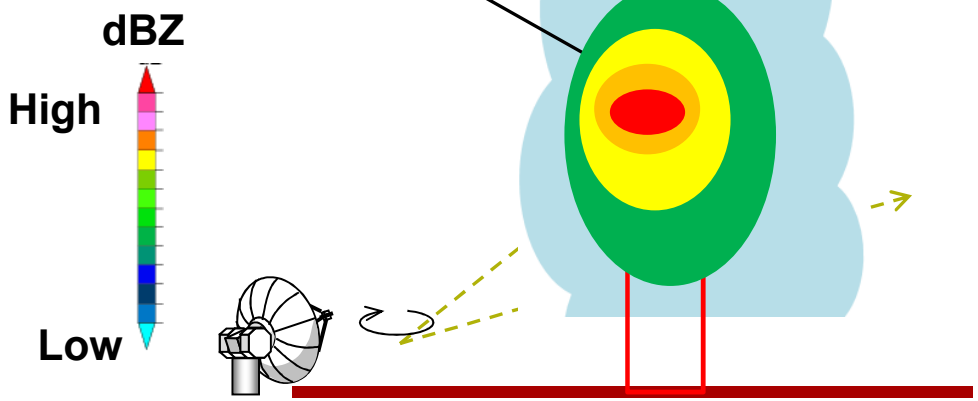
- It causes local but enormous damage to crops.

Relationships between Hail and Various Radar Echo Indices

Single-pol (operational)

Top: Top height (km)

Zmax: Maximum refrectivity (dBZ)



VIL: Vertically Integrated Liquid water content(kg/m^2)
$=\Sigma(M(h)\Delta h)$

($M=3.44\times10^{-6}\times Z^{4/7}$)

VILD: VIL density(g/m^3)= VIL / Top

The threshold depends on regions/seasons.

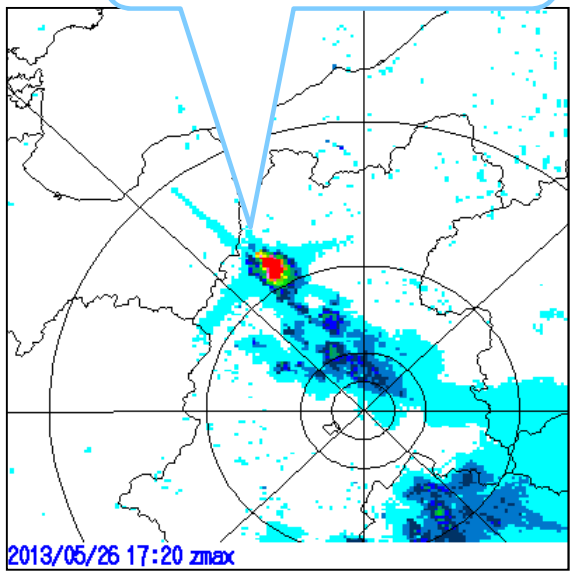
	Zmax	VIL	VILD	Top
Chance of Hail	55dBZ or more	Extremely large value	$3.5g/m^3$ or more	8km or more
	Geotis (1963)		Amburn and Wolf (1997)	Uchida et al. (2010) in Japanese

Hail detection via single-pol radar in Japan

Single-pol
(operational)

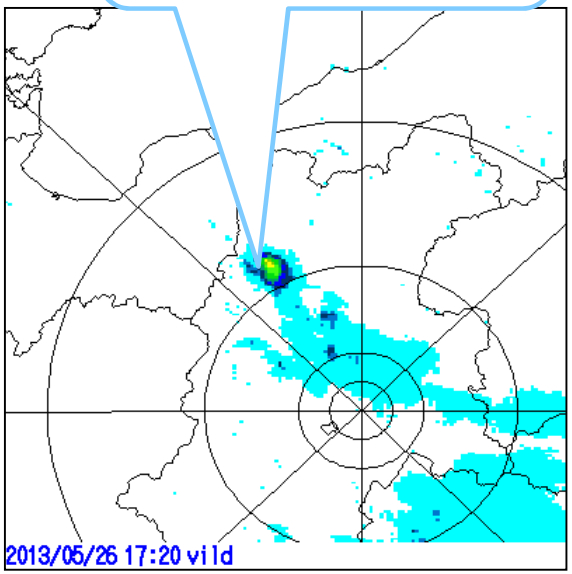
ZMAX

Max: 62 dBZ
(> 55 dBZ)



