Calibration

1 February 2024

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Japan Meteorological Agency

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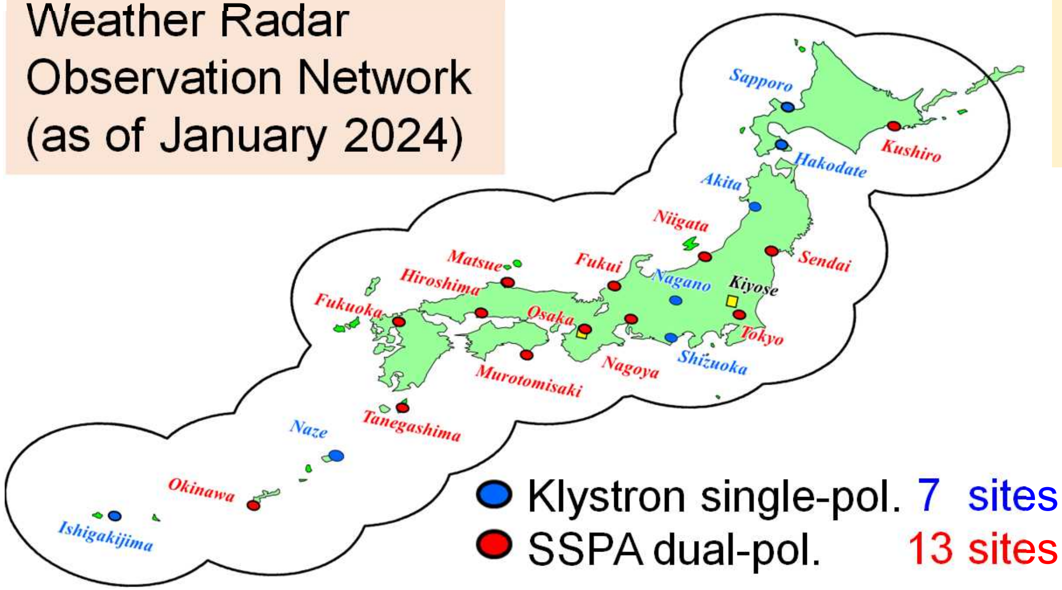
5. Summary

Dual-pol.

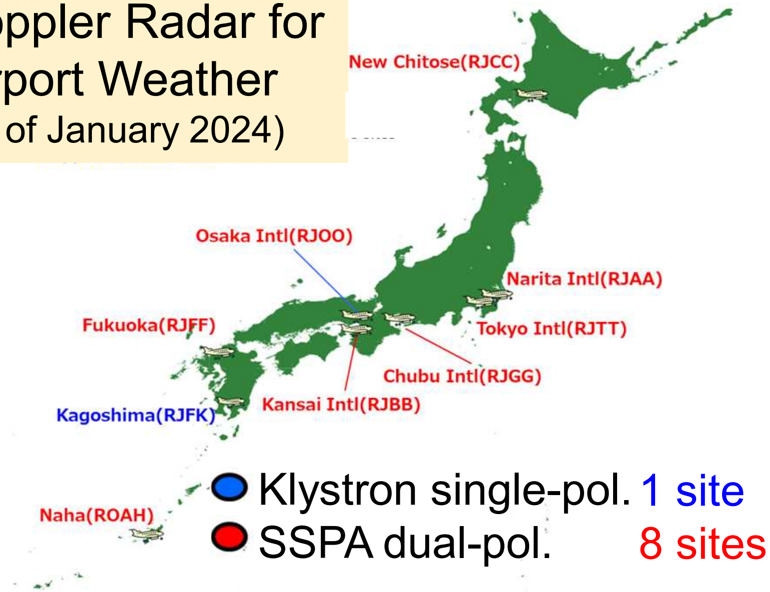
Weather radar in Japan

気象庁
Japan Meteorological Agency

Weather Radar Observation Network
(as of January 2024)



Doppler Radar for Airport Weather
(as of January 2024)

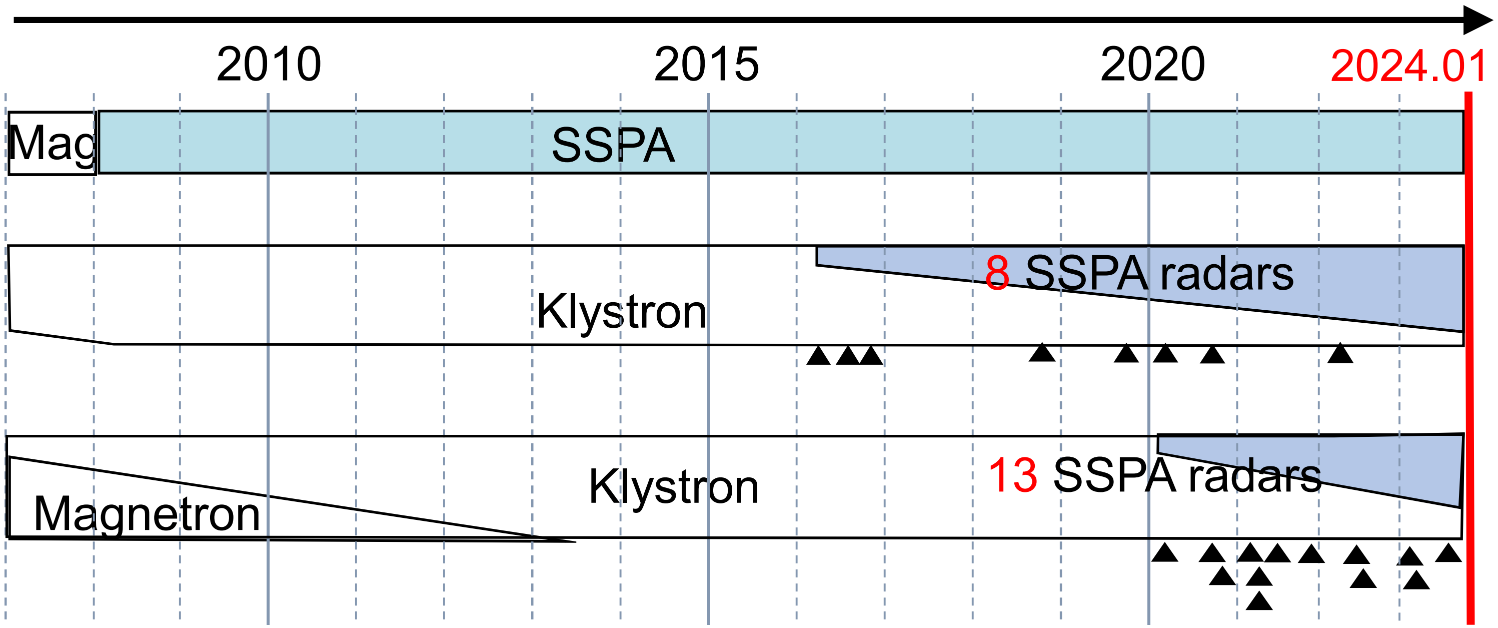


Chronology

C-band Prototype
(Meteorological Research Institute)

C-band TDWR
(total 9 radars)

C-band radar
(total 20 radars)



Use of short and long pulses in dual-pol.

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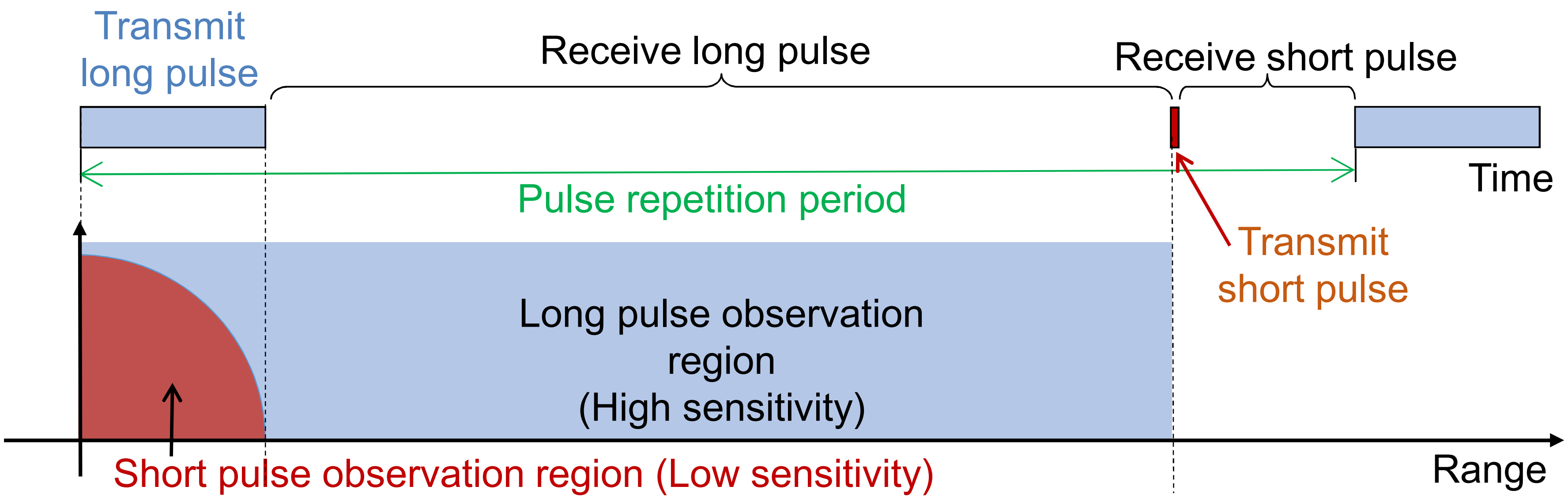
- Solid-state element transmitters are characterized by low peak power (3 - 5kW).
- Reception sensitivity for low peak power is limited.



- Nationwide radars use one short and three long pulses.
- Pulse compression provides sufficient reflectivity and high range resolution.
- Observation modes which observe narrower area use shorter long pulses.

Pulse	Pulse width
short	1μs
long	32, 64,128μs

Requirements for accurate calibration

<Accuracy requirements>

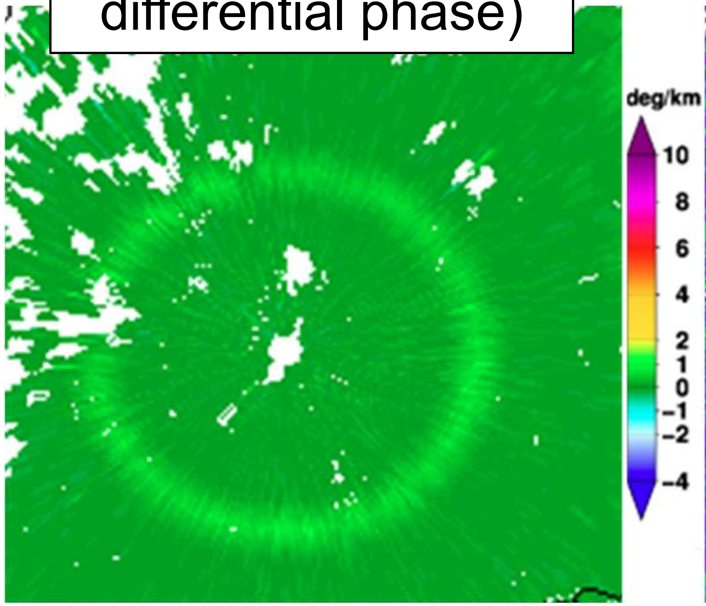
※WMO/Guide to Instruments and Methods of Observation (GIMO)
※NOAA/National Weather Service Radar Functional Requirements (2015)

- Reflectivity factor (Z) : ±1dB
- Differential reflectivity (Z_{DR}) : ±0.1～0.2dB

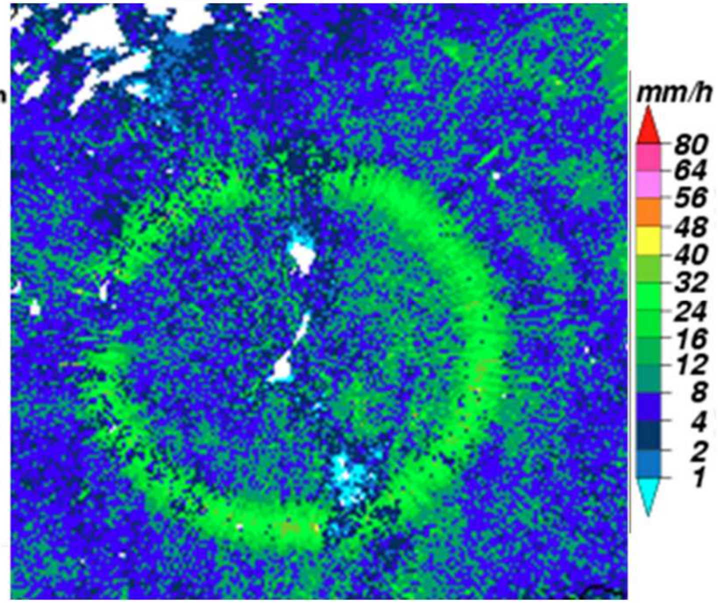
<Use of short and long pulses>

- Differential phase (Φ_{DP}) : Generation of the bias between short and long pulses

K_{DP} (Specific differential phase)



Precipitation intensity



Requirements for accurate calibration

	Single-pol.	Dual-pol. (Except SSPA)	SSPA dual-pol.	Notes
Z	○	○	○	
Z_{DR}	—	○	○	
Φ_{DP}	—	○	○	bias incurred between each polarization
	—	—	○	bias incurred in the boundary between short and long pulse region

○: Possibility of bias generation — : No potential for bias generation

Without polarimetric variable calibration…

- Inaccurate estimation of precipitation intensity
- Incorrect classification of precipitation type

- Z and Z_{DR} must be calibrated accurately.
- Φ_{DP} for short and long pulses must be calibrated accurately.

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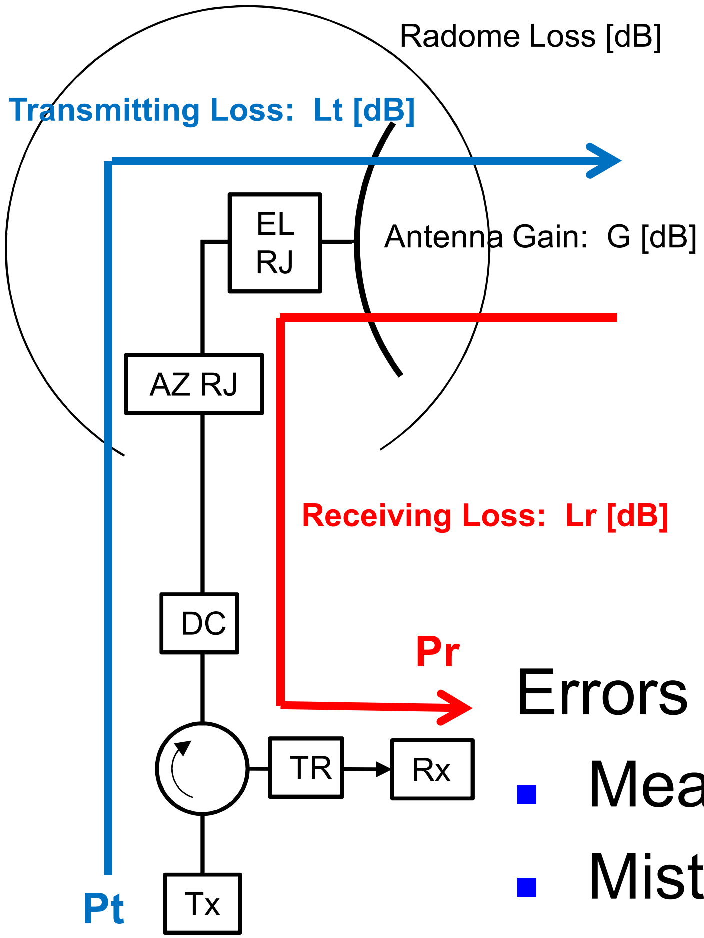
Single- and dual-pol.

