The characteristics of observation using solid-state dual-polarization radar

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3rd WXRCalMon
18th Nov. 2021

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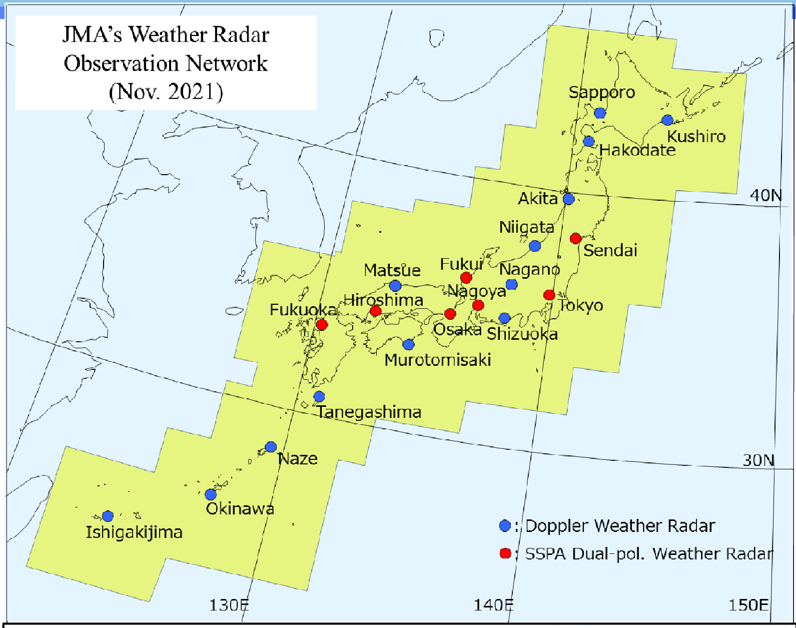
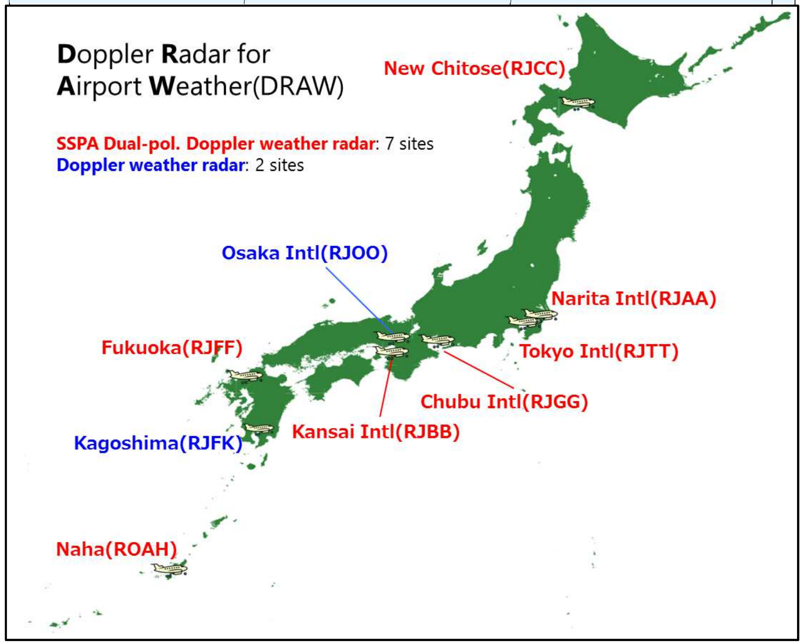
1. History of SSPA dual-pol. weather radar in Japan





History of solid-state dual-pol. radar in Japan

Total 14 C-band radars as SSPA dual-pol. (as of 2021 Nov. JMA)

2020

Start of operational radar update to SSPA dual-pol. (JMA, 2020)

Start of TDWR update to SSPA dual-pol. (JMA, 2016)

Start of installation of C-band SSPA dual-pol. radar (MLIT, 2012)*

2010

Start of installation of X-band SSPA dual-pol. radar (MLIT, 2010)*

Development of C-band SSPA radar (MRI, 2008)

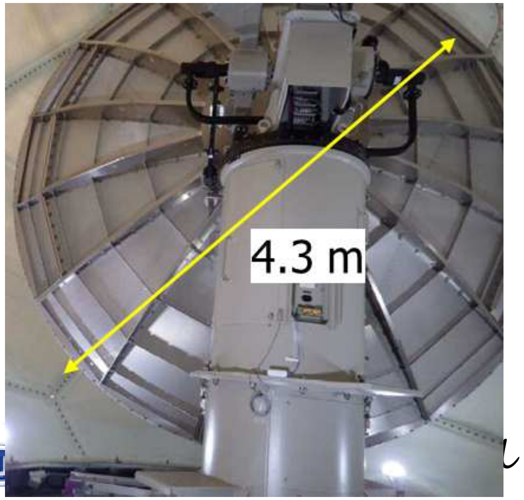
2000

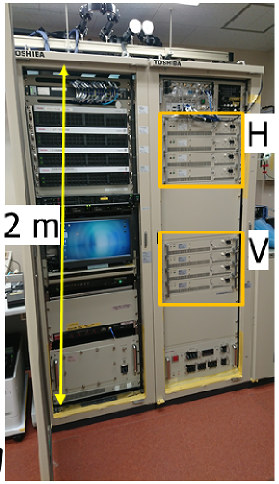
*The early models introduced Klystron, and the current radars develop nationalwide with SSPA.

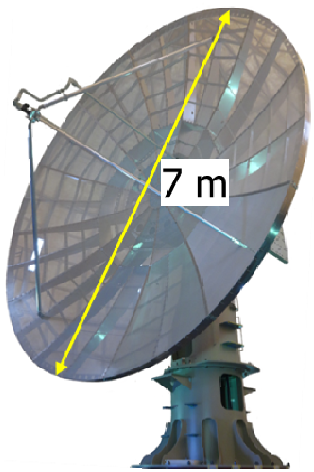
C-band SSPA dual-pol. radar in JMA

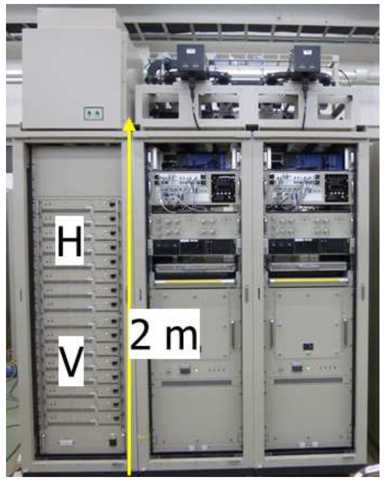
National-wide weather radar (2020~)	
Transmitting frequency	5350.0 MHz (Osaka, Fukui) 5357.5 MHz (Tokyo) 5360.0 MHz (Hiroshima, Nagoya) 5365.0 MHz (Sendai, Fukuoka)
Antenna	Parabola, Diameter 4.3 m
Beam width	0.95 degree
Transmitter	**Gallium / Nitride HEMT**
Peak transmitting power	Horizontal **3 or 4 kW** Vertical **3 or 4 kW**
Pulse width	Short Pulse: 1 μsec **Long Pulse: 30 – 200 μsec**

TDWR (2016~)	
Transmitting frequency	5330 MHz (Haneda) 5335 MHz (Narita, Fukuoka) 5340 MHz (New-Chitose) 5350 MHz (Chubu) 5360 MHz (Kansai) 5365 MHz (Naha)
Antenna	Parabola, Diameter 7 m
Beam width	0.7 degree
Transmitter	**Gallium / Nitride HEMT**
Peak transmitting power	Horizontal **5 kW** Vertical **5 kW**
Pulse width	Short Pulse: 1 μsec **Long Pulse: 30 or 64 μsec**