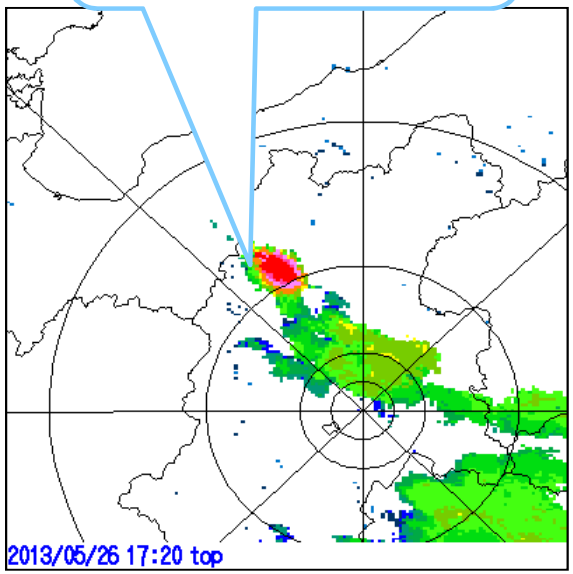
VILD

Max: 4.3 g/m^3
(> 3.5 g/m^3)



TOP

Max: 15 km
(> 8 km)



Nagano radar

2013/05/26
Hail in Nagano

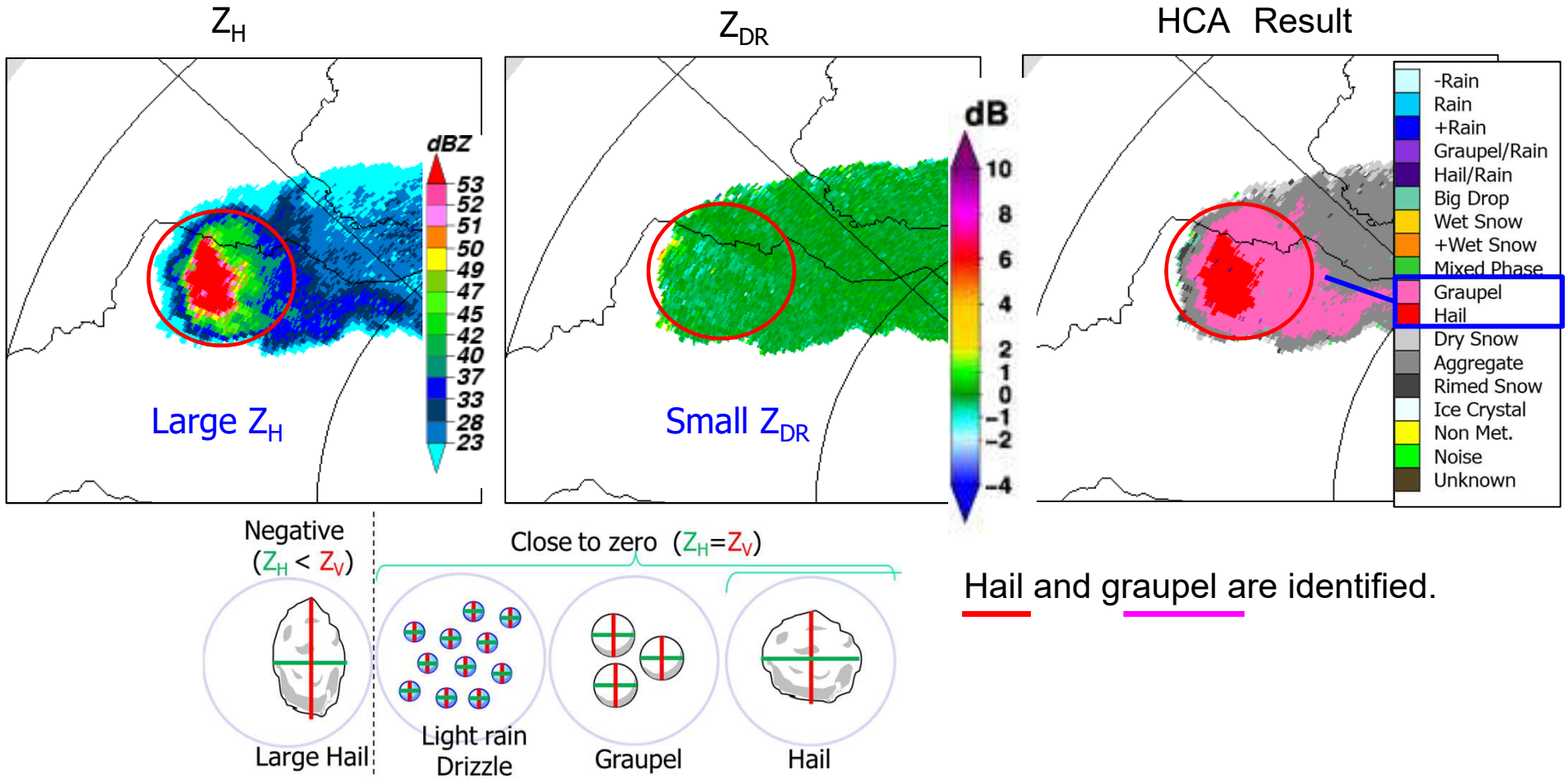
- Here, Zmax, VILD and Top are above their thresholds, indicating a high chance of hail.

Detection of Hail by HC

Hydrometeor Classification (HC)

Dual-pol
(under development **)**

- Downburst/gust front and hail event on 2nd June 2022

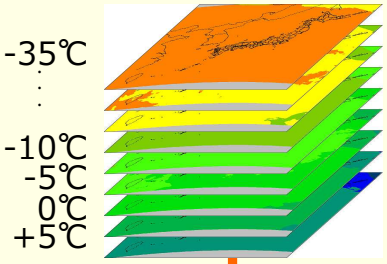


Hail and graupel are identified.

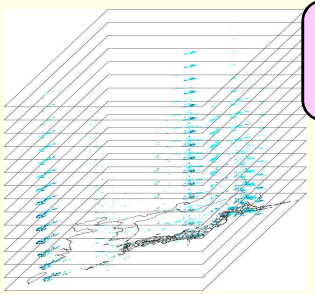
Detection of Thunderstorms

Single-pol (operational)

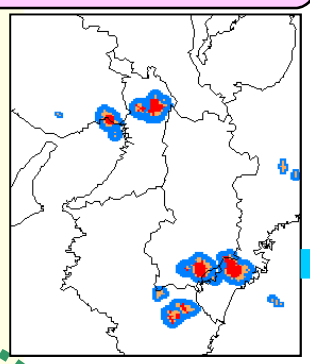
Use of temperature data from meso-scale models



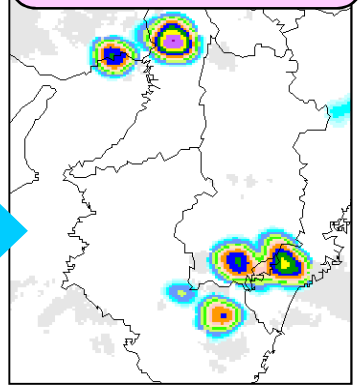
CAPPI data



Detected Convective cells



Radar-Thunderstorm index（1km）



－10℃ plan Z
－15℃ ≈
－20℃ ≈

VIL

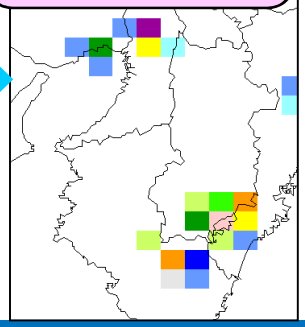
T O P

reflectivity Z

RLA10

Operation

Radar-Thunderstorm index（10km）

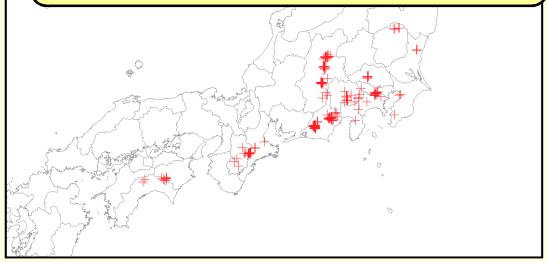


Logistic regression analysis

Analyzing the lightning risk level (0 to 100) within 30 minutes from radar data

Checked by:
・MSM PoT data
・LIDEN CG data within 60 minutes

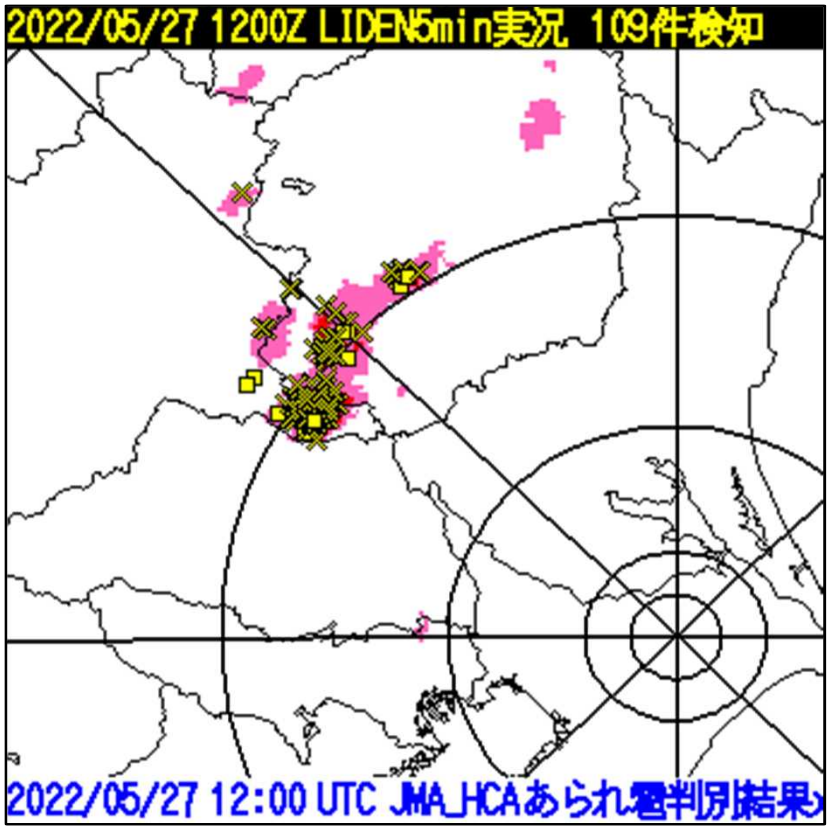
LIDEN CG detection with 30 minutes



*LIDEN(JMA lightning detection network)

Dual-pol
(under development **)**

- Comparison with lightning data by JMA's lightning detection network (LIDEN).



Statistics for April-September 2022 based on JMA's Tokyo radar show that 92% of lightning were detected within 5km of the hail/graupel class bin. → good agreement

Second content summary: hydrometeor Classification

- Single-polarization radar
  - Operational ML/severe weather detection
    - Quality control for the removal of bright bands in JMA QPE involves the use of 3D radar information from single polarization radar and temperature information from meso-models.
    - 3D radar information on reflection intensity can be used to estimate hail areas.
- Dual-polarization radar
  - New Hydrometeor Classification tools
    - JMA's hydrometeor classification algorithm based on Bayesian estimation discriminates effectively between typical precipitation types,-such as graupel/hail and melting layers.
    - Application of HCA for variety of nowcasts, information and other products is expected.

Thank you for your attention.