Basics of Weather Radar

29-30 January 2024

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Disasters caused by Heavy Rainfall or Storms

Landslide

Lightning

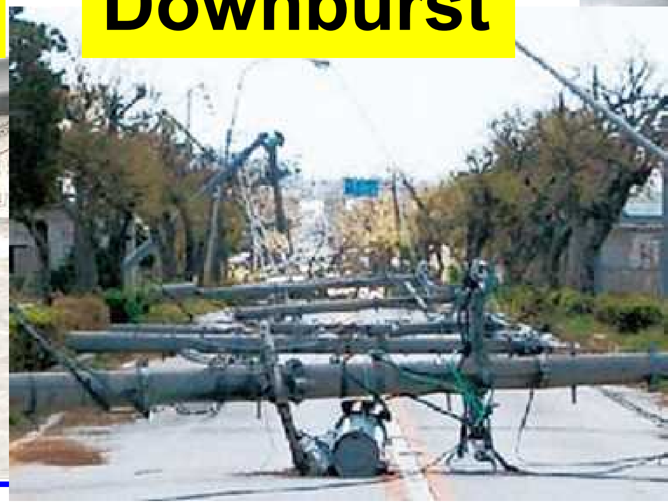
Hail

Tornado

Flood

Inundation

Downburst



Utilization of Radar to detect Severe Phenomena

- Rainfall amount

  Z-R relation

  Combination of radar with rain gauge

  Dual-pol observation

- Severe Phenomena

  Lightning

  Hail

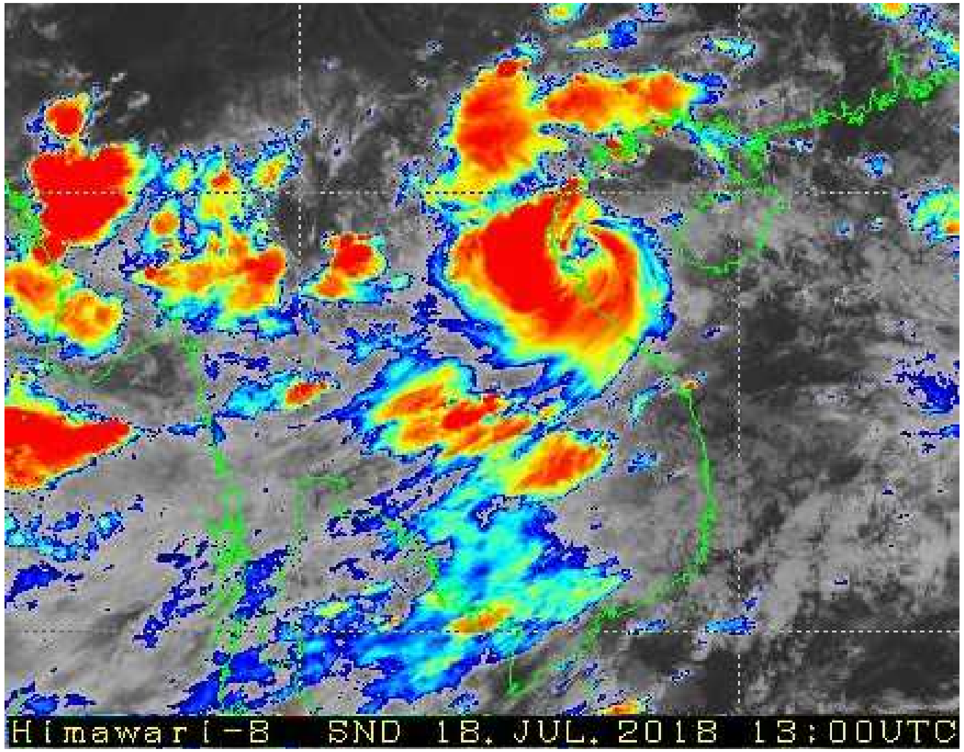
  Tornado

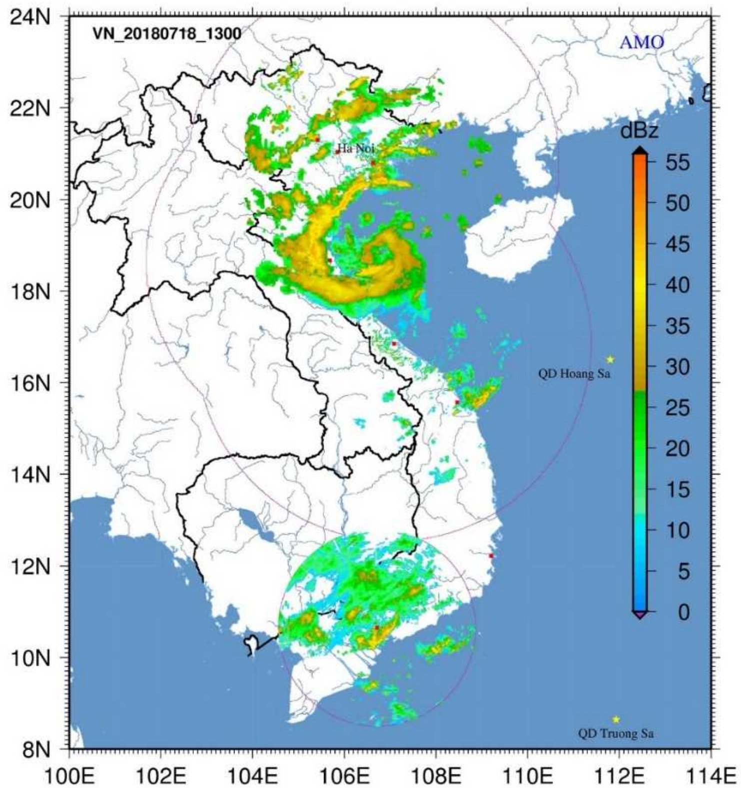
  Downburst (or severe wind shear)

How rain gauge / radar / satellite observations are useful to observe rainfall amount ?

	Merits	Demerits
Rain gauge	- Accurate measurement	- Can not cover area
Radar	- Detect wide area with high resolution in time and space	- Relationship between radar intensity and rainfall amount is not simple - Resolution decreases with range
Satellite (IR, VIS)	- Detect huge area with high resolution in time and space, especially over ocean	- Can not detect rain directly

Combination of satellite data and radar data is more useful to monitor the characteristics of Typhoon and its development





Utilization of radar

Items to be thought in the planning stage

Characteristics of Radar Hardware

Purpose of Radar Observation

Characteristics of Signal & Data Processing

QC and Quantitative data utilization

Maintenance

Guide map to master weather radar

Basic knowledge

Principle of radar, radar equation, Z-R relation, effective beam height, etc.

Applied knowledge

Hardware

- Installation
- Calibration
- Maintenance

Advanced techniques

- Solid-state transmitter with pulse compression

Observation

- Obs. Scheduling (inc. scan sequence)
- Quality control with **dual-pol info.**
- Sites composite
- Doppler velocity

Utilization

- QPE&QPF with **dual-pol info.**

Severe Phenomena

- Detecting mesocyclone, wind shear by Doppler obs.
- **Hydrometeor classification by dual-pol obs.**

Open Source Software (Pyrad)

The content of this lecture

- Brief history of radar
- Several parameters to characterize radar
- Characteristics of radar observation
- Effective beam height
- Radar equation, Z-R relation
- Quantitative Precipitation Estimation (QPE)
- Quality control of radar data

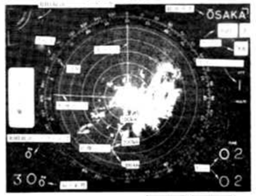
Focus of this lecture

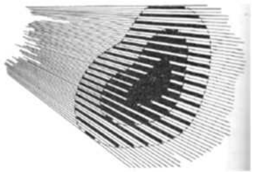
- We will understand that radar observation needs good organization to provide high-quality, sustainable radar data.
- We will know the focus and problem in case of new radar installation.
- We will consider why the data quality decreases.
- We will know how the data quality is checked and controlled.