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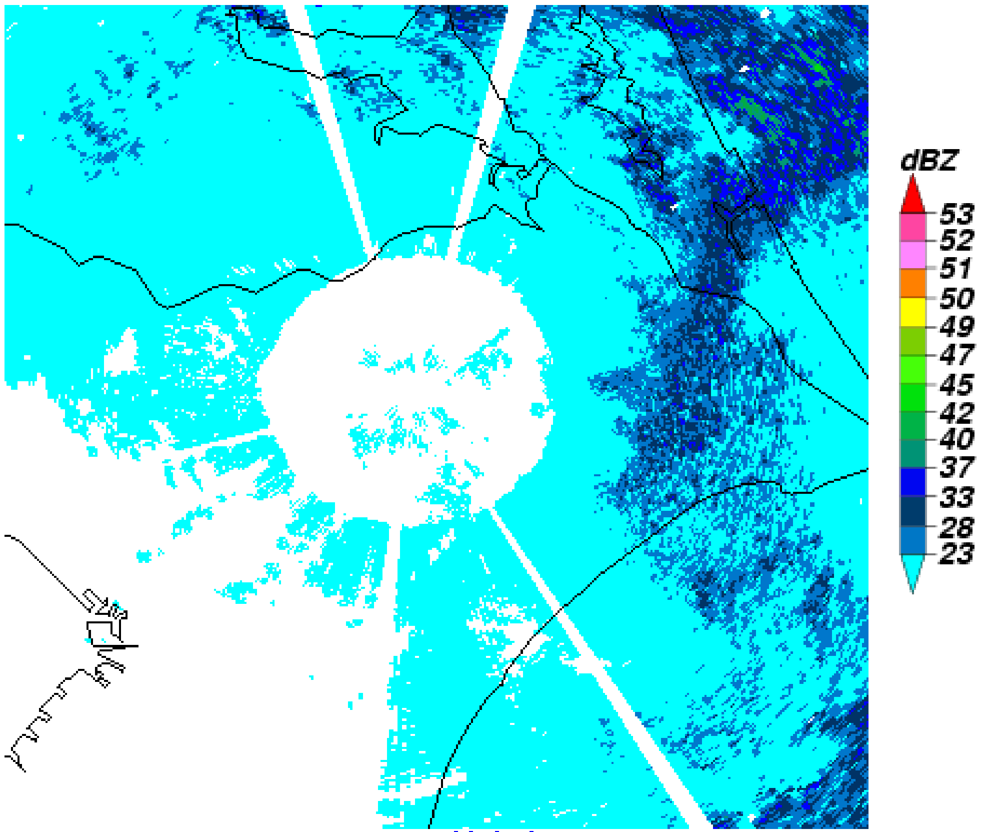
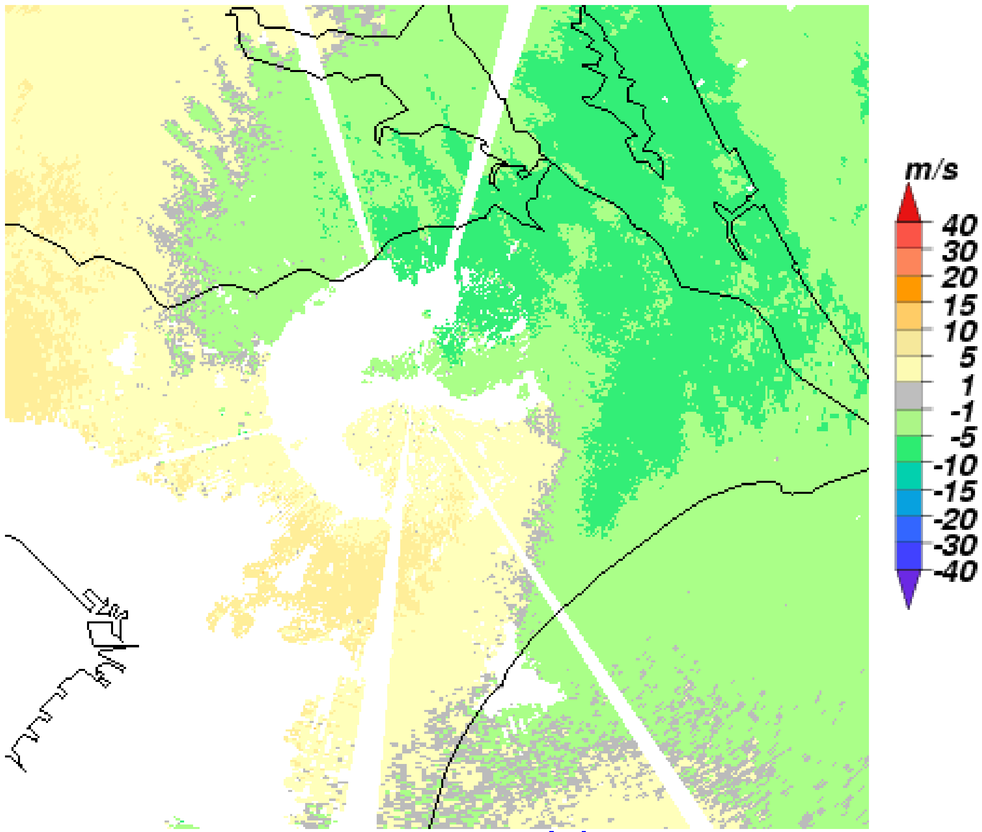
Improvement of sensitivity around radar site

- SSPA radar has **<u>low sensitivity area within the short-pulse range</u>** where pulse compression is not available. → No echo in light rain
- The adaptation of various countermeasures (e.g. NLFM, combination of various width of long pulses) lead to reliably detect weak echoes in vicinity.