Dual-pol.

Causes of Z bias



Radar equation

$$P_r = \frac{\pi^3 \cdot c}{2^{10} \log_e 2} \cdot \frac{P_t \cdot \tau \cdot G^2 \cdot Lt \cdot Lr \cdot \theta \cdot \phi}{\lambda^2} \cdot \frac{1}{r^2} \left| \frac{\varepsilon - 1}{\varepsilon + 2} \right|^2 Z$$

$$Z = \frac{2^{10} \log_e 2}{\pi^3 \cdot c} \cdot \boxed{\frac{\lambda^2}{P_t \cdot \tau \cdot G^2 \cdot Lt \cdot Lr \cdot \theta \cdot \phi}} \cdot r^2 \left| \frac{\varepsilon + 1}{\varepsilon - 2} \right|^2 \boxed{P_r}$$

Errors in hardware variables cause bias in Z.

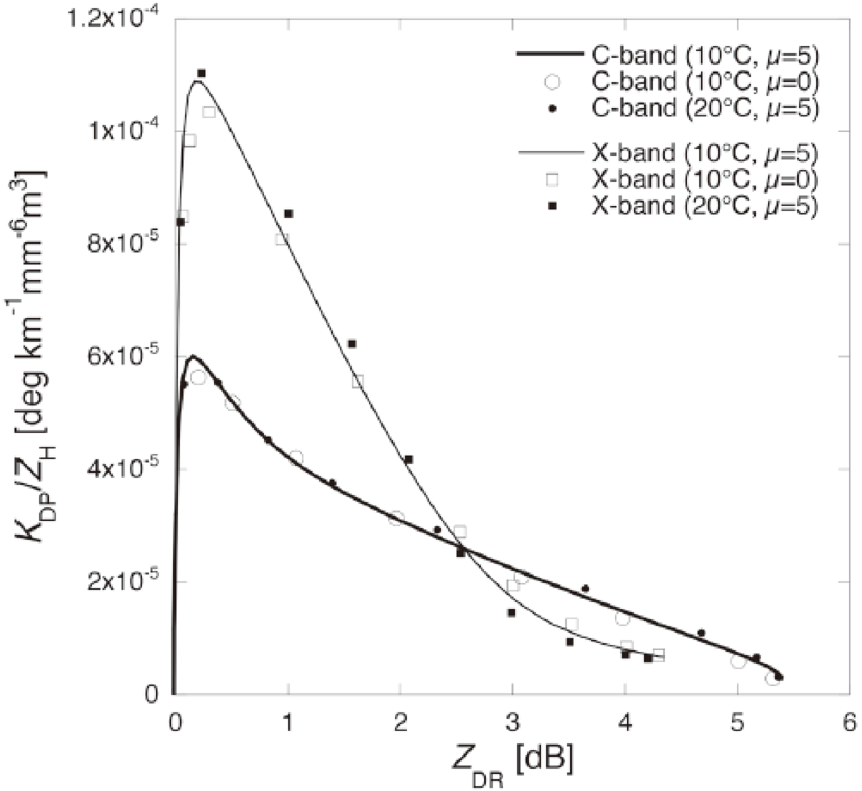
- Measurement errors of hardware variables
- Mistakes in setting of radar variables
- Changes with age

Calibration of Z is called “absolute calibration.”

Calibration of Z

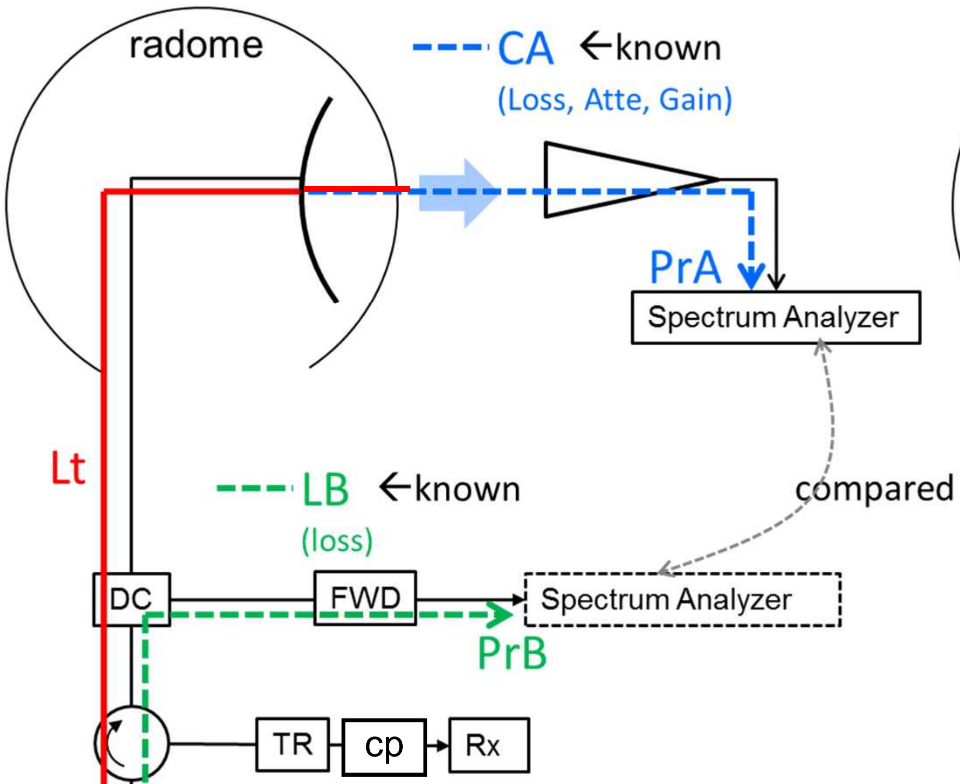
- Using metal sphere
- Using external receiver and transmitter
- Using disdrometer
- Using rain-gauges
- Self-consistency

Adachi et al. 2015: Estimation of Raindrop Size Distribution and Rainfall Rate from Polarimetric Radar Measurements at Attenuating Frequency Based on the Self-Consistency Principle



Using external receiver and transmitter

①Measurement of transmitting loss



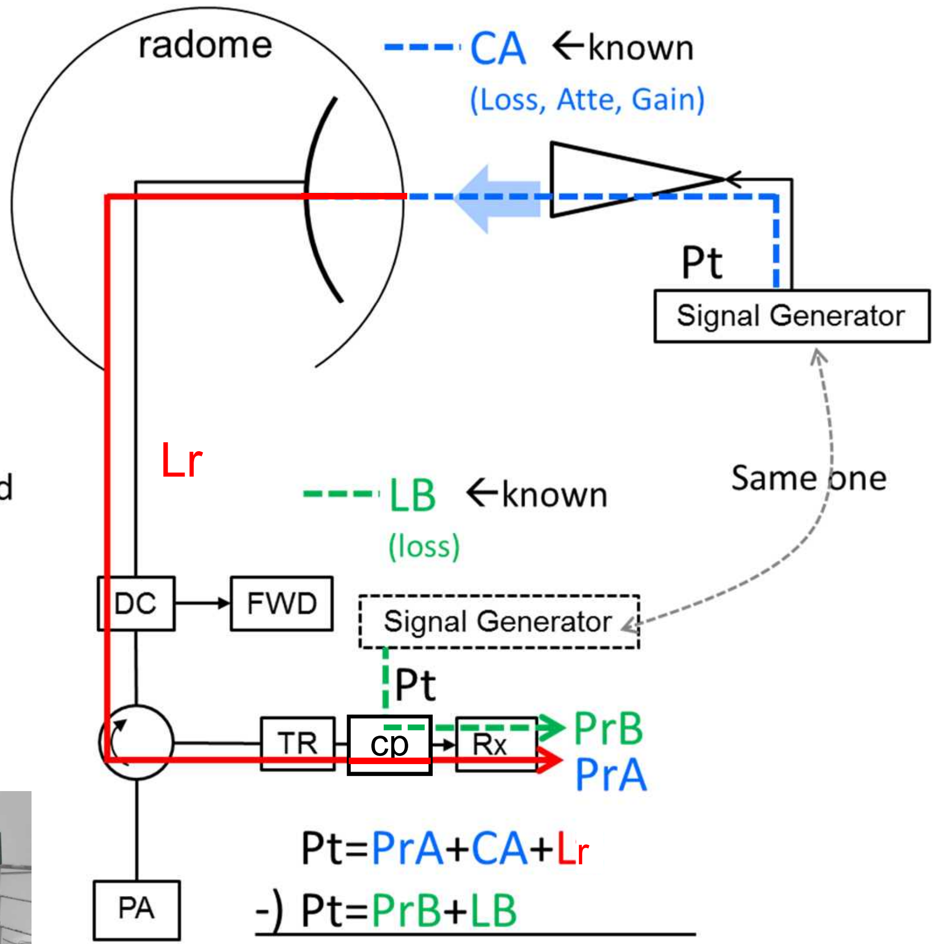
Pt=PrA+CA+Lt

-) Pt=PrB+LB

Lt=-PrA+PrB-CA+LB

known / measurable

②Measurement of receiving loss



Pt=PrA+CA+Lr

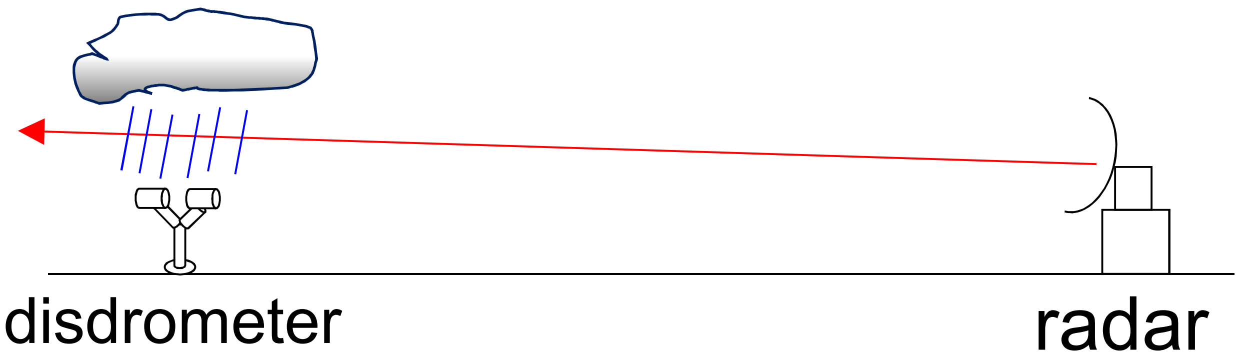
-) Pt=PrB+LB

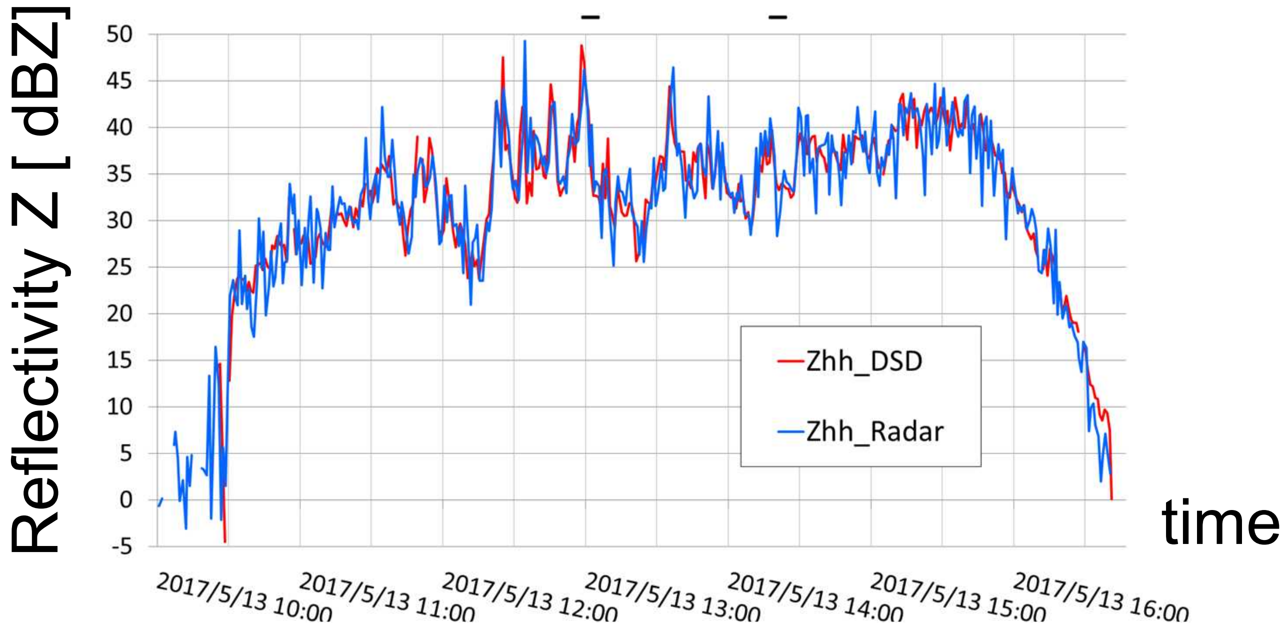
Lr=-PrA+PrB-CA+LB

known / measurable

Using disdrometer

Both radar and disdrometer observe Z.

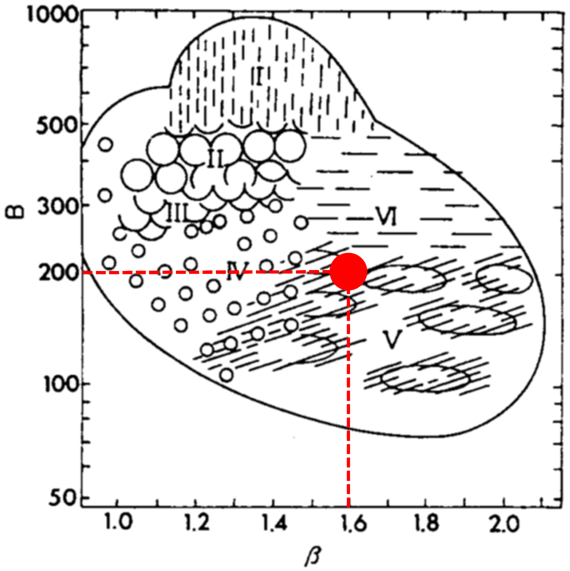




Courtesy of Mr. Umehara

Using rain-gauges

- Assuming Z-R relation (B, β)
- Bias derived as a ratio between accumulative rain-amount observed by rain-gauges and that estimated by radar



Z-R relation

$$Z = BR^{\beta}$$

$$R = \left(\frac{Z}{B}\right)^{\frac{1}{\beta}}$$

Bias

$$A = \frac{\frac{1}{N}\sum_{i=1}^{N}\mathcal{G}_i}{\frac{1}{N}\sum_{i=1}^{N}\mathcal{R}_i}$$

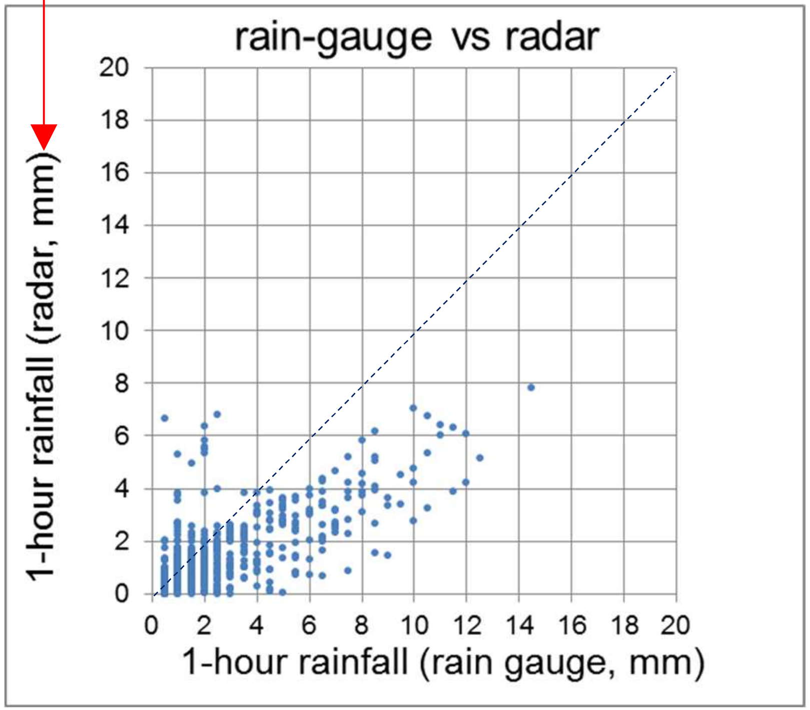
Bias correction

$$Z_{corr} = A^{\beta} Z$$

Steiner et al, 1999: Effect of bias adjustment and rain gauge data quality control on radar rain fall estimation. *Water Resour. Res.*, 35, 2487-2503.