History of radar observation of JMA

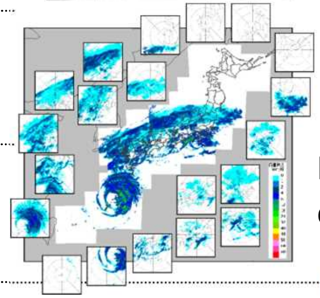
- **1954** First Operational Analog Radar started
- **1964** Mt. Fuji Radar started
- **1971** Nationwide Analog Radar Network completed and Analog Quantitative Radar started
- **1982** Digital Radars started
- **1994** Nationwide Digital Radar Network completed
- **1995** Doppler Weather Radar for Airport (DRAW) started
- **2004** 1 km-mesh Digital Coherent Radar started
- **2006** Doppler Radar Network started
- **2008** JMA-HQ-controlled Digital Radar Network completed
- **2016** Solid-state dual-polarization DRAW started

1964-1999





Gray-scale echo display



Radar composite

Kansai DRAW (TDWR)

Shizuoka

Nagano

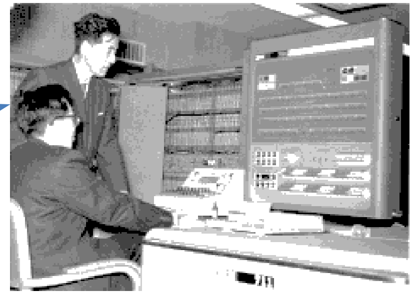
Tokyo

Narita DRAW

History of modernization of weather services in JMA

1950 1960 1970 1980 1990 2000 2010

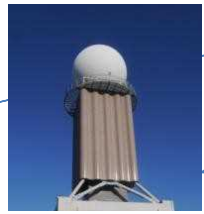
- 1952 Meteorological Service Act
- 1954 First Operational Weather Radar
- 1959 Start of Numerical Weather Prediction using IBM704



- 1964 Mount Fuji Radar

- 1974 Automated Met Data Acquisition System (AMeDAS)
- 1977 First Geostationary Meteorological Satellite (Himawari-1)

- 1982 Digital Weather Radars
- 1983 Quantitative Precipitation Estimation (Radar-Raingause Composite Map)
- 1987 Quantitative Precipitation Forecast

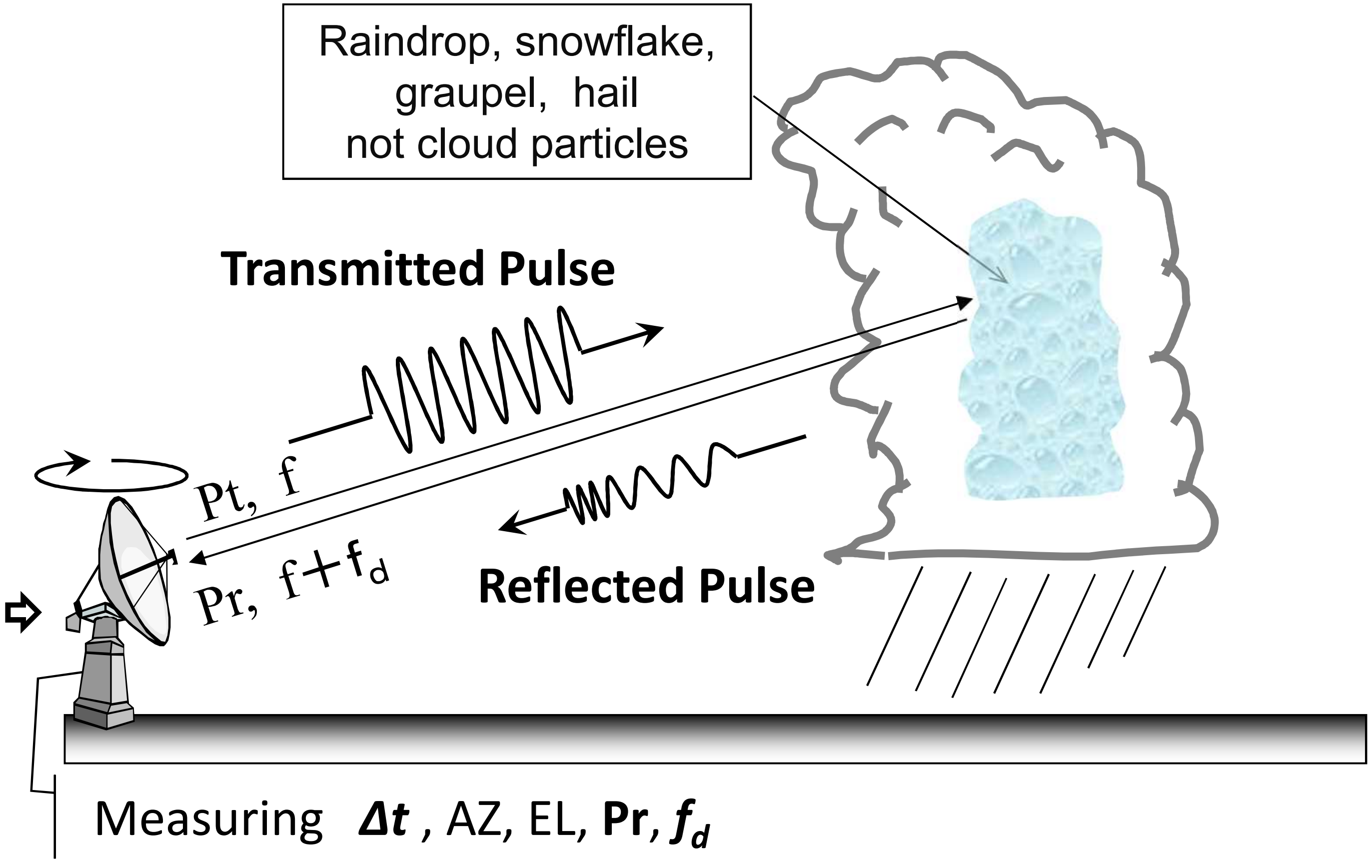


Wind Profiler Network ■ 2001 Precipitation Nowcast

Solid-state Dual-polarlization TDWR ■ 2016

What is weather radar ?

RADAR : Radio Detection And Ranging



Measuring ***Δt*** , AZ, EL, **Pr**, $\boldsymbol{f_d}$

Distribution of Precipitation | **Precipitation Intensity** | **Air flow in Precipitation Area**

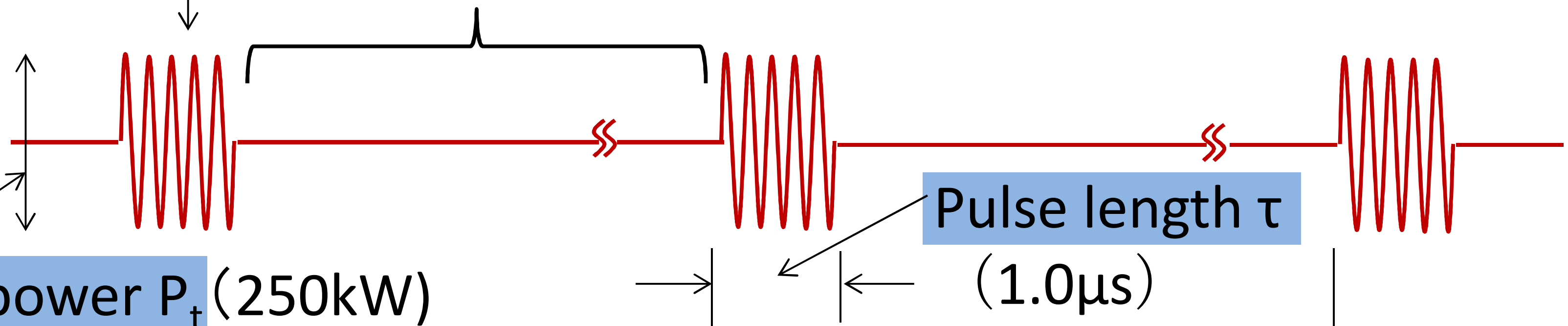
Radar Specifications

- Transmitter Type:
  Magnetron, Klystron, Solid state
- Polarization:
  Single (horizontal, vertical), Dual
- Doppler processing: Yes/No
- Antenna gain, beam width, level of side lobes
- Peak power of transmitter
- Pulse length, Pulse compression
- Frequency:
  X-band, C-band, S-band

What is radar pulse ?

Transmitted pulse
（frequency 5600MHz）

Period for receiving signals



Pulse length τ
（1.0μs）

Peak power P_t（250kW)

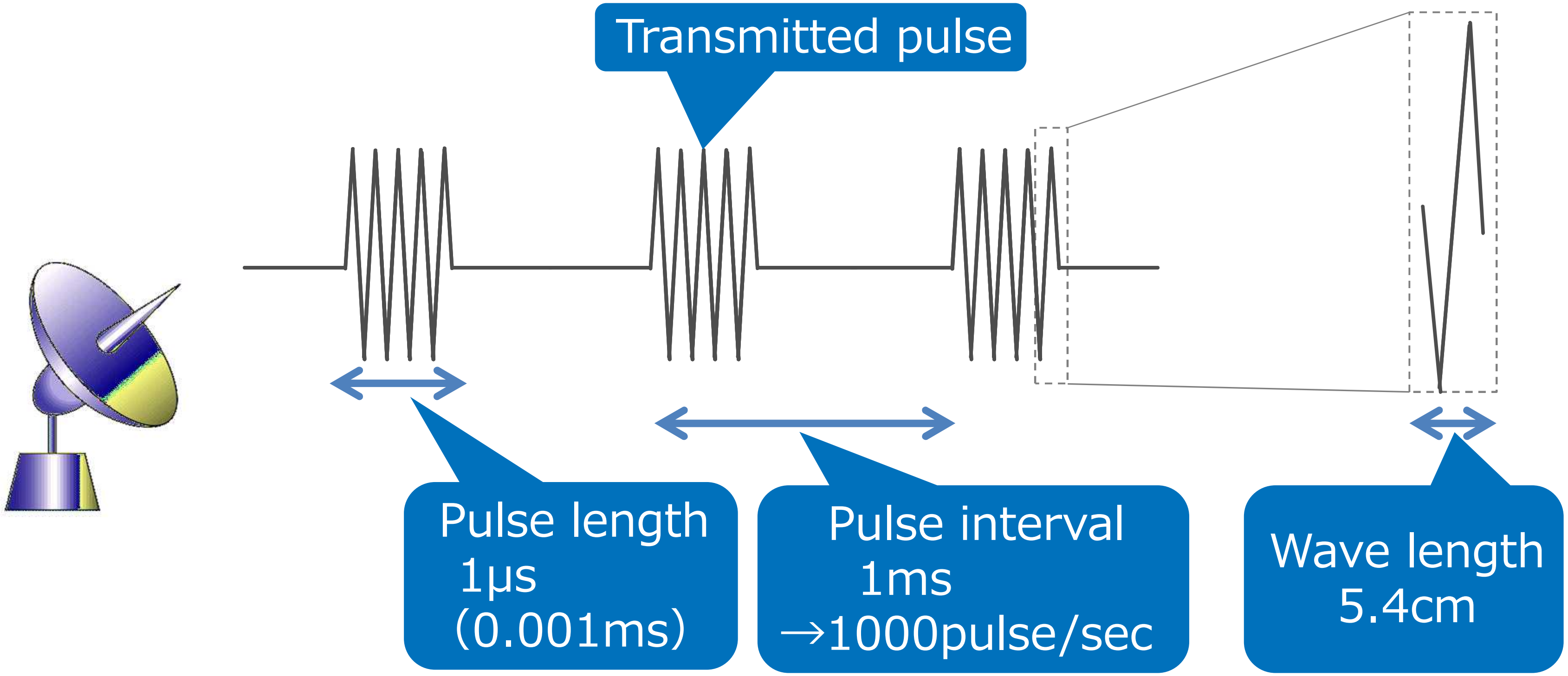
Average power P_{av} = $P_t \cdot \tau \cdot fr$
= 250 × 10^3 × 1.0 × 10^{-6} × 1000
= 250 (W)

Pulse interval (Tr)
（1.0ms）

PRF (Pulse Repetition Frequency)

$$fr = \frac{1}{Tr} = 1/0.001 = 1000 \text{ (Hz)}$$

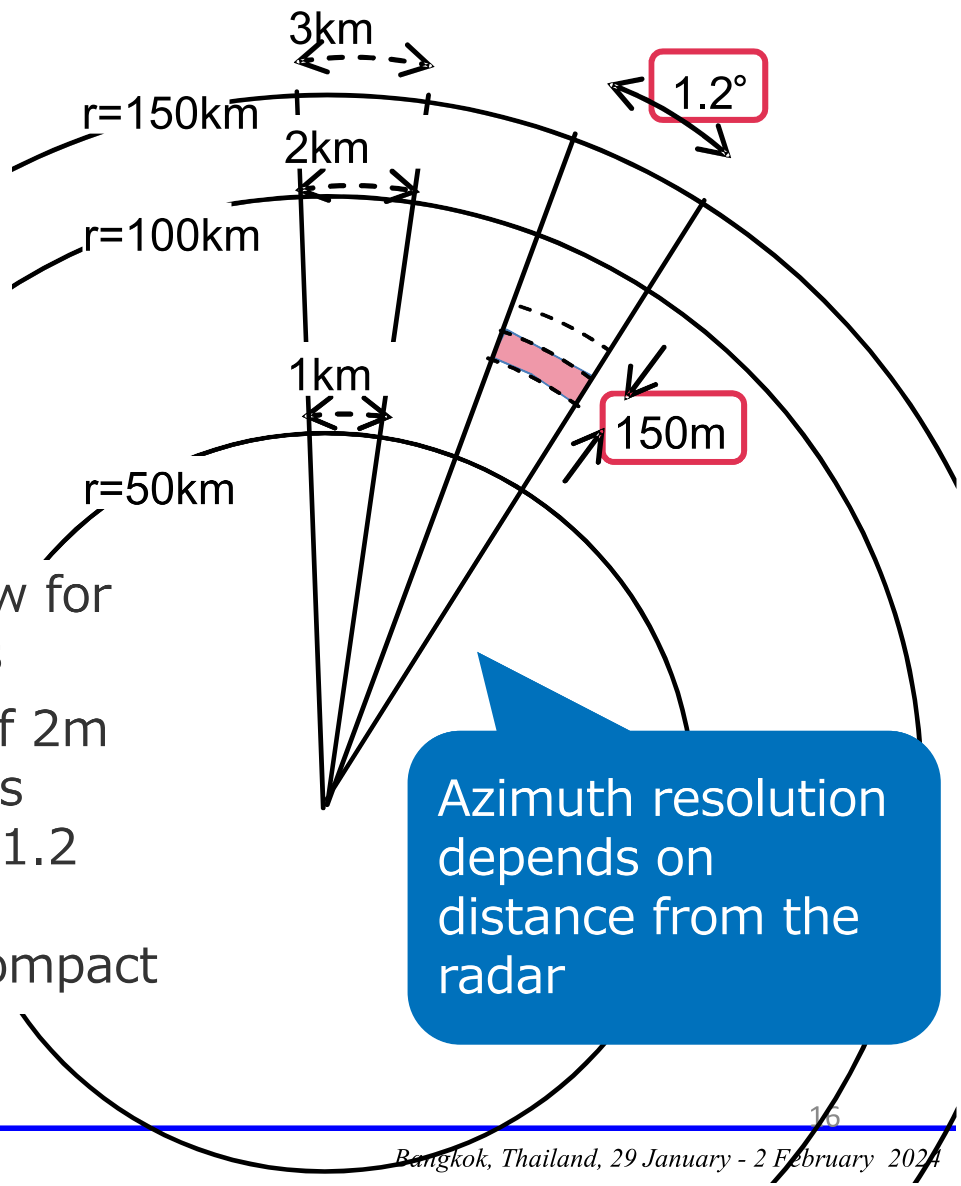
What is radar pulse ?



- During 1 μs, the electromagnetic wave travels 300 m.
  → range resolution is 150m (Half value considering round trip)
- During 1 ms, the electromagnetic wave travels 300 km.
  → maximum detection range is 150km

Observational resolution