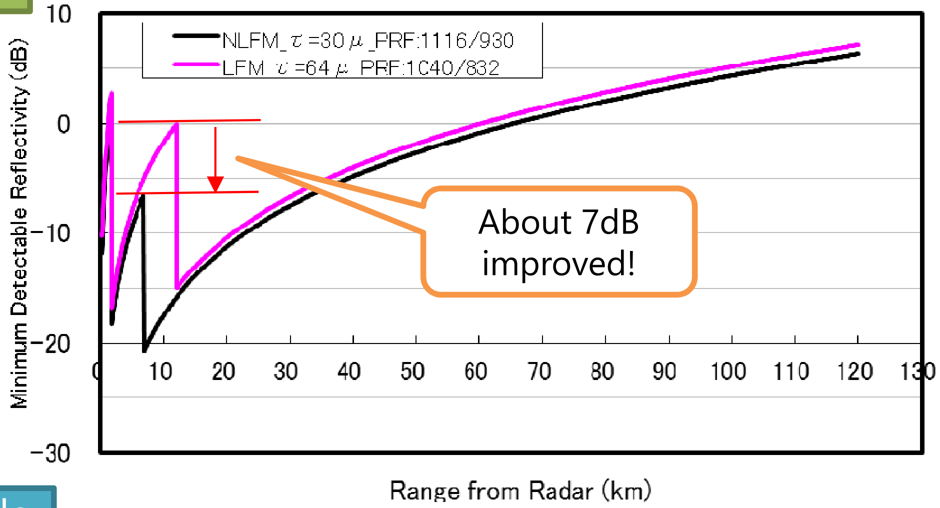
2017/01/20 14:00 SP-DRAW反射強度0.7deg



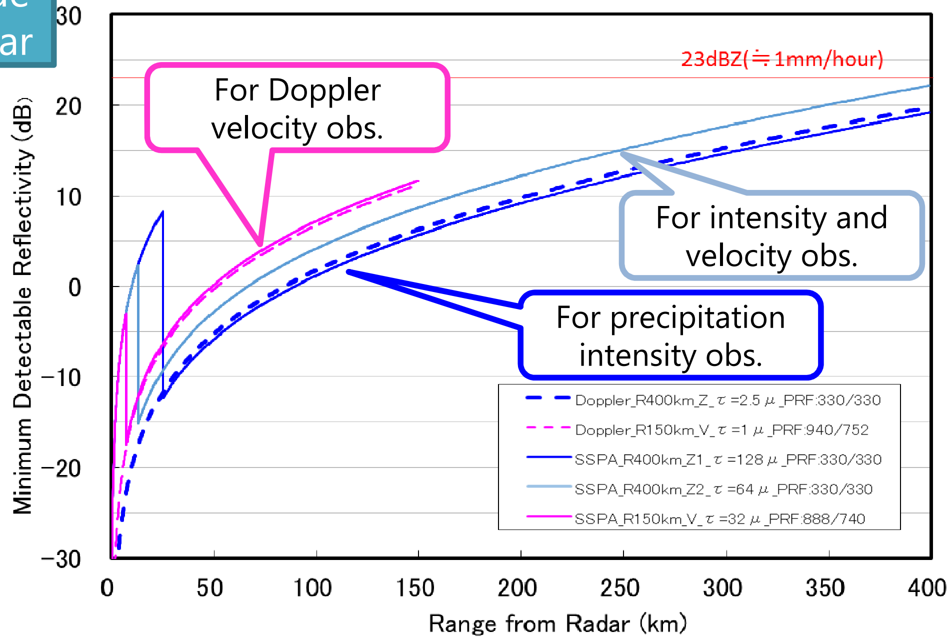
2017/01/20 13:55 SP-DRAWドップラー速度0.7deg

Improvement of sensitivity around radar site

TDWR



National-wide weather Radar

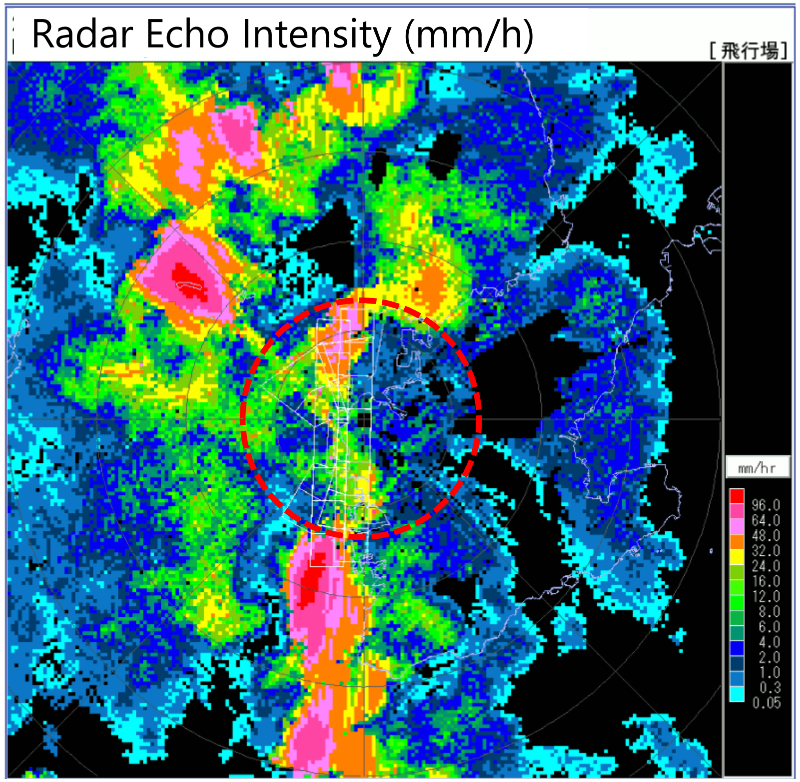


- Early SSPA TDWR adapted τ=64μs, PRF:1040:832(5:4), LFM.
  → low receiving sensitivity area around radar site
- Late-model SSPA TDWR adapted τ=30, PRF:1116:930(6:5), NLFM*.
  → Improved receiving sensitivity
  → About 7dB improved at the boundary between short/long pulse.

*including receiving loss improvement (about 1.5 dB)

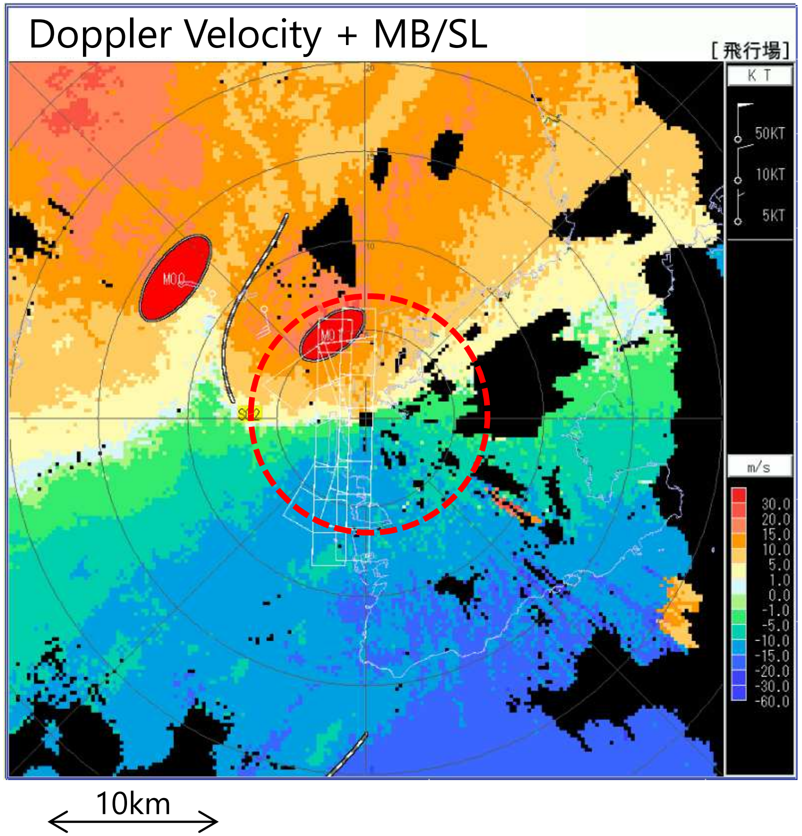
- National-wide weather radar adapted NLFM, and pulse width and PRF were individually determined in response to intensity and velocity observation.
  → Achieved the same sensitivity of observation as before.

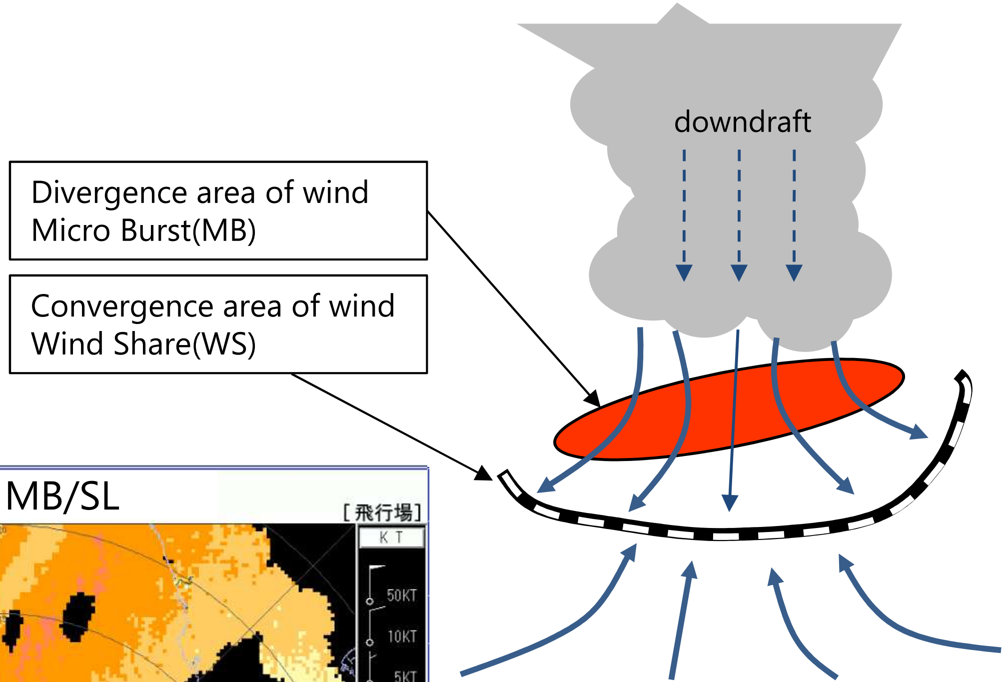
Case study (Low-level wind shear detection)

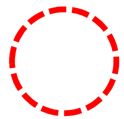


LLWS detection by Naha TDWR
2021/9/13 03JST

Cumulonimbi passed one after another on the line, and many MB/SL were detected around the airport.



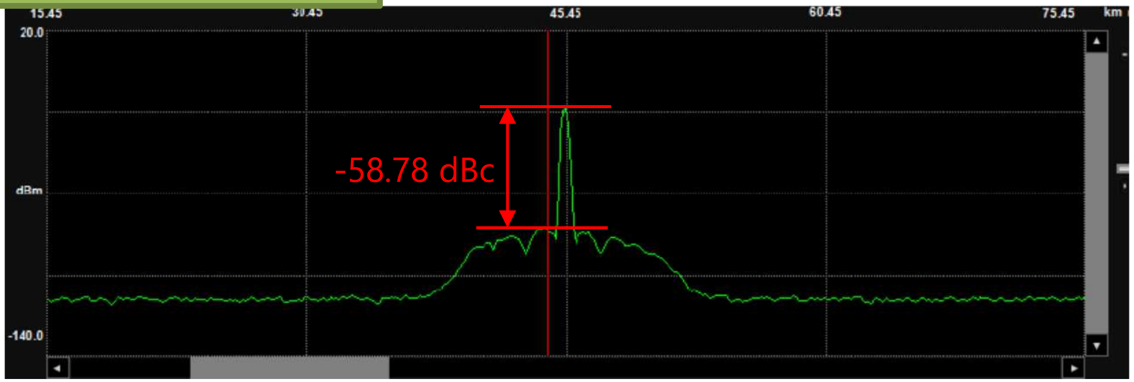




Boundary between long and short pulse
(radius: about 7km)

Suppression of range sidelobe

TDWR LFM



TDWR NLFM

	NLFM	LFM
Range sidelobe suppression	60～65 dBc	55～60 dBc
Pulse width (compressed)	0.94～0.99 μs	～1.56 μs
Range resolution	141～148.5 m	234 m
Chirp width	1.63 MHz	1.20 MHz

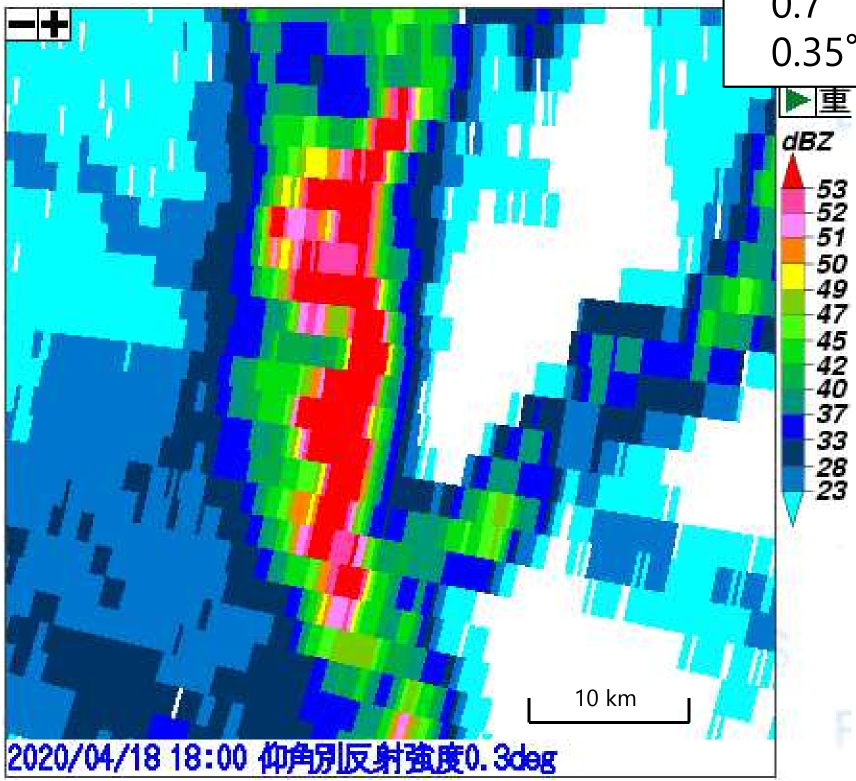
- NFLM improved suppression of range sidelobe by about 5 dBc compared to LFM.
- Moreover, NLFM improved range resolution (compressed).

Improvement of resolution

High resolution image

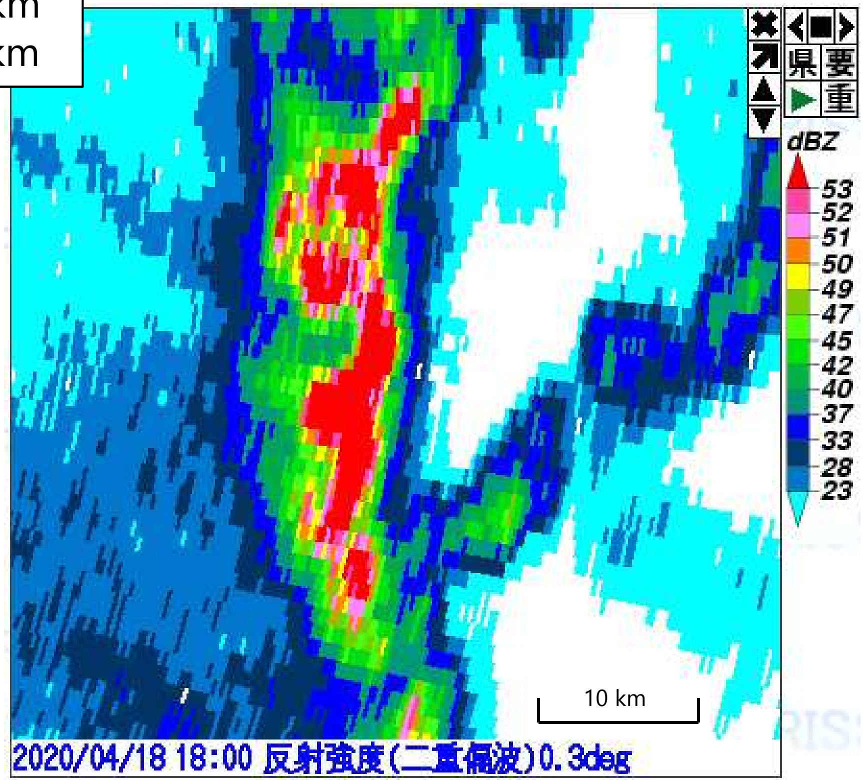
- Azimuth resolution: **0.7°⇒0.35°** (adaptation of super-resolution)
- Range resolution: **250m⇒125m**
  (averaging 2 bins to 250m resolution in order to improve observation error)
- These make it possible to clearly distinguish far-off echoes!

Conventional image



(Azimuth resolution)
0.7° : about 2km@160km
0.35° : about 1km@160km

High resolution image



Calibration technique between short/long pulse

- In the WXRCalMon in 2019, we introduced the method of calibration for ΦDP and Zdr of short and long pulse in JMA.

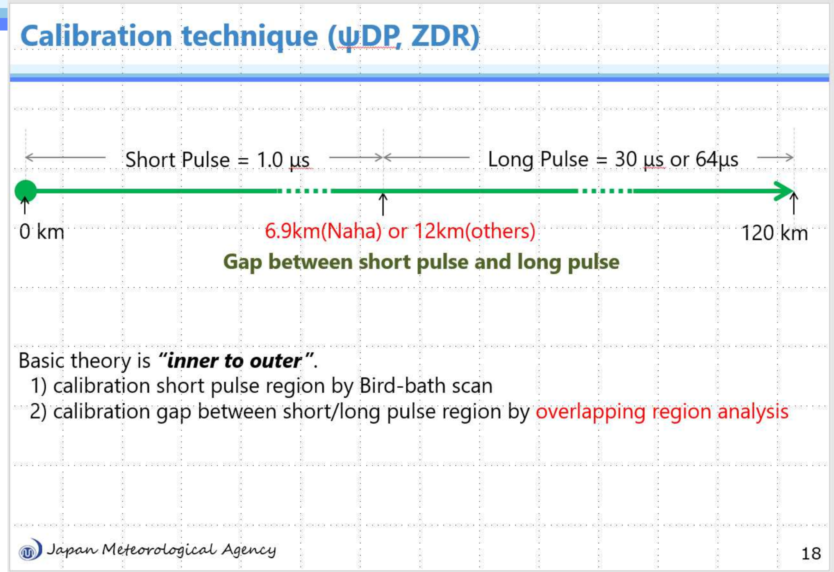
Concepts; "inner to outer"

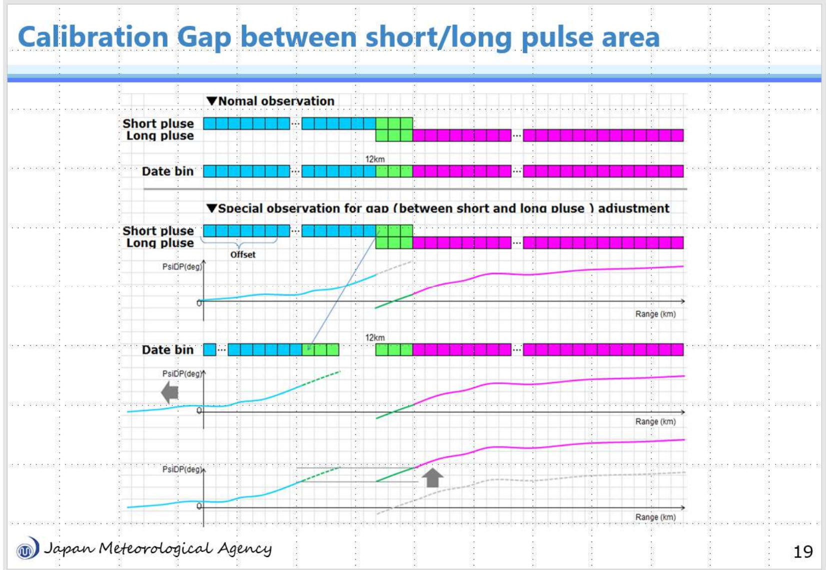
- (short pulse) calibration by Bird-bath scan first.

↓

- (long pulse) calibration gap between short and long pulse region by overlapping region analysis.

→ Prepared calibration monitoring tool for gap between long and short pulse.





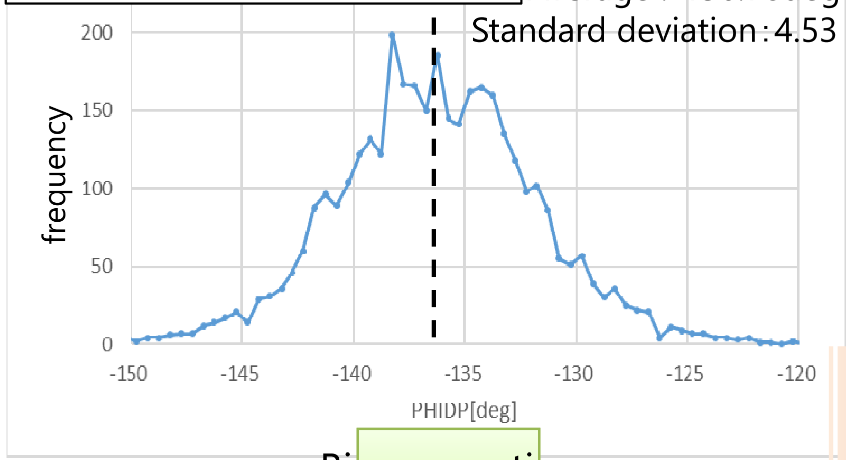
Calibration and monitoring experience with JMA's SSPA dual-pol. radars
Hotta et al., WXRCalMon 2019

Calibration technique between short/long pulse

1) Bird-bath scan calibration (short pulse)

ΦDP (**before adjustment**)

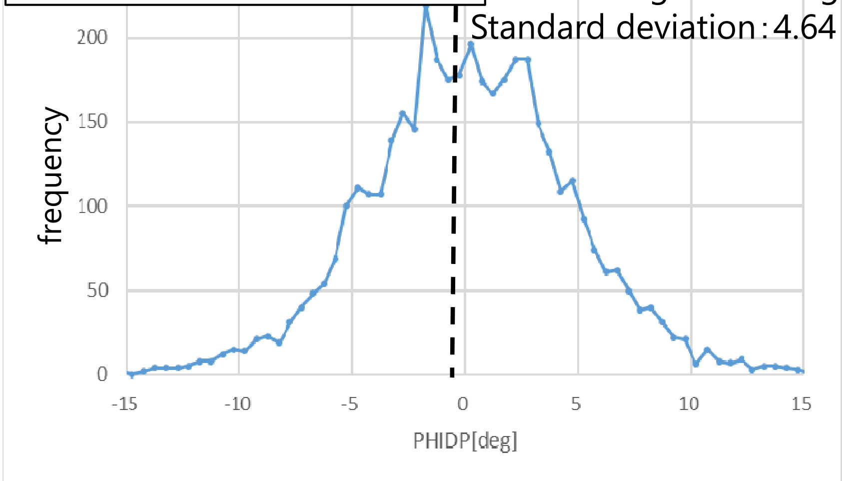
Average :-136.78deg
Standard deviation : 4.53



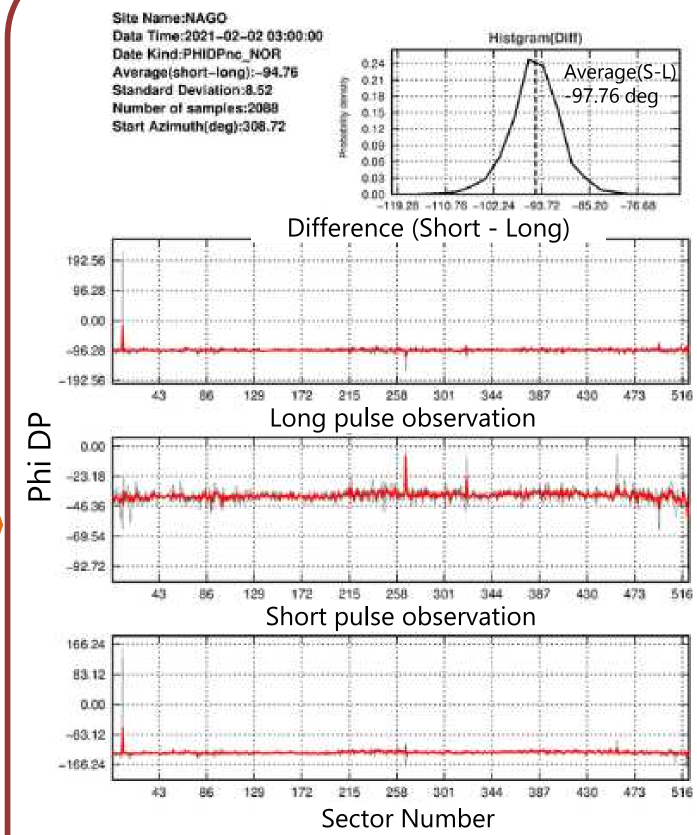
Bias correction

ΦDP(**after adjustment**)

Average :-0.30deg
Standard deviation : 4.64



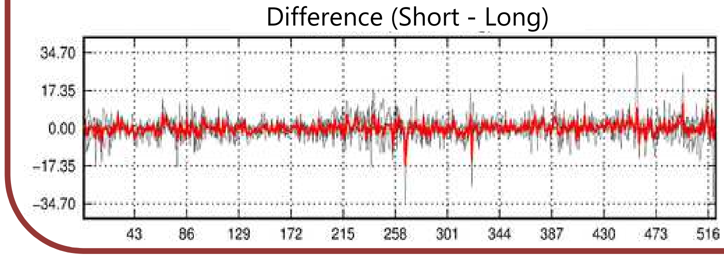
2) Overlapping region analysis

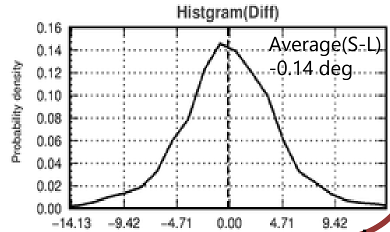


<= Overlapping region monitoring tool*

Long pulse correction

Φdp difference (short - long) (**after adjustment**)



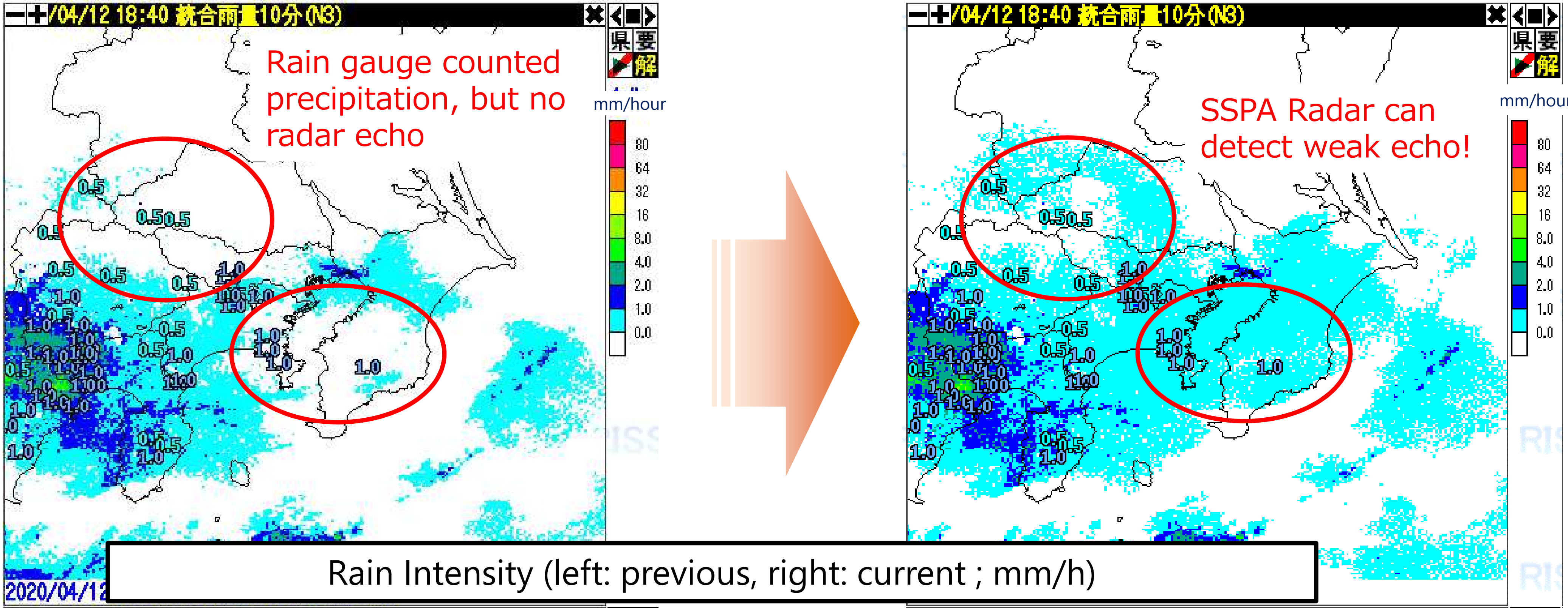


*developed by Toshiba Infrastructure Systems & Solutions Corporation

SSPA radar case study（improvement of weak echo）

Mitigation of cutting off Z process

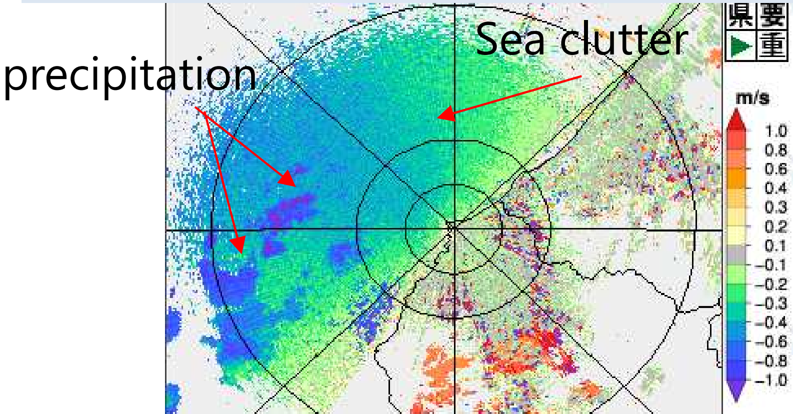
- Z ≦15.3dBZ(0.33mm/h) was not used until updating to dual-pol radar for sea clutter and clear air echo.
- Z ≧5 dBZ(0.10mm/h) is used for Removal of sea clutter and clear air echo using dual-pol variables.



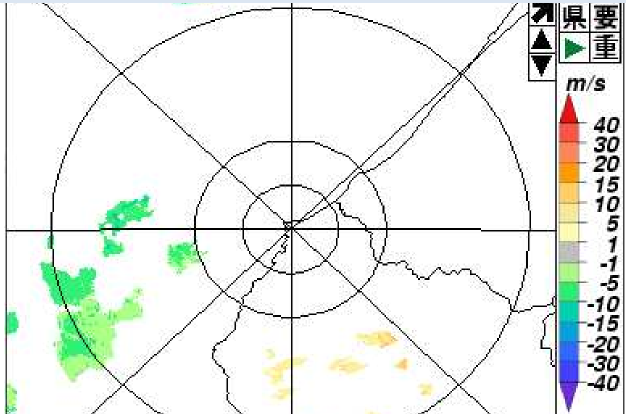
Rain Intensity (left: previous, right: current ; mm/h)

SSPA radar case study (Removal of non-preciepitation echoes)

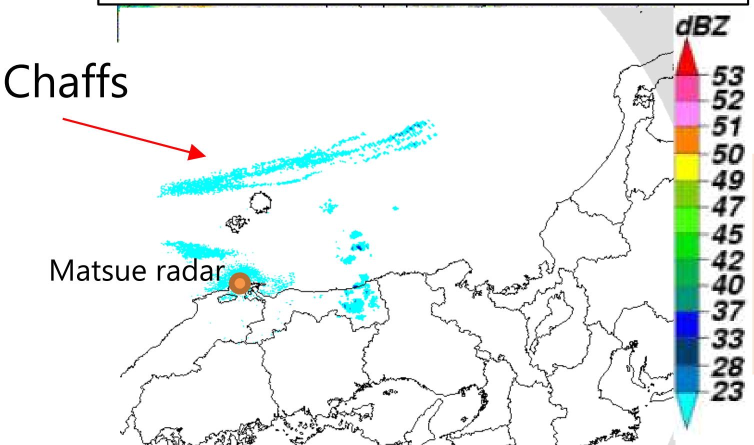
- SSPA radar can discriminate non-precipitation echoes (sea clutter, clear air echoes, chaffs···) by using dual-pol. parameters.
- Precipitation intensity and velocity observation has improved due to quality control.



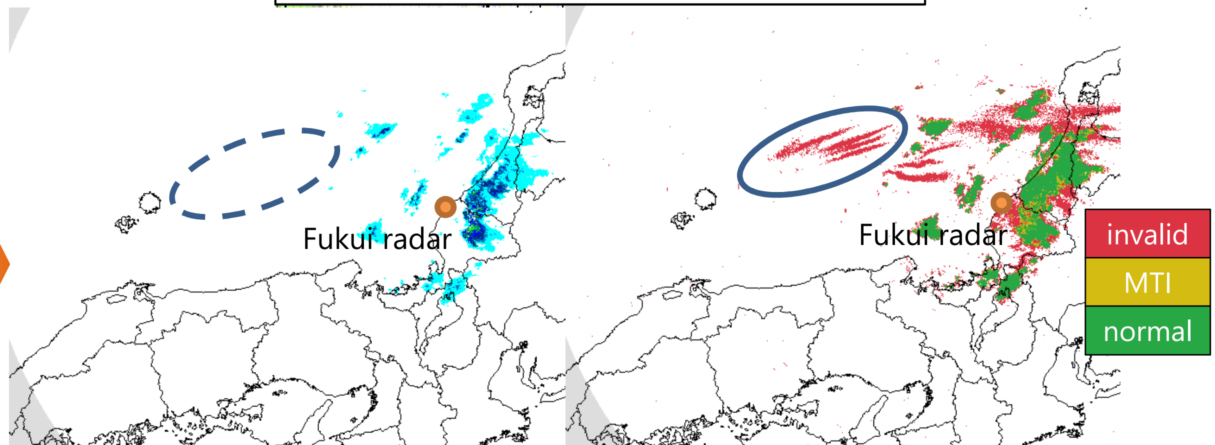
Doppler velocity (before QC)



Doppler velocity (after QC)



Radar reflectivity
Matsue radar (Non SSPA dual-pol.)

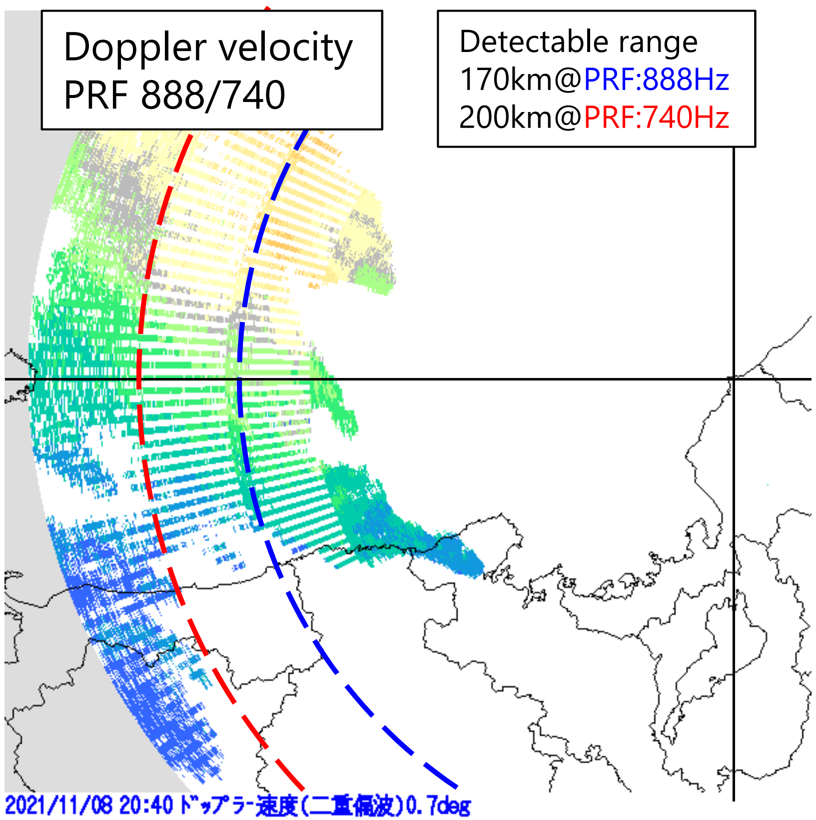


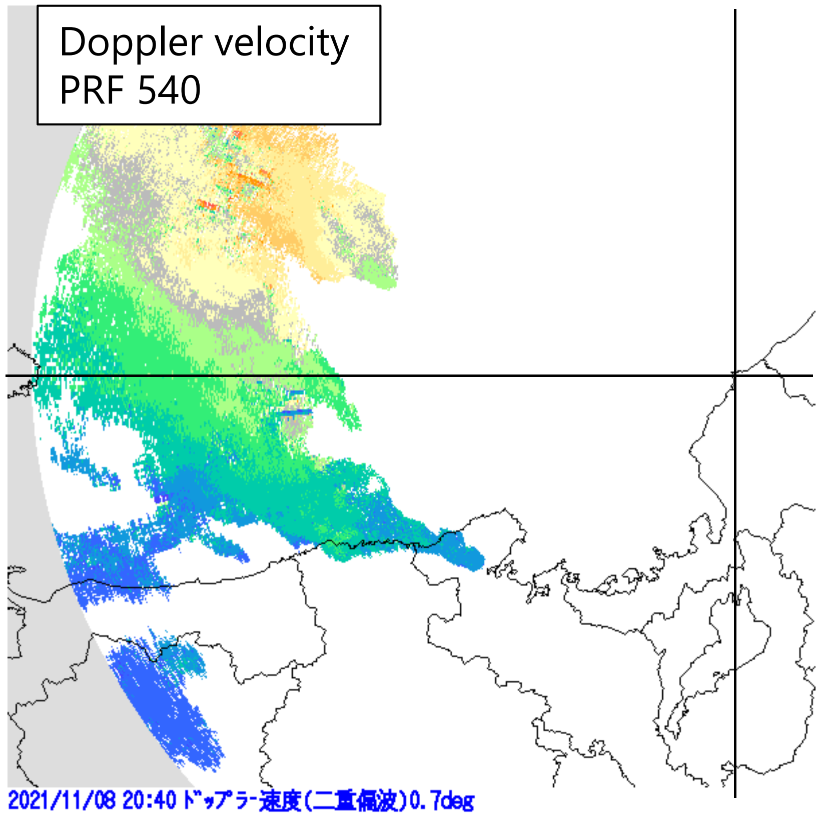
(Left)Radar reflectivity (Right)Quality Control map
Fukui radar (SSPA dual-pol.)