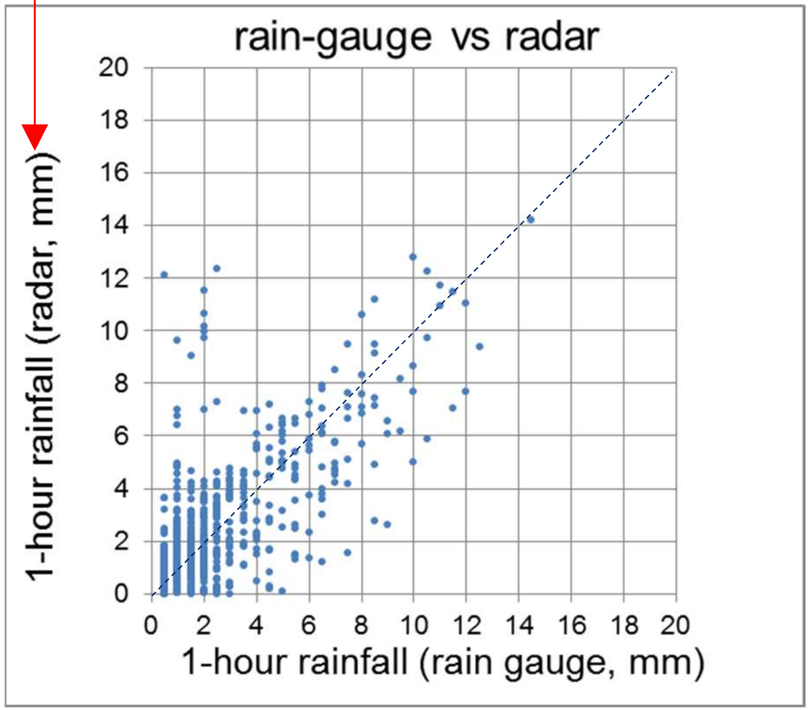
Using rain-gauges

$$R = \left(\frac{Z}{B}\right)^{\frac{1}{\beta}}$$



After correction

$$R = \left(\frac{Z_{corr}}{B}\right)^{\frac{1}{\beta}}$$

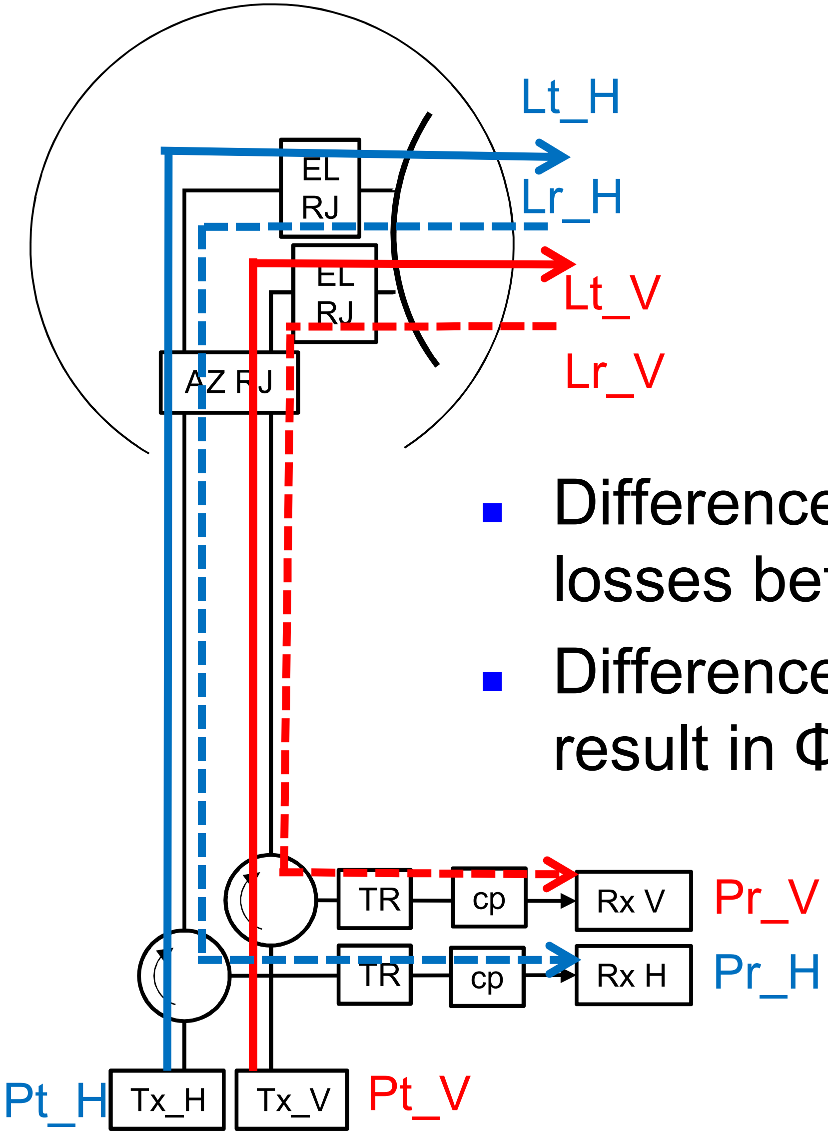


Contents

Single- and dual-pol.

Dual-pol.

Causes of Z_{DR} and Φ_{DP} bias



- Difference of Tx power, Rx sensitivity, losses between H and V result in Z_{DR} bias.
- Difference of path length between H and V result in Φ_{DP} bias.

Contents

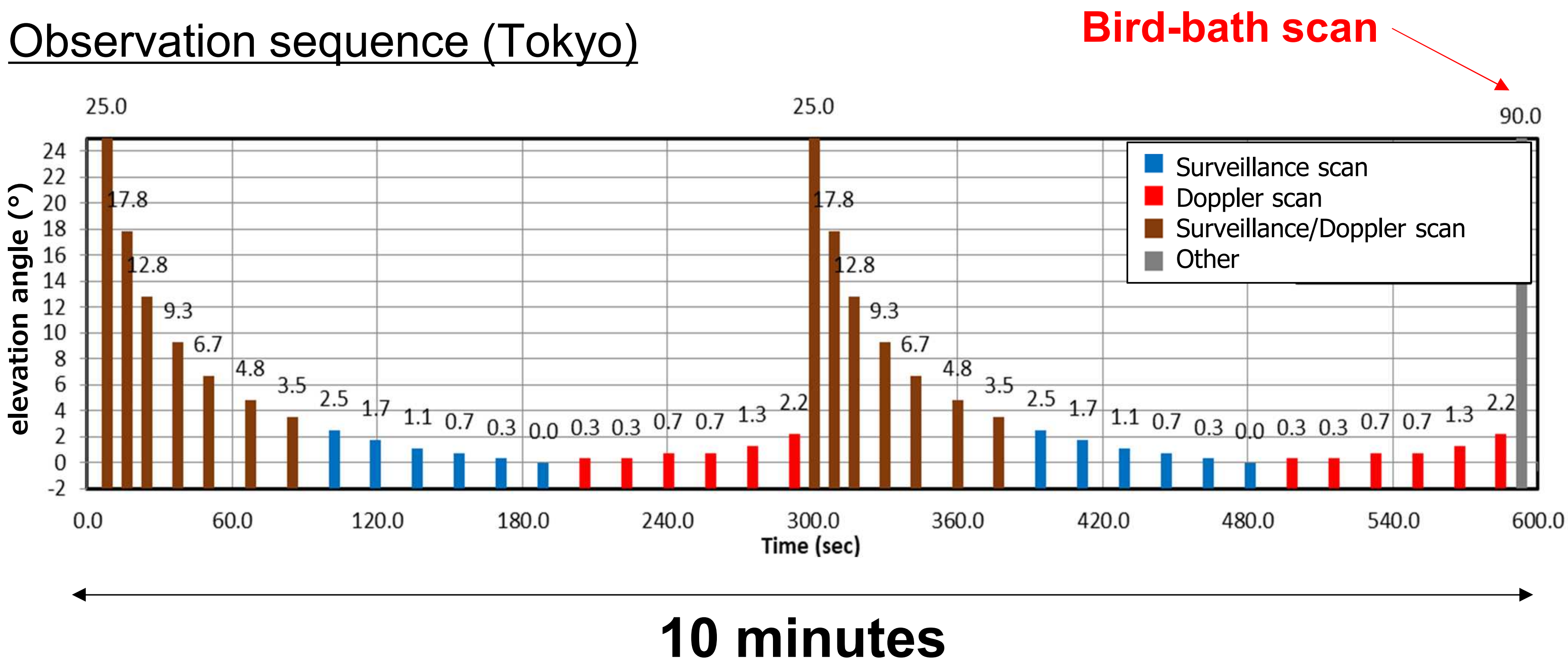
Single- and dual-pol.

Dual-pol.

Observation sequence in dual-pol.

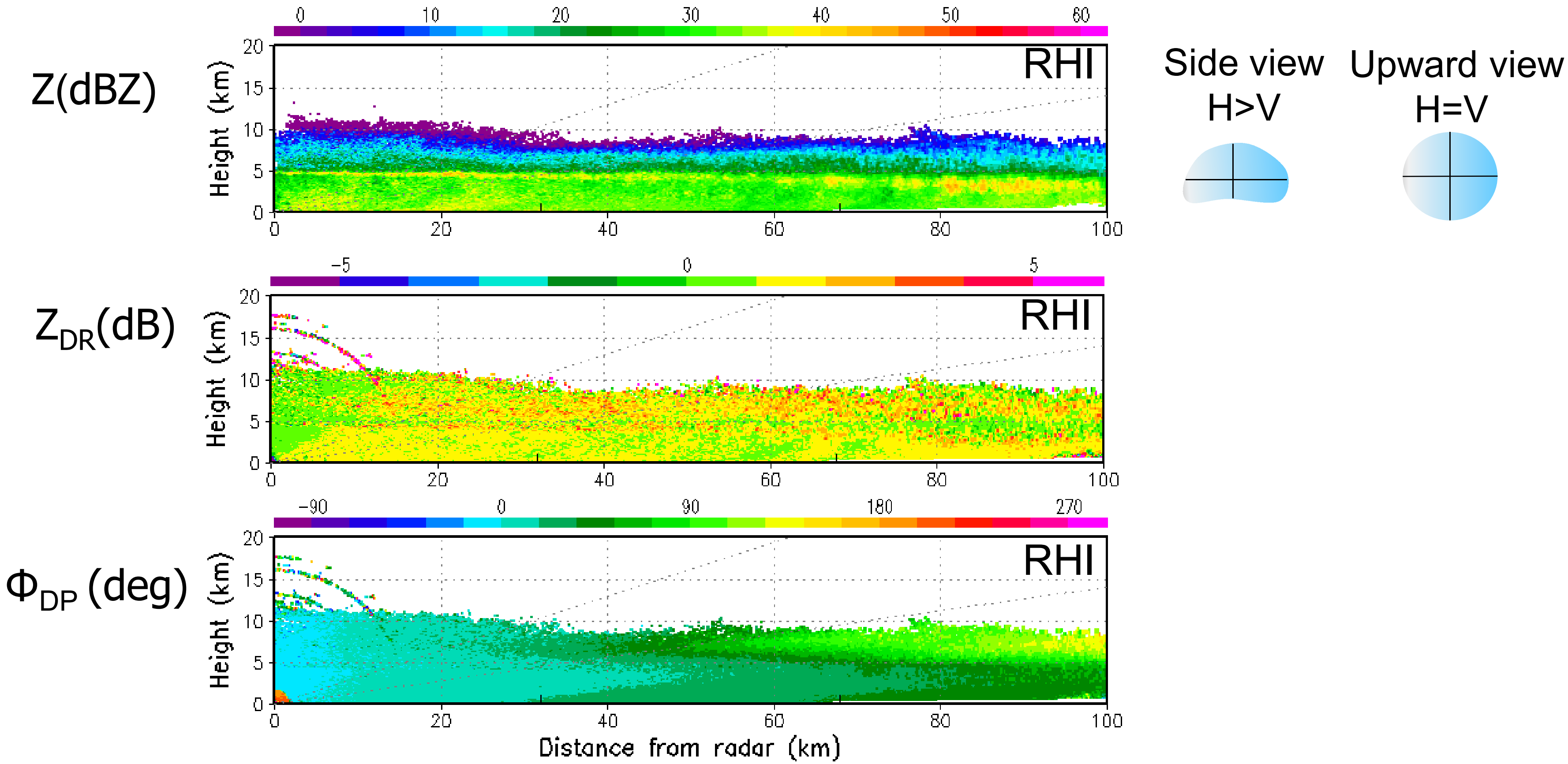
- Bird-bath scan at all radars every 10 minutes
- Bird-bath scan is suitable for polarimetric variables monitoring and calibration.

Observation sequence (Tokyo)



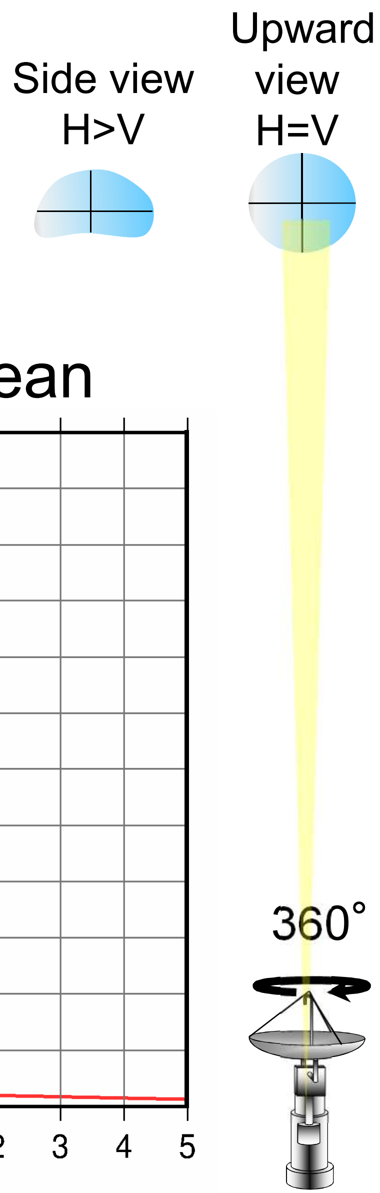
Bird-bath scan

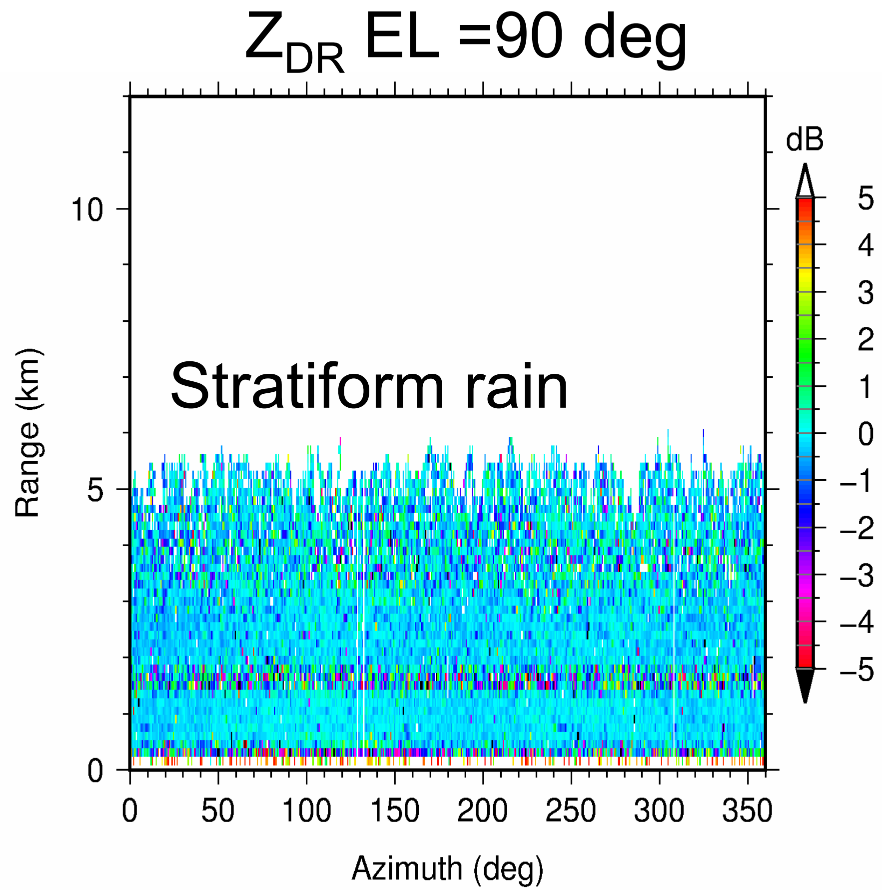
- From upward view, even a large rain drop looks circle.

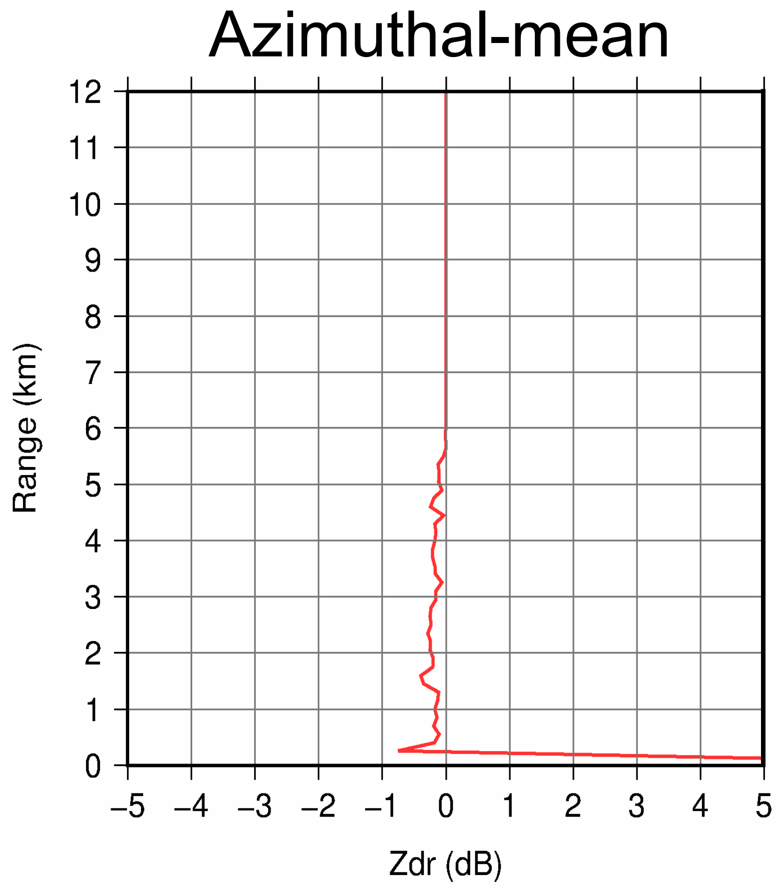


Bird-bath scan

- Be useful in estimating Z_{DR} bias and Φ_{DP} bias.
- Z_{DR} and Φ_{DP} must be zero.







Using data from low elevation scan

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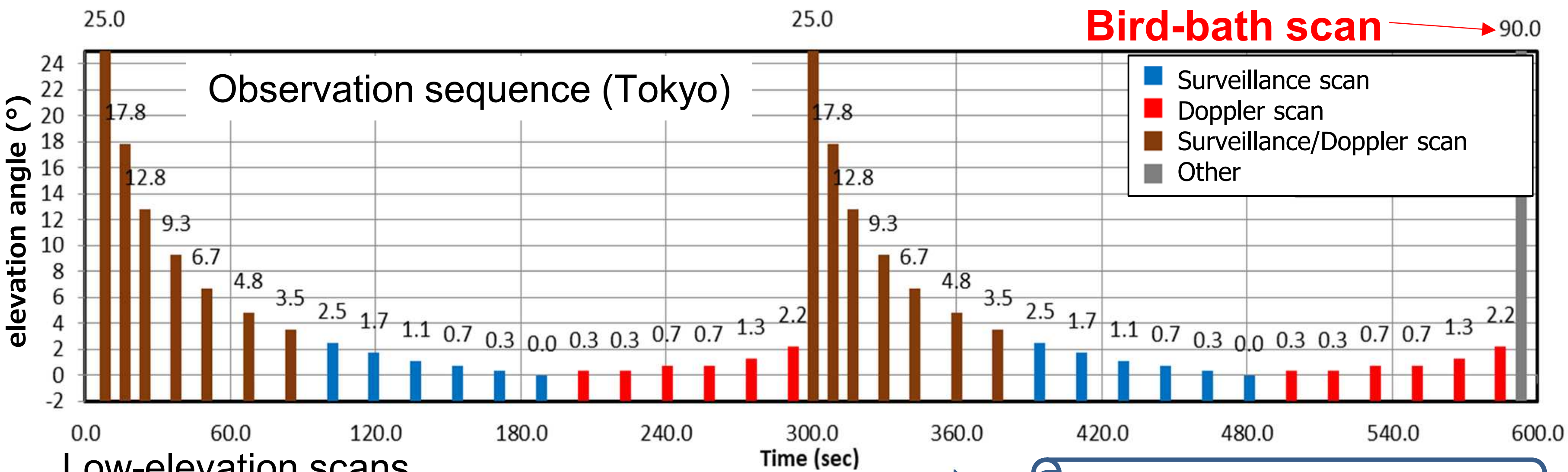
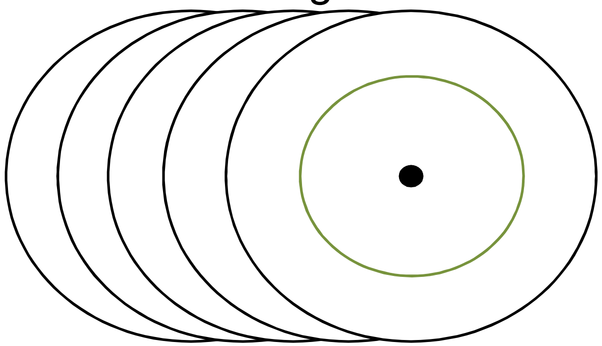
- Bird-bath scans at all radars only every 10 minutes
- Use of data from low-elevation scans due to difficulty of long pulses monitoring with bird-bath scans



Low-elevation scans
(Elevation angle:∼0.7°)



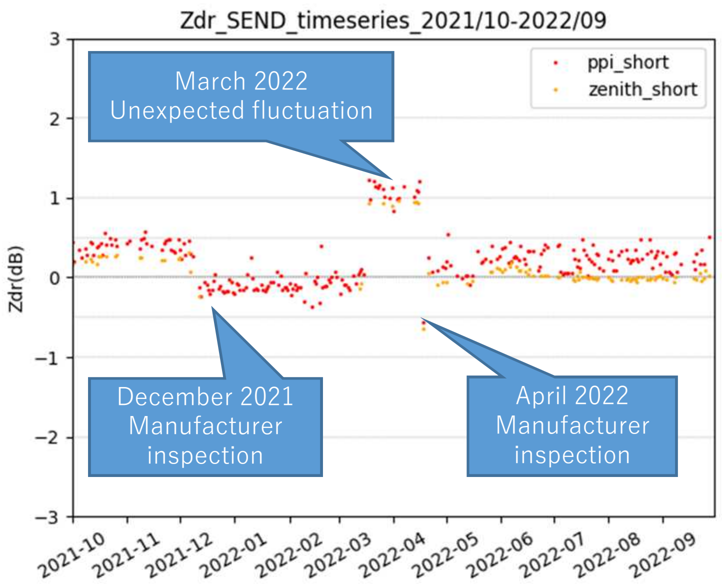
Data extraction condition (light rain)

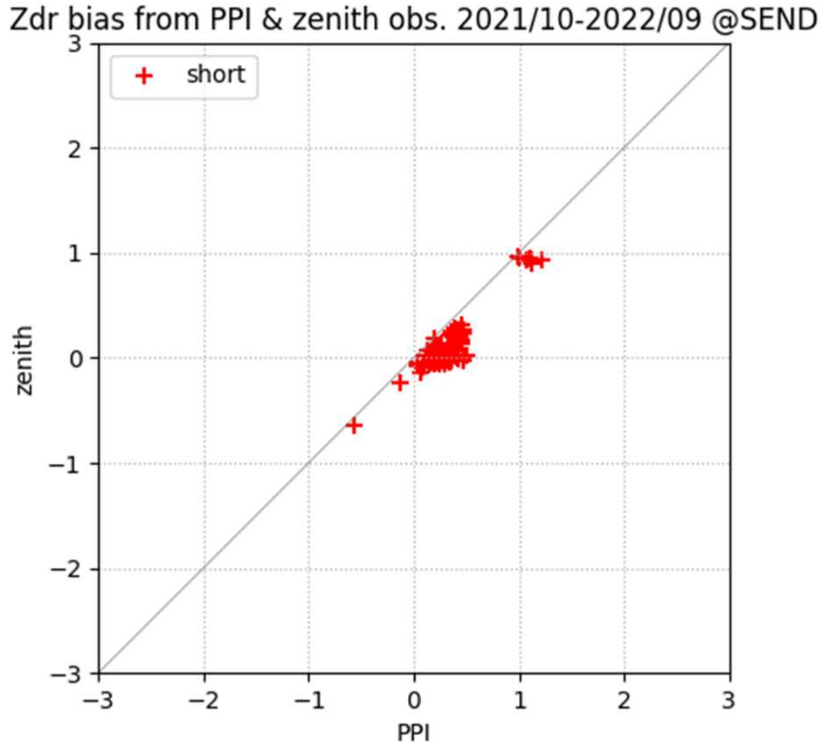
$|Z_{DR}| < 5.0$
$0.99 < \rho_{HV} <= 1.0$
$10.0 < Z_H < 15.0$
$|S(Z_{DR})| < 0.3$
$|S(\rho_{HV})| < 0.01$

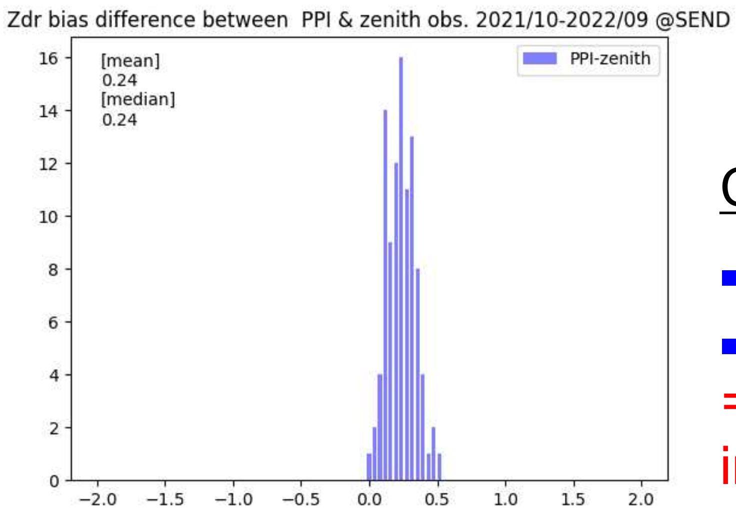
<u>Calculation for individual pulse regions</u>

- Average
- Standard deviation
- Valid data count

(Hotta et al., 2nd WXRCalMon 2019)







<u>Comparison of short pulse region daily average</u>

- Z_{DR}: 0.24 dB (low-elevation ＞ bird-bath)
- Consistent Z_{DR} fluctuation trend

⇒ It is possible to use low-elevation scans data in addition to bird-bath scans data

Bias monitoring tool development

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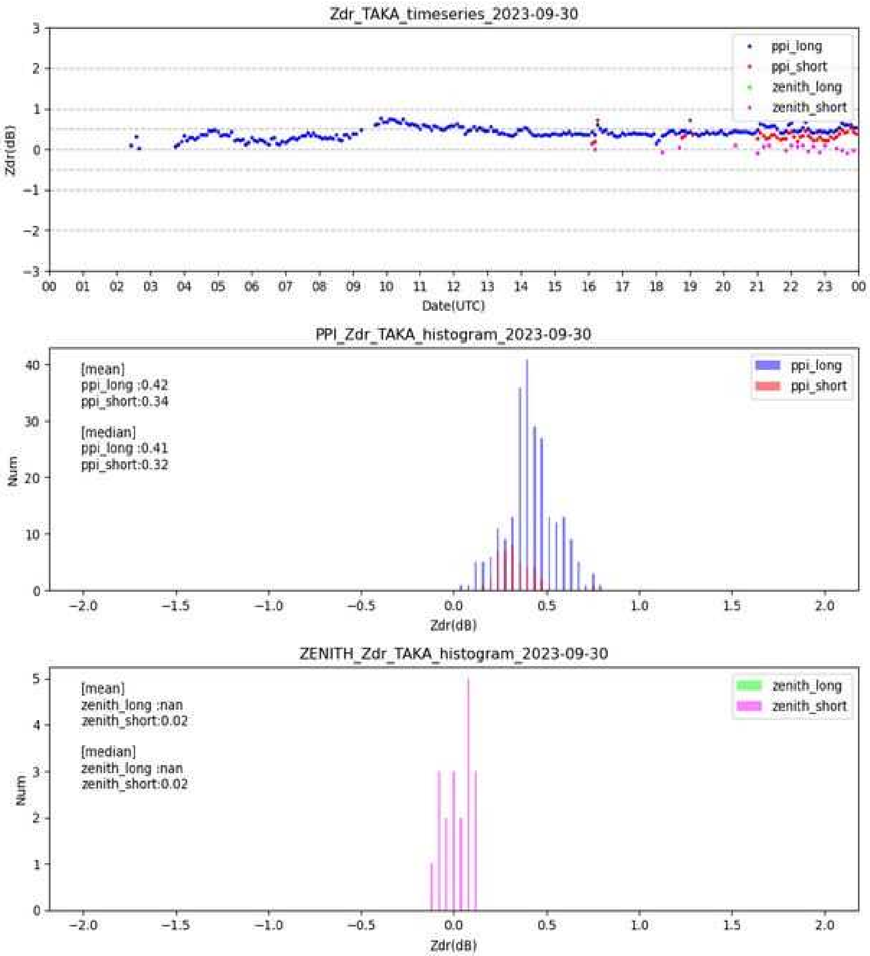
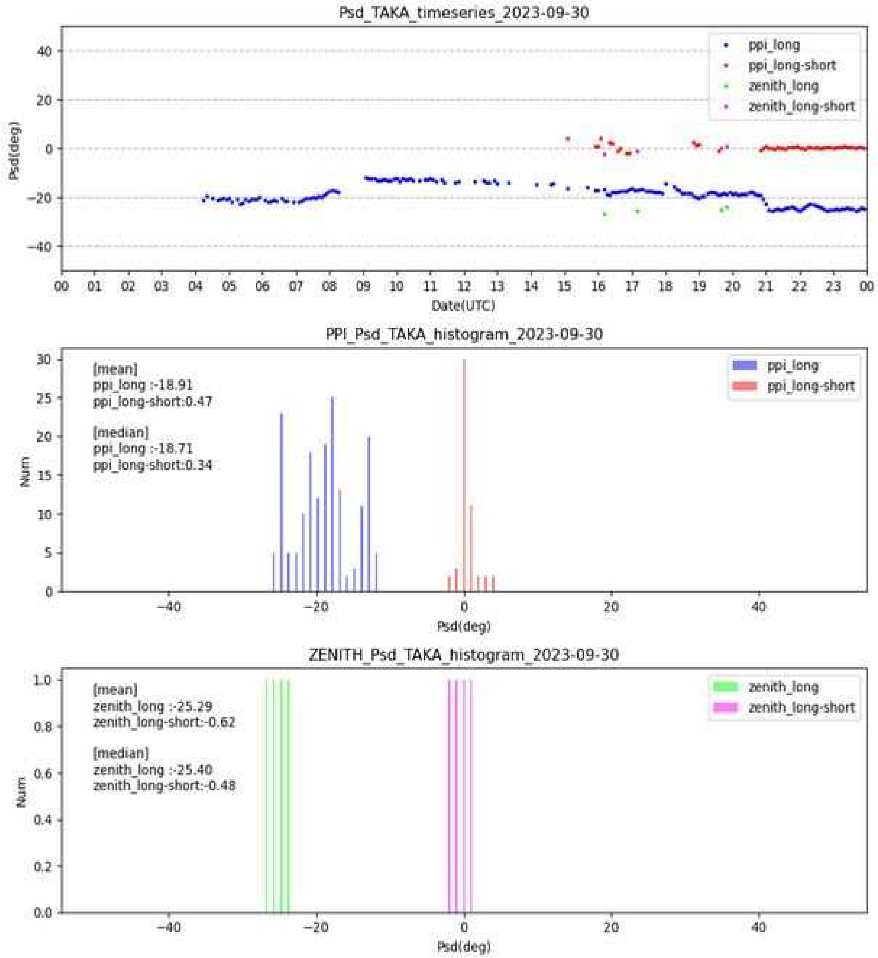
Japan Meteorological Agency

Z_{DR}



Φ_{DP}



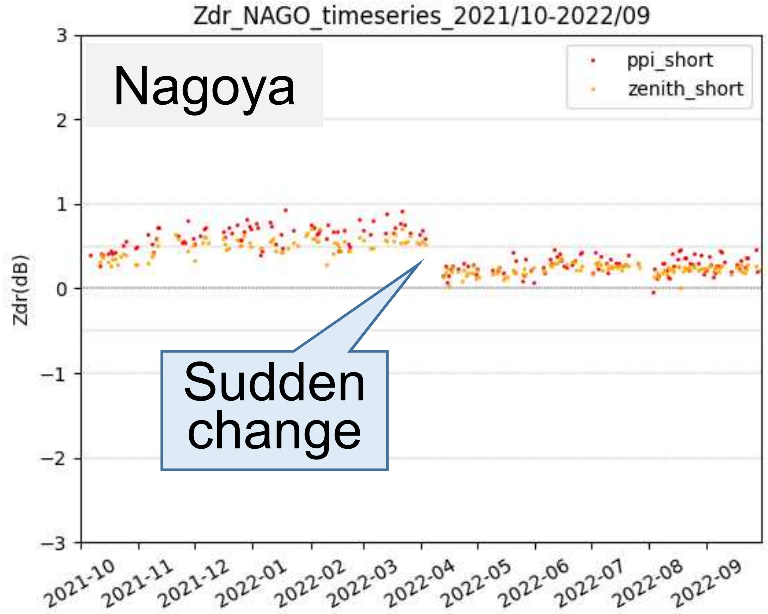
- Monitoring of Z_{DR} and Φ_{DP} in bird-bath and low-elevation scans
- Capacity for checking of daily and monthly time-series representations

Bias monitoring tool development

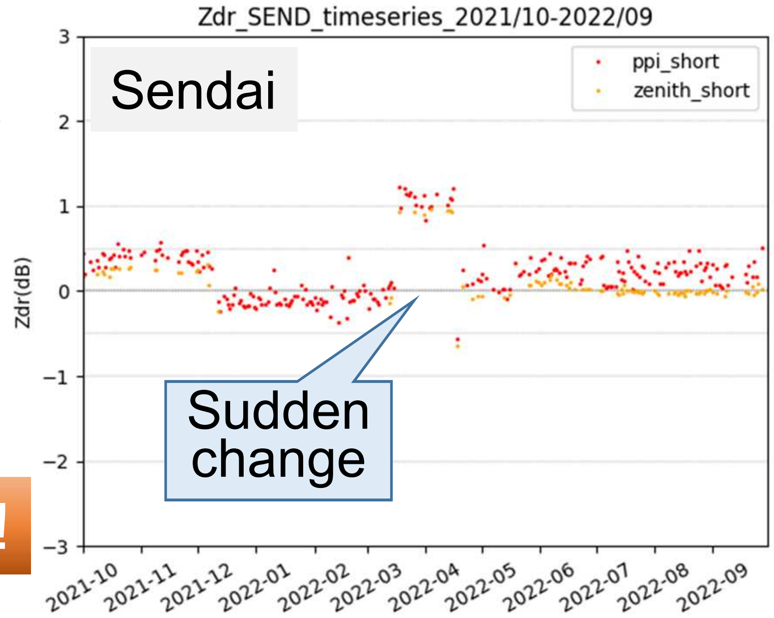
気象庁 Japan Meteorological Agency

- Bias monitoring tool for weather radar is under development partly.
- We can find the Z_{DR} changed later.
- Finding the cause is difficult.

Note: Sudden change at Nagoya site may be caused by manufacturer's maintenance.



- Cause of Z_{DR} change at Sendai site is unknown.



Real time monitoring is very important!

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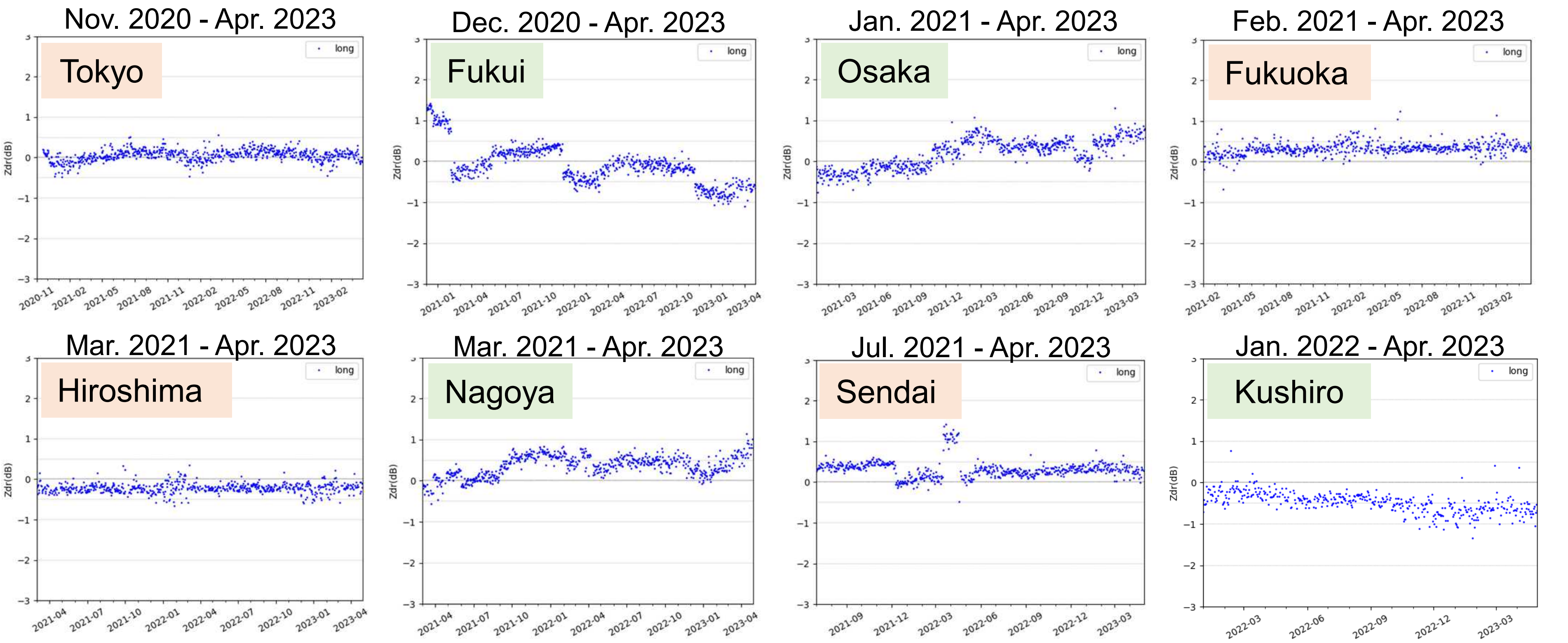
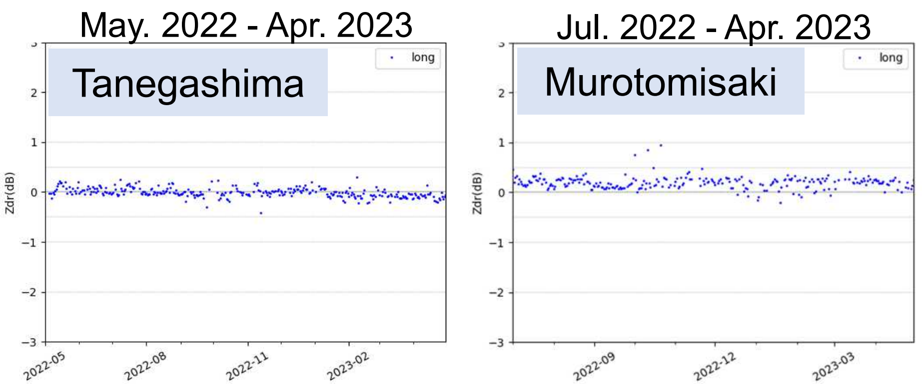
Single- and dual-pol.

Dual-pol.

Long-term Z_{DR} bias trend (low-elevation scans)





Manufacturer 1 | Manufacturer 2 | Manufacturer 3

- Long-term Z_{DR} fluctuation in all radars
- Manufacturer-centric differences in Z_{DR} bias

Cyclically changed Z_{DR} in bird-bath scans

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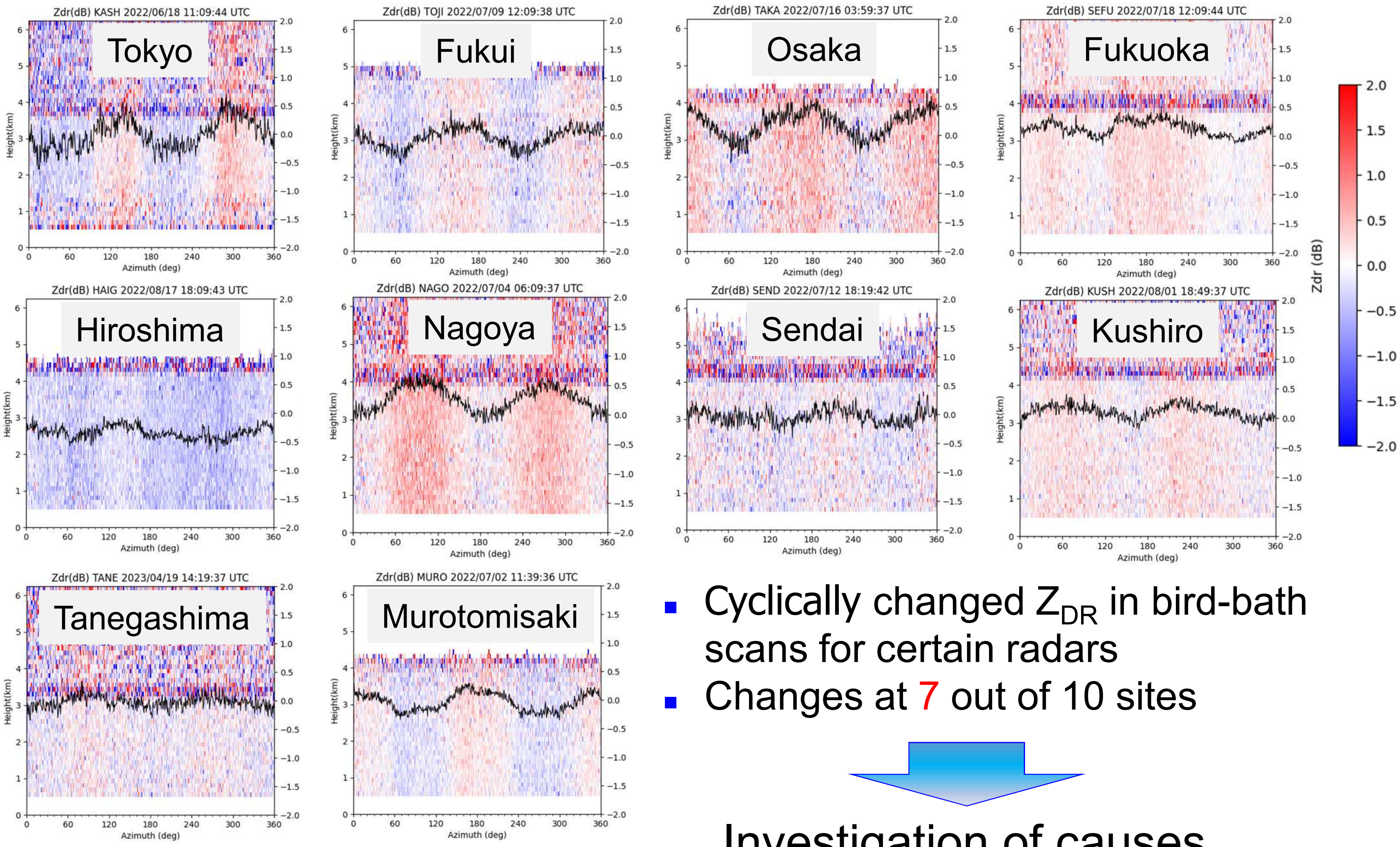

- Cyclically changed Z_{DR} in bird-bath scans for certain radars
- Changes at 7 out of 10 sites

Investigation of causes

Investigating causes of Z_{DR} bias

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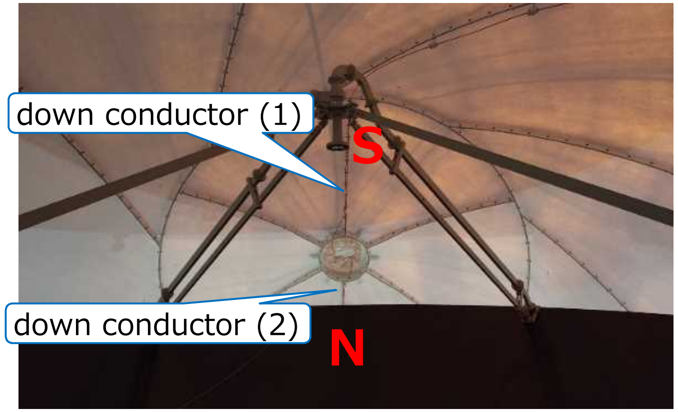
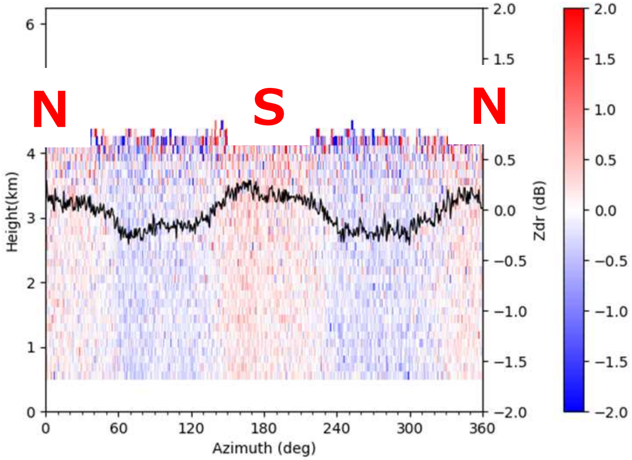
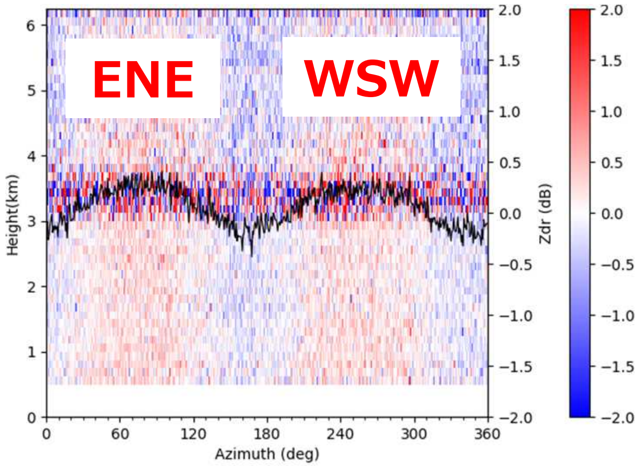
① Down conductors (Murotomisaki)

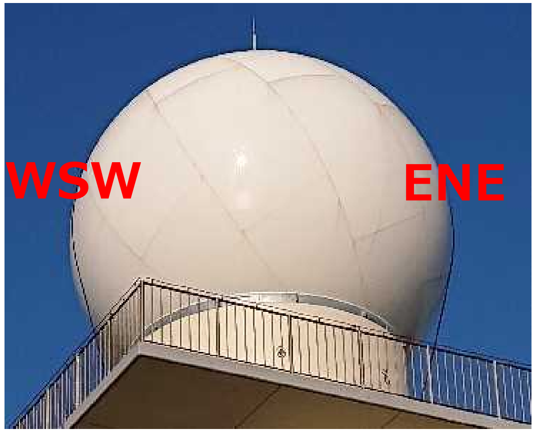


Note: South-facing antenna



② Maintenance ropes (Kushiro)





Do the directions match?

① Positive bias of Z_{DR} ≒ Down conductors

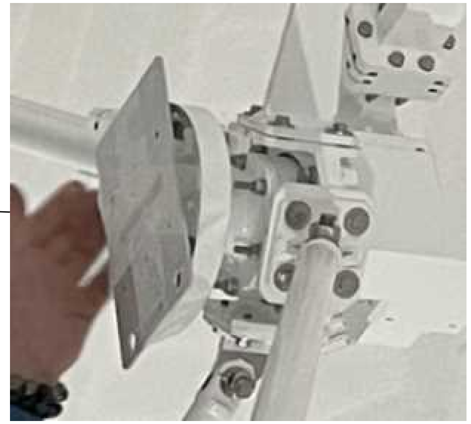
② Positive bias of Z_{DR} ≒ Maintenance ropes

Investigating causes of Z_{DR} bias

③ Rotary Joint (R/J) (Tokyo)

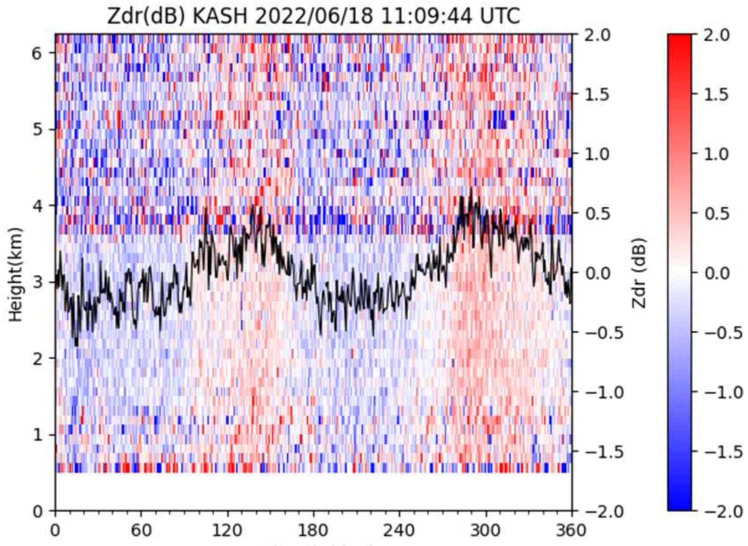
<Investigation method>

1. Attachment of iron plate on the reflector
2. Set of elevation angle: 90 degrees
3. Rotation of antenna like bird-bath scans
4. Z_{DR} displayed by Signal Processor software

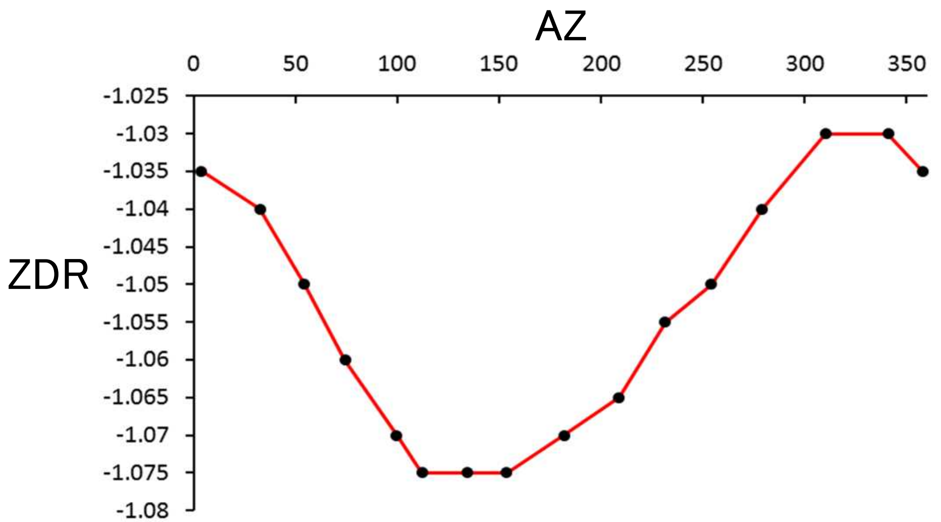


Note: No maintenance ropes on the surface of radome panels in Tokyo radar.

Wave number: 2



Wave number: 1



- R/J is unlikely to affect cyclic Z_{DR} bias.
- We should investigate causes in other radars about ① and ②.

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Single- and dual-pol.

Dual-pol.

Φ_{DP} bias generation

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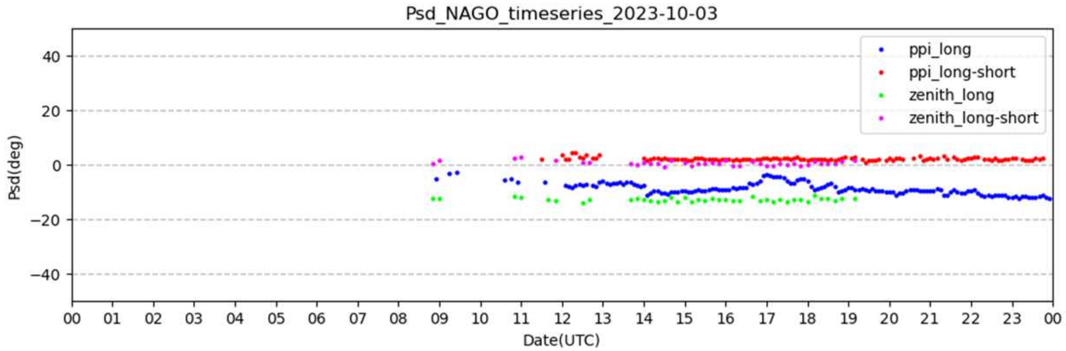
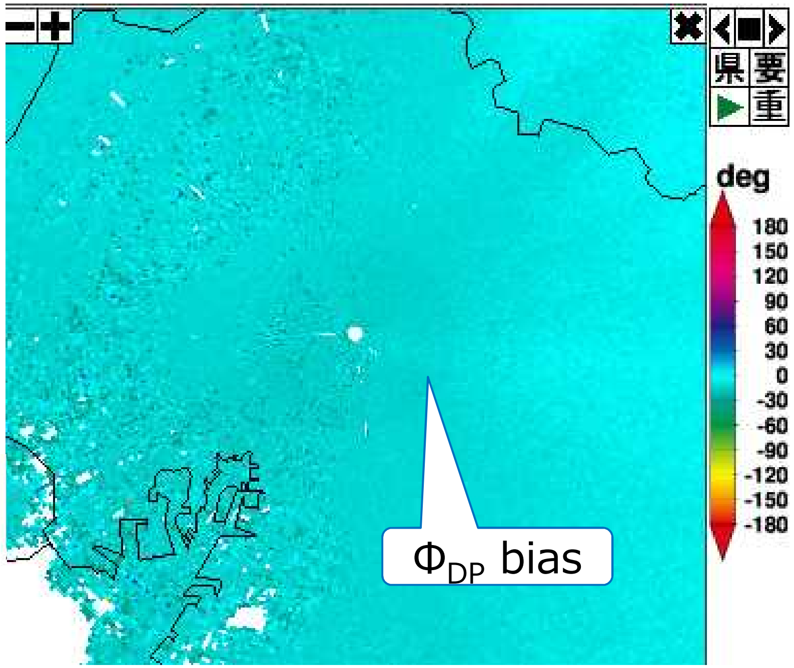
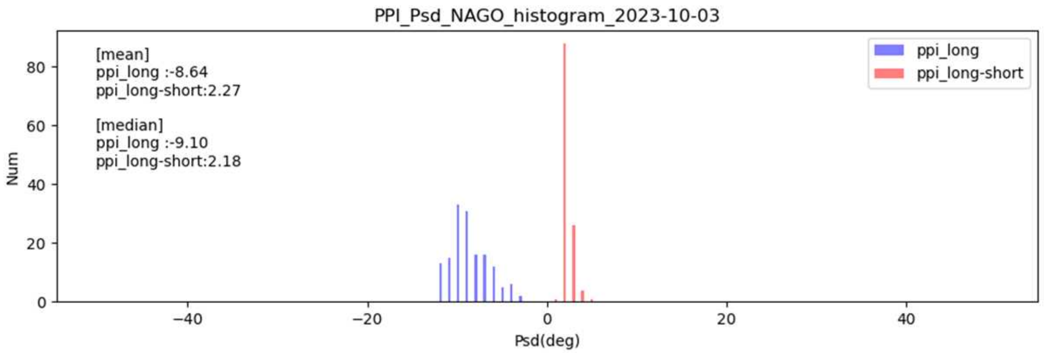
Time series of Φ_{DP} for a day



Distribution of Φ_{DP}



Histogram of Φ_{DP} for a day



Using the bias monitoring tool

- Φ_{DP} step between short and long pulses: approx. 2 degrees
- Negative Φ_{DP} bias with long pulses: approx. 10 degrees

Φ_{DP} bias adjustment by JMA staff

気象庁 Japan Meteorological Agency

- GUI-based adjustment of variable in the radar system
- Possible to change variables for in-service operation

信号処理パラメータ 編集

信号処理パラメータファイル名

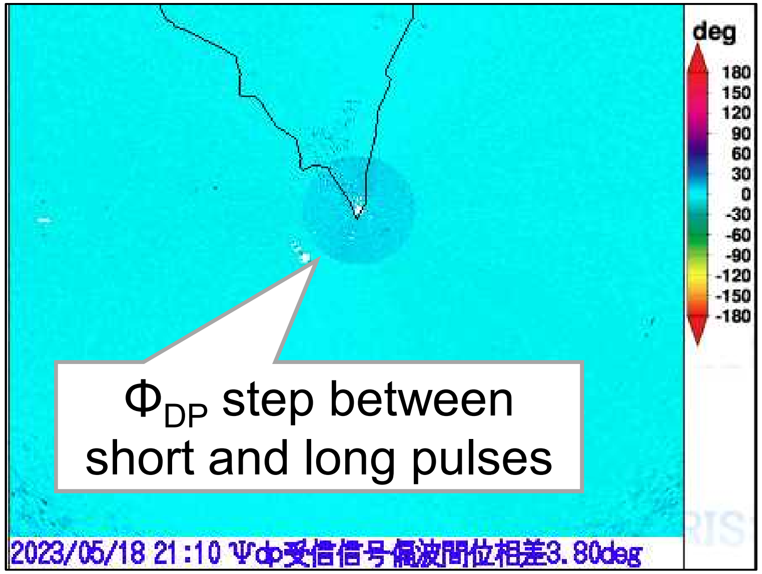
PrmSp_330_330.ini　ファイル名変更

制御項目

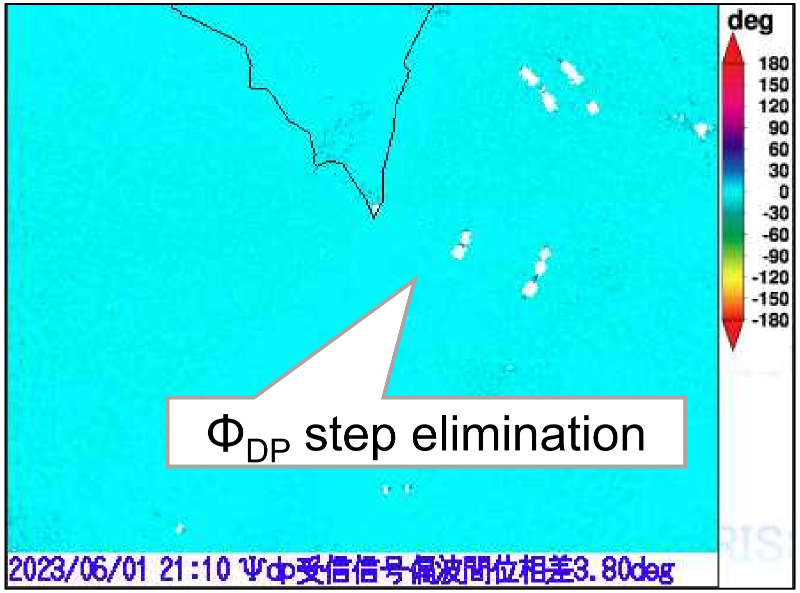
DSP処理解析　位相補正

項目	値	データ内容
パイロット補正 ON/OFF	0	0 : OFF 1 : ON
パイロット補正 基準値(High)	0.00	-360.00～360.00[deg]
パイロット補正 基準値(Low)	0.00	-360.00～360.00[deg]
パイロット補正 許容差(High)	360.00	0.00～360.00[deg]
パイロット補正 許容差(Low)	360.00	0.00～360.00[deg]
段差補正 ON/OFF	1	0 : OFF 1 : ON
段差補正量(短-High)	94.05	-360.00～360.00[deg]
段差補正量(短-Low)	101.33	-360.00～360.00[deg]
段差補正量(長-Low)	100.15	-360.00～360.00[deg]

Before adjustment (Φ_{DP})



After adjustment (Φ_{DP})



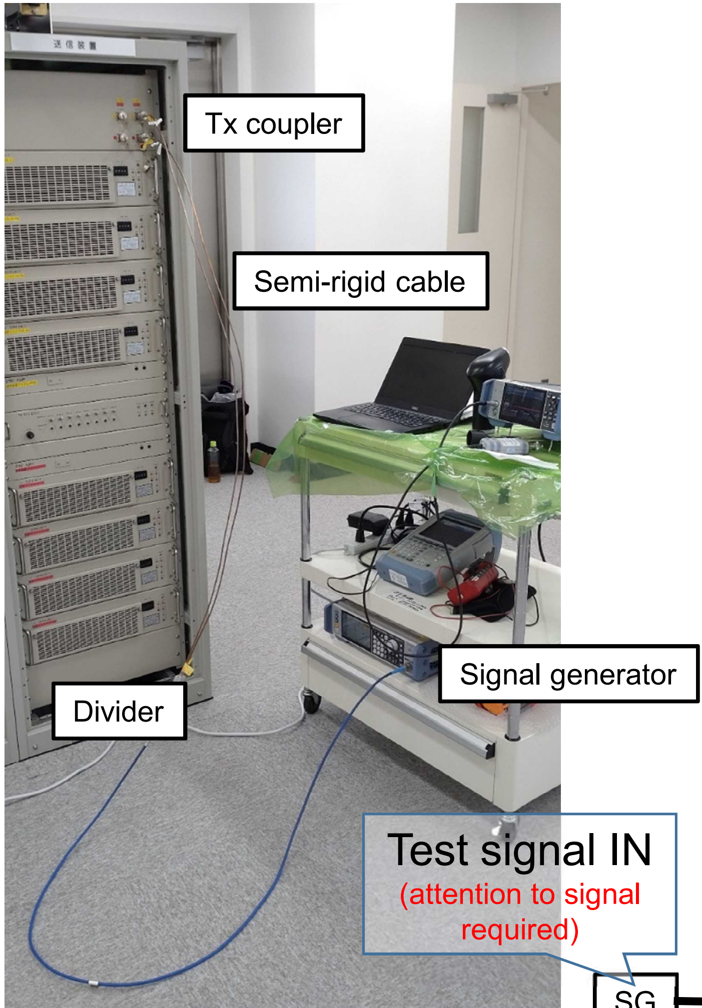
Instant polarimetric variable calibration is important for accurate observation.

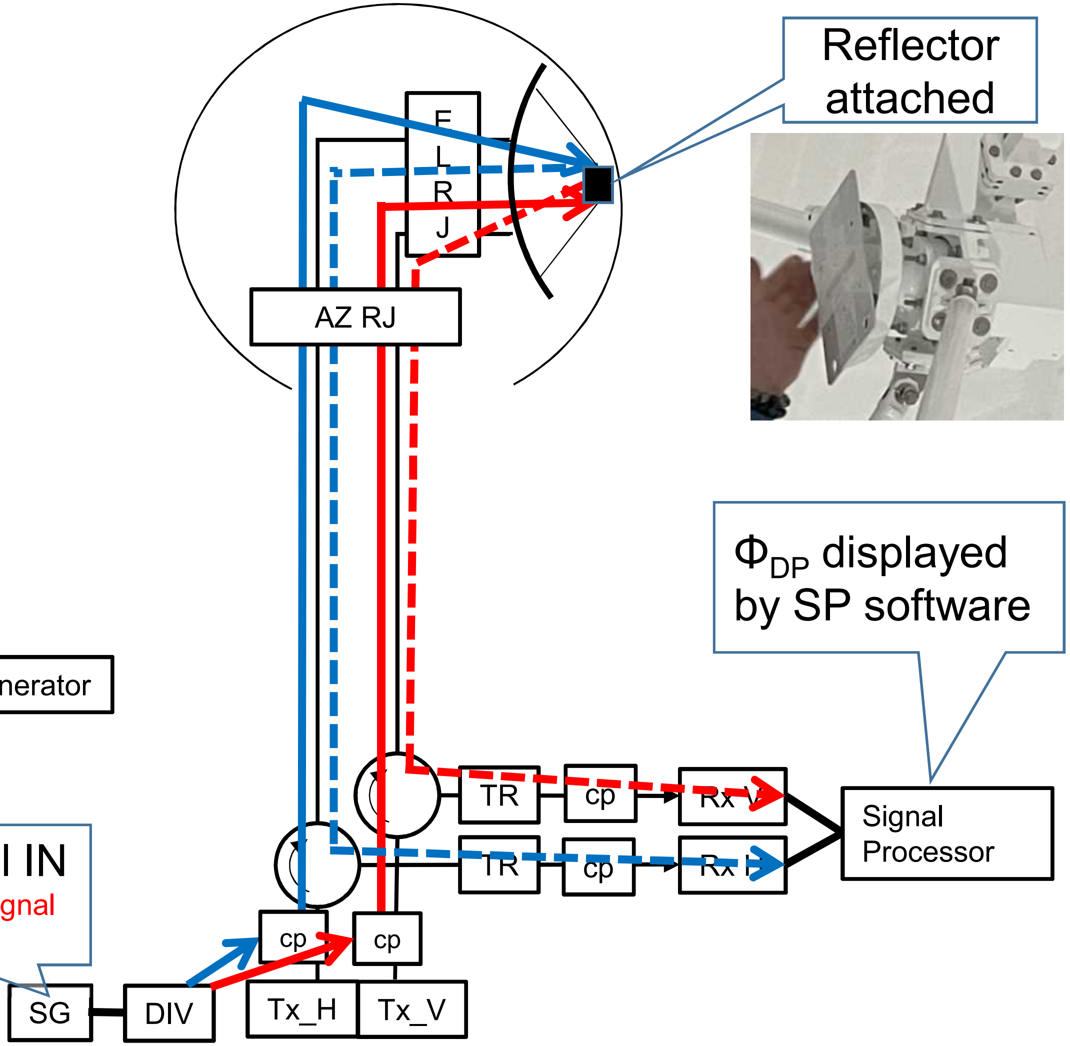
Φ_{DP} inspection by manufacturer

Φ_{DP} is checked semiannually by manufacturer for inspection.

When Φ_{DP} bias is confirmed, manufacturer investigates the cause.

First Φ_{DP} measurement



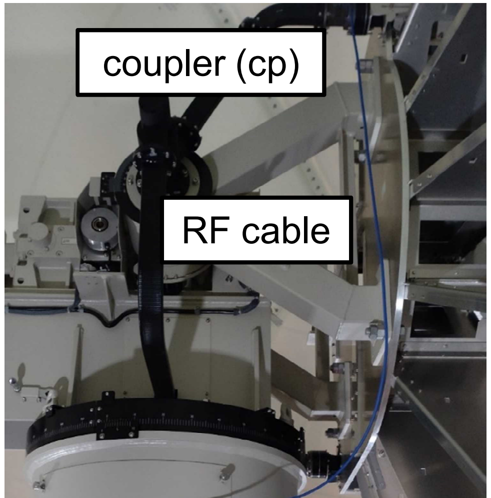


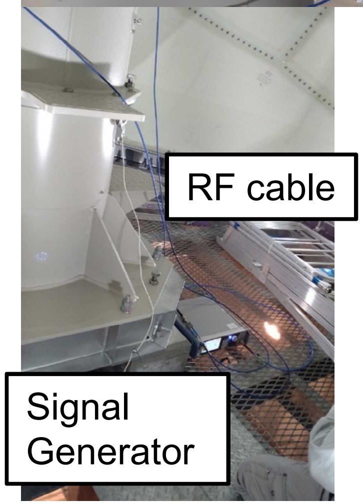
Φ_{DP} inspection by manufacturer

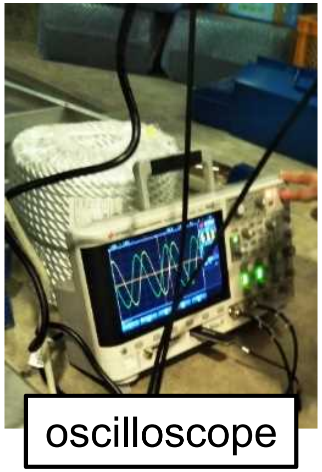
Φ_{DP} is checked semiannually by manufacturer for inspection.

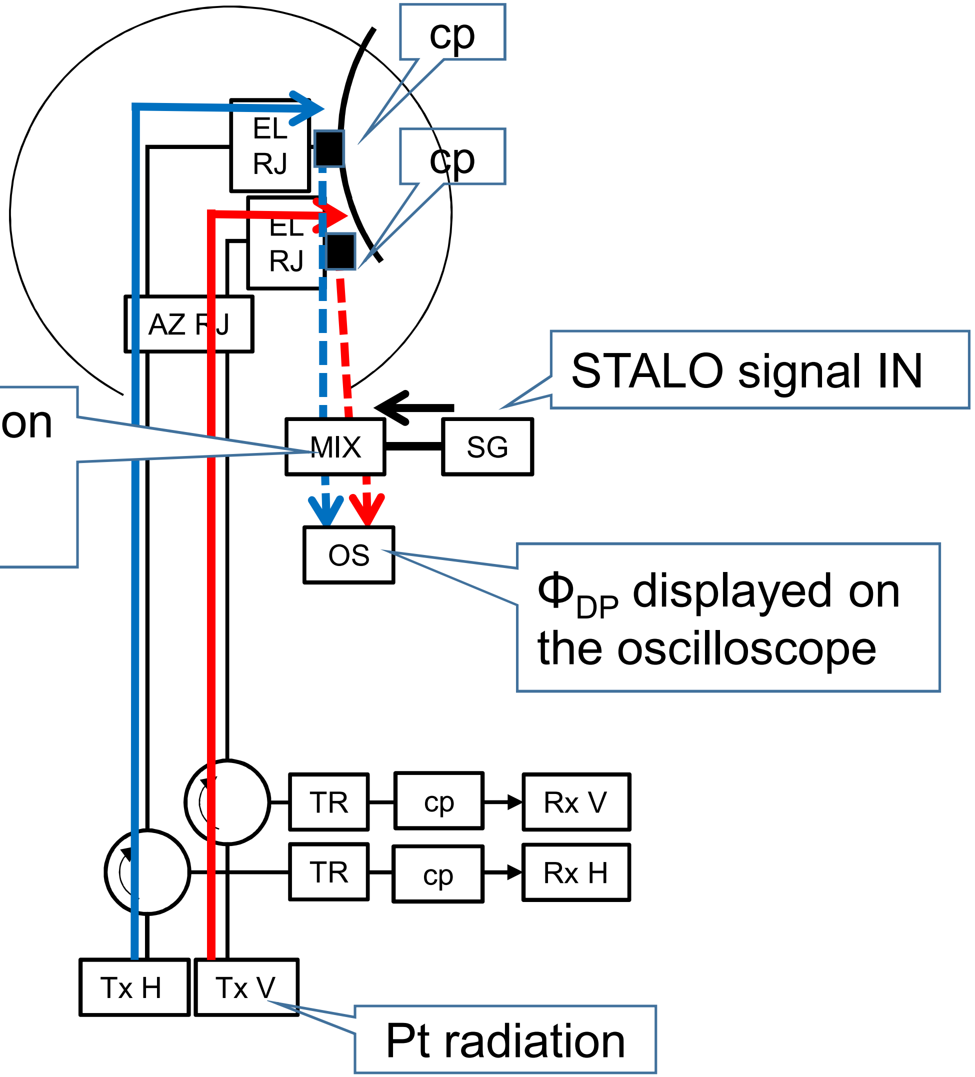
When Φ_{DP} bias is confirmed, manufacturer investigates the cause.

Second Φ_{DP} measurement







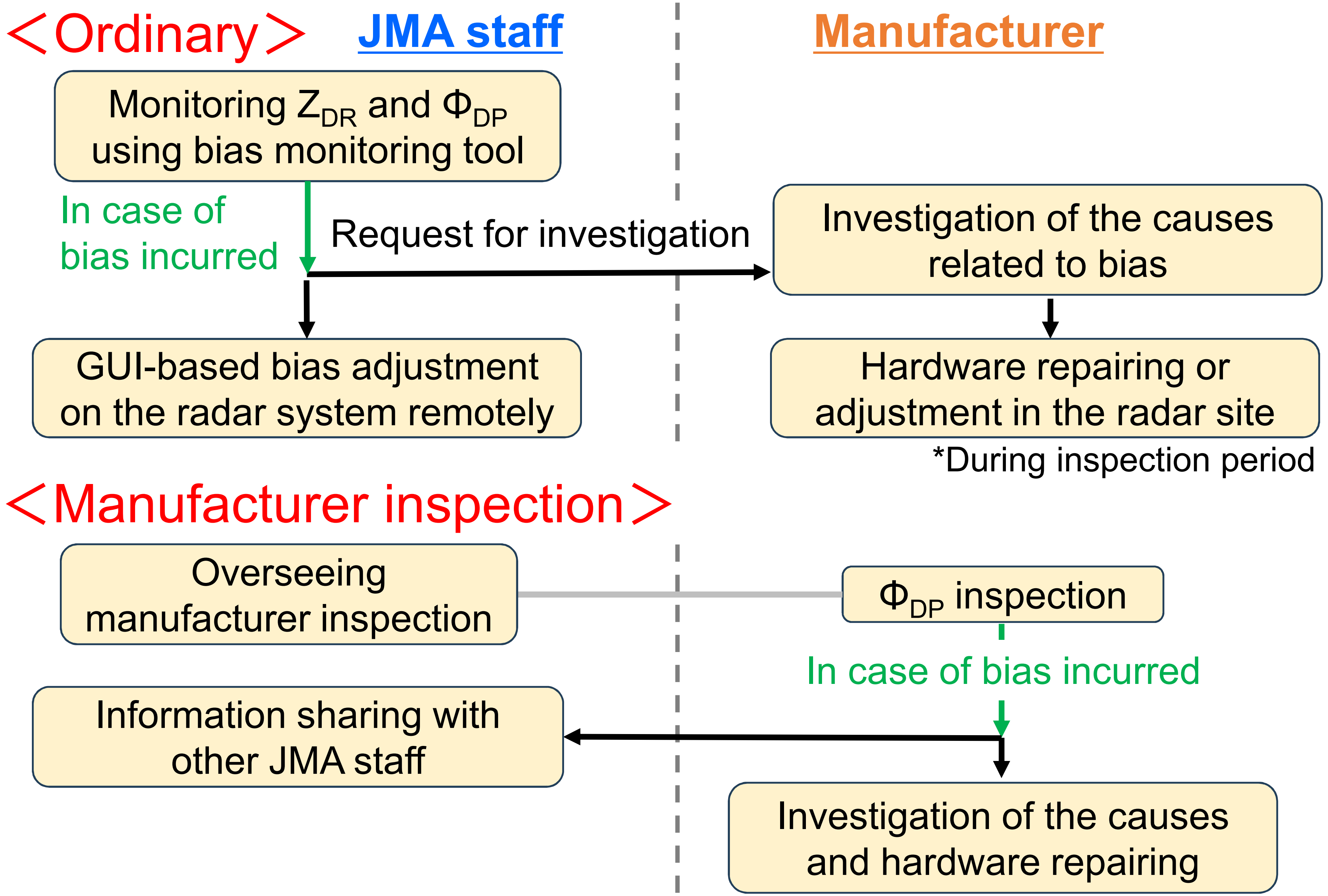


Contents

Single- and dual-pol.

Dual-pol.

Response procedure related to calibration



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気象庁 Japan Meteorological Agency

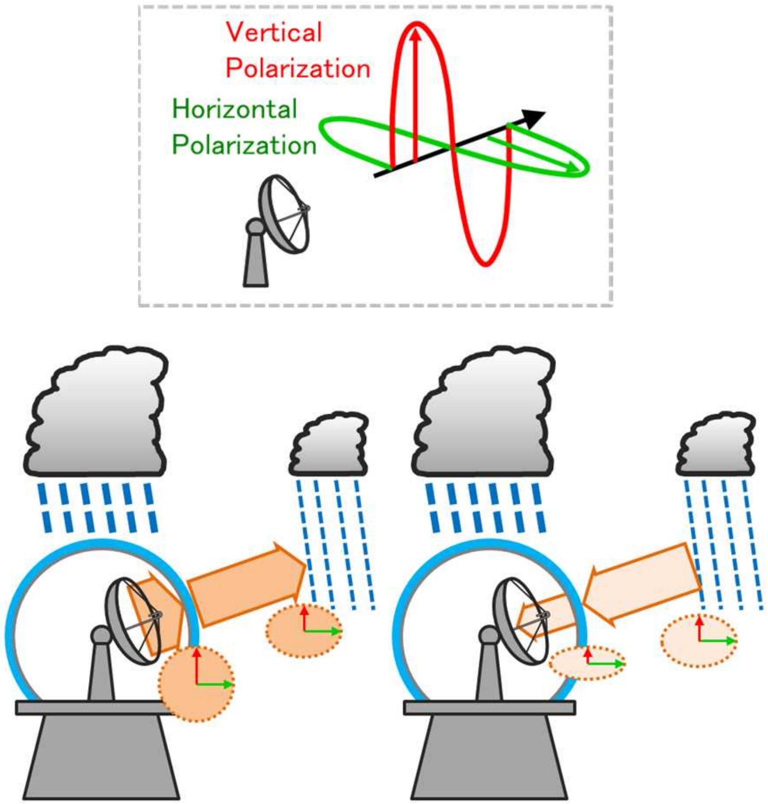
Single- and dual-pol.

Dual-pol.

Radome water repellency

Levels of attenuation are more accentuated with vertical polarization because water flows downward. → **Z_{DR} positive bias**
This leads to mis-identification of precipitation particle shapes.

**WMO guidelines call for a difference of under 0.2 dB between polarizations.*



Frech, 2009
The effect of a wet radome on dualpol data quality

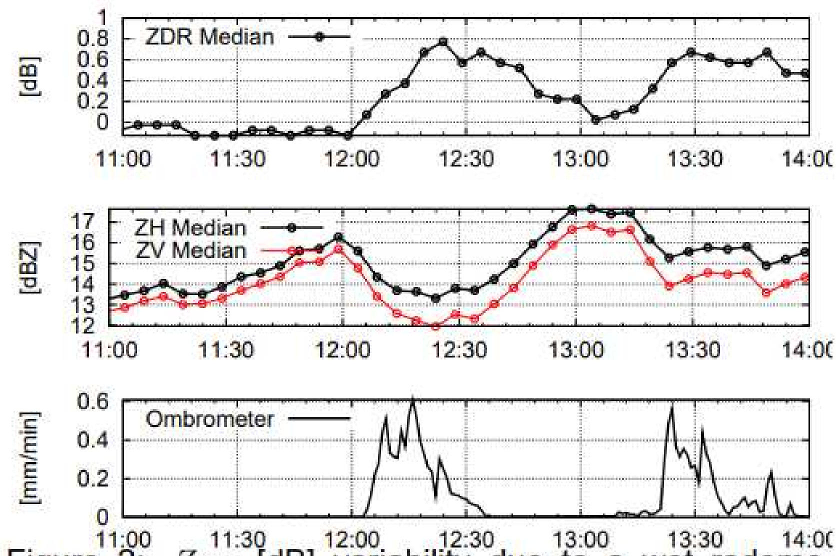
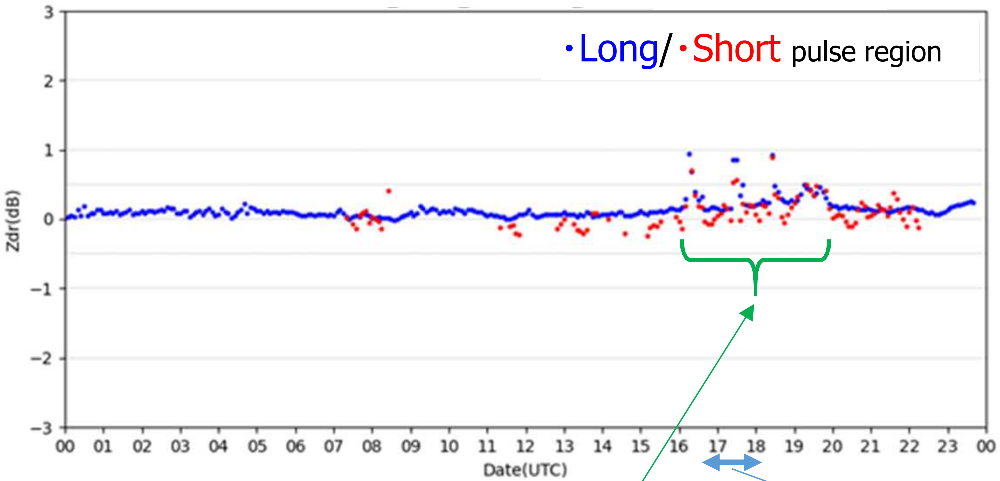


Figure 2: Z_{DR} [dB] variability due to a wet radome. Before the precipitation reaches the radar site, Z_{DR} is slightly negative. During the precipitation event Z_{DR} becomes positive ($Z_{DR} \approx 0.8$).

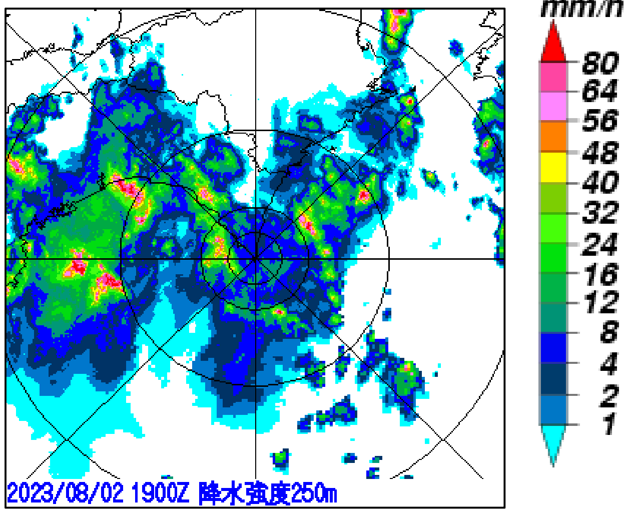
Rain-related Z_{DR} biases

Positive Z_{DR} biases due to wetting from heavy rain

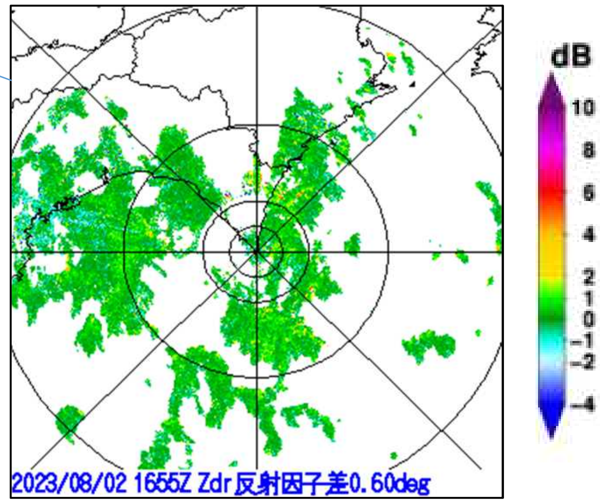
【Murotomisaki radar】Z_{DR} (August 2, 2023)



Precipitation Rate (19:00)



Z_{DR} (16:55~18:00)



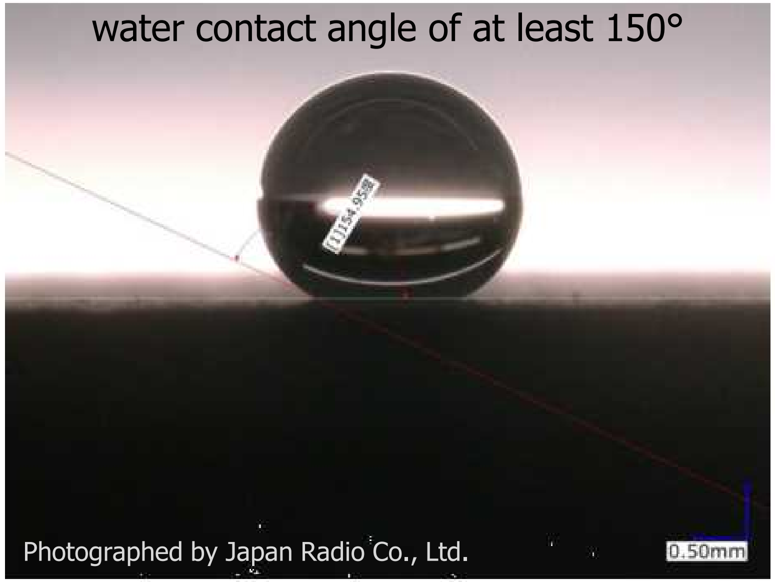
- An upward spike of approximately 0.5 dB is seen at around 19:00 UTC
- Spike-like rise toward 1 dB (approx.. 16:30, 17:30, 18:30)

⇒ Apparent positive Z_{DR} bias due to wetting

Super-hydrophobic radome coating from 2023

気象庁
Japan Meteorological Agency

Photographed by NIHON TOKUSHU TORYO CO., LTD.



SKY-HULLO HAS (developed by SUBARU CORPORATION and NIHON TOKUSHU TORYO CO., LTD.)

- **Super-hydrophobic**: produces a water contact angle of at least 150°
- **Highly durable**: the hardest super-hydrophobic coating available (designed for aircraft). Resistant to UV rays.
- **Recoating possible**
- **Addition of anti-algae agent possible**

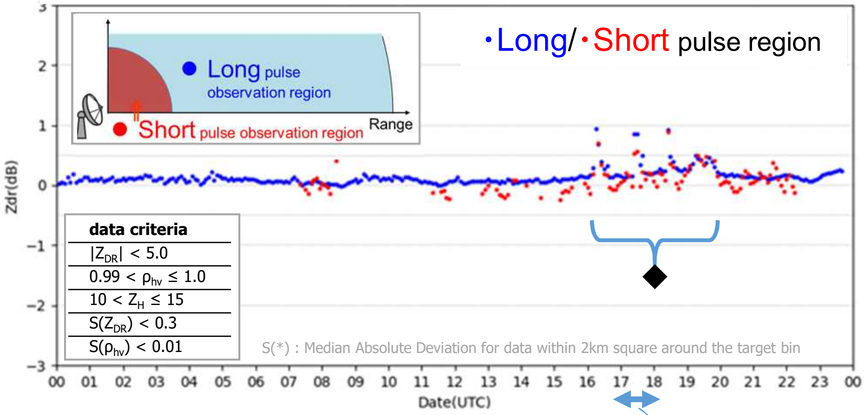
*Negligible radio wave attenuation

Comparison of regular and super-hydrophobic radome coating

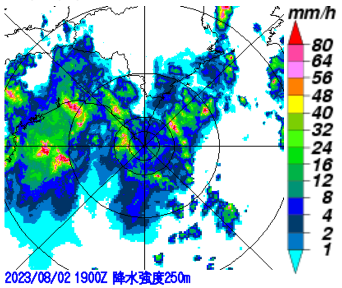
気象庁 Japan Meteorological Agency

Regular radome coating

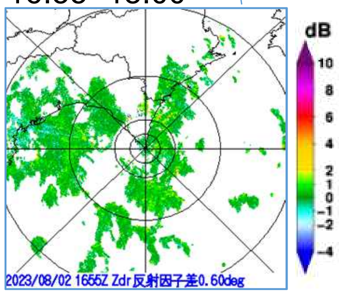
【Murotomisaki radar】Z_{DR} (August 2, 2023)



19:00



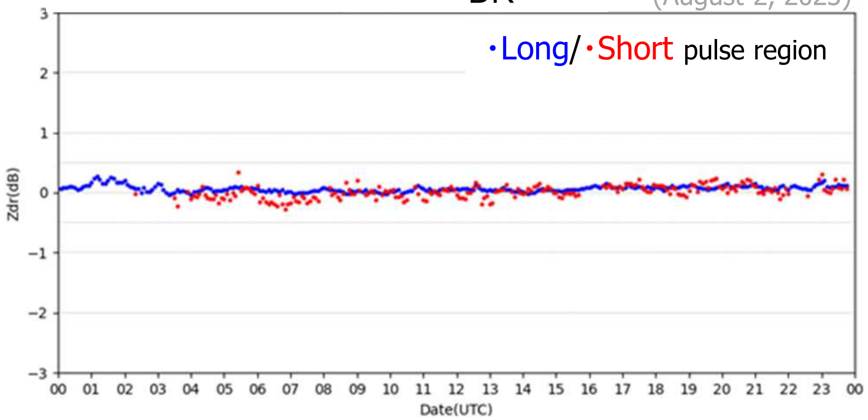
16:55~18:00



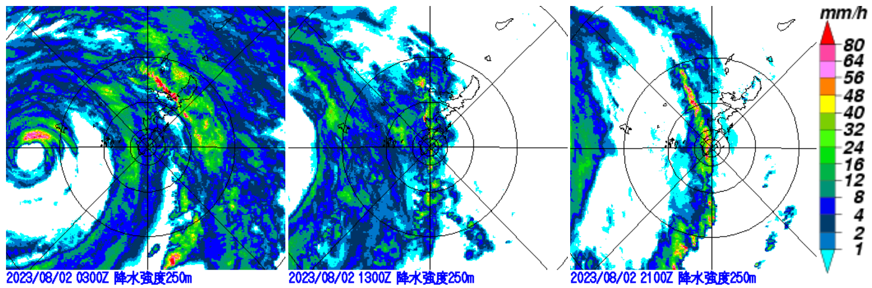
- An upward spike of approximately 0.5 dB is seen at around 19:00 UTC
- Spike-like rise toward 1 dB (approx.. 16:30, 17:30, 18:30) → Apparent positive Z_{DR} bias due to wetting

Super-hydrophobic radome coating

【Okinawa radar】Z_{DR} (August 2, 2023)



03:00 13:00 22:00



<u>No major effects on Z_{DR} are observed</u> despite heavy rain and strong wind throughout the day. Probably attributable to the super-hydrophobic radome coating.

Anti-algae agent

Greenish residue on Ishigakijima radome surface

April 2011 → June 2012

This may be aerial algae or lichen.

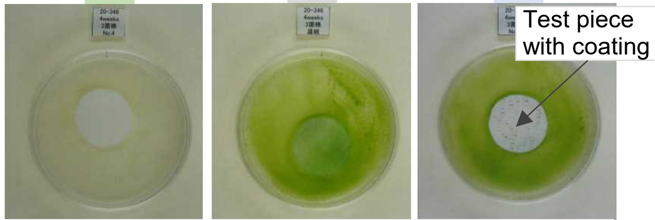
*Located in mountainous terrain on a remote island

Effect of anti-algae agent

Algae growth and adhesion are reduced in those with anti-algae (left) compared to those without (right).

SKY-HULLO HAS with anti-algae	No coating	SKY-HULLO HAS without anti-algae

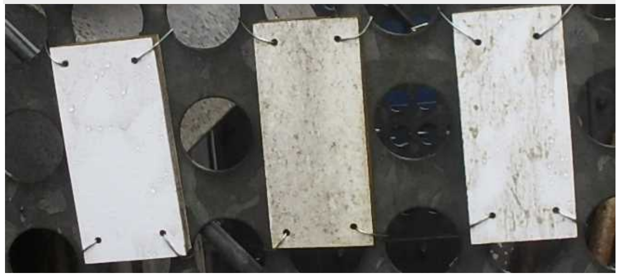
Experiment with standard algae
*4 weeks after the start of the experiment



No algae are found throughout the petri dish.	Algae thrives on the test piece.	No algae are found on the test piece.

Photographed by NIHON TOKUSHU TORYO CO., LTD.

Field test at Ishigakijima radar
*15 months after installation



Summary

- There are some methods of Z calibration.
- Polarimetric variable monitoring is important.
  - High accuracy is needed for dual-pol data to make use of them.
- Bias monitoring tool can monitor polarimetric variables in real time.
  - This tool uses low-elevation and bird-bath scan data for long pulses monitoring.
  - It is important to check Z_{DR} bias and Φ_{DP} discontinuity between short and long pulses.
- Super-hydrophobic coating is applied to radome equipment.
  - This coating eliminates Z_{DR} bias caused by radio wave attenuation associated with wet radome surfaces.
  - Effectiveness will continue to be monitored for reference in future JMA radar updates.

JMA's mascot, "Harerun"

Thank you for your attention.