SSPA radar case study（Range doubler）

Extension of detection area

- Doppler velocity in the area of range doubler (dual-PRF 888/740Hz) can be observed almost the same as middle PRF observation (540Hz).
- Restoration error of reflectivity is less than 1dB, rejection ratio of primary echo is less than 1dB.





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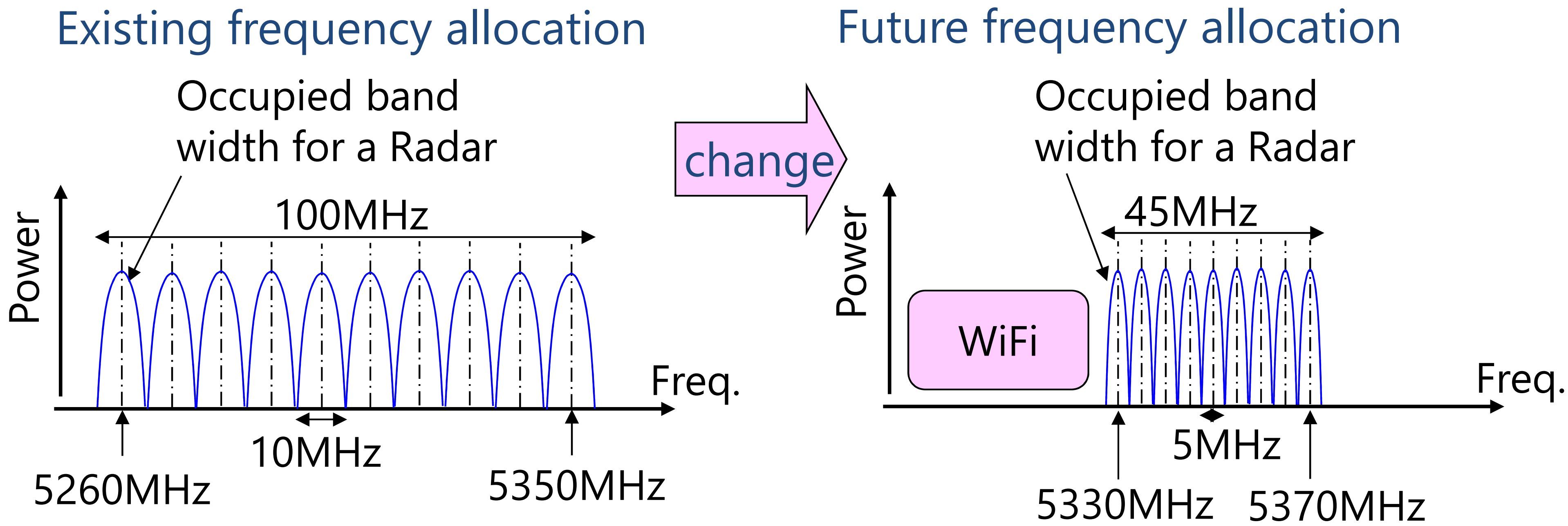
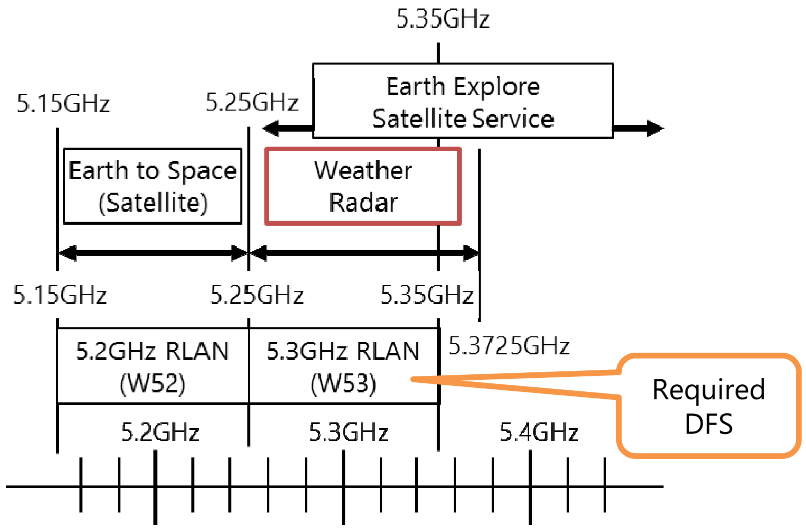
Trigger to introduce SSPA transmitter in Japan

- Rapid increase in usage of WiFi.
- Meteorological radars are requested to reduce band width.
- Electron tube technology cannot meet the request.



Technical requirements (DFS of RLAN in the 5.3-GHz bands)

Frequency allocation of 5GHz Band in Japan



RLAN's Frequency Band and available Locations

Spectrum Band	2.4 GHz	5GHz		
		5.2GHz	5.3GHz	5.6GHz
Outdoor use	○	○ *conditional	×	○

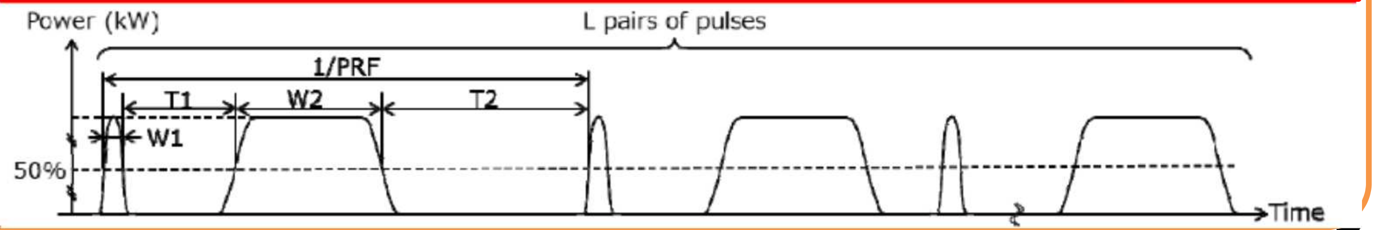
- Spectrum sharing in the 5-GHz bands between weather radar and RLAN in Japan.
- Prohibition of outdoor use and requirement of DFS for frequency protection of weather radar.
- With the spread of SSPA radar, DFS technical standards have been established to address pulse patterns using chirp modulation.

DFS pulse pattern standard for W53 in Japan

Radar test signal # (see note 1 to note 3)	W1 Pulse width (μs) (see note 9)		PRF Pulse repetition frequency (PPS)		Number of different PRFs	L Minimum number of pairs of pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1'	0,5	5	200	1000	1	10
2'	0,5	15	200	1600	1	15
1"	0,5	5	200	1000	1	min(A1, max(A2, ceil (S * PRF)))
2"	0,5	15	200	1600	1	min(A1, max(A2, ceil (S * PRF)))
13'	0,5	1,5	1114	1118	1	30
14'	0,5	1,5	928	932	1	25
13"	0,5	1,5	886	890	1	24
14"	0,5	1,5	738	742	1	20

For Short pulse only radar (1', 2')

For Short and Long pulse combined (1" to 14")



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Summary

- JMA has updated 14 of its 29 C-band weather radars to SSPA dual-polarization version.
  - More and more radars are planed to be renewed to SSPA radars in the next few years.

- SSPA radar performs as well as conventional radar with electron tube.
  - By using various width of long pulse and PRF, SSPA radar can make equivalent observations.
  - Moreover, SSPA radar improves observation capability (resolution, low sensitivity, quality control).
  - Constant calibrations is required to maintain performance.

Thank you for your attention !

JMA's mascot, "Harerun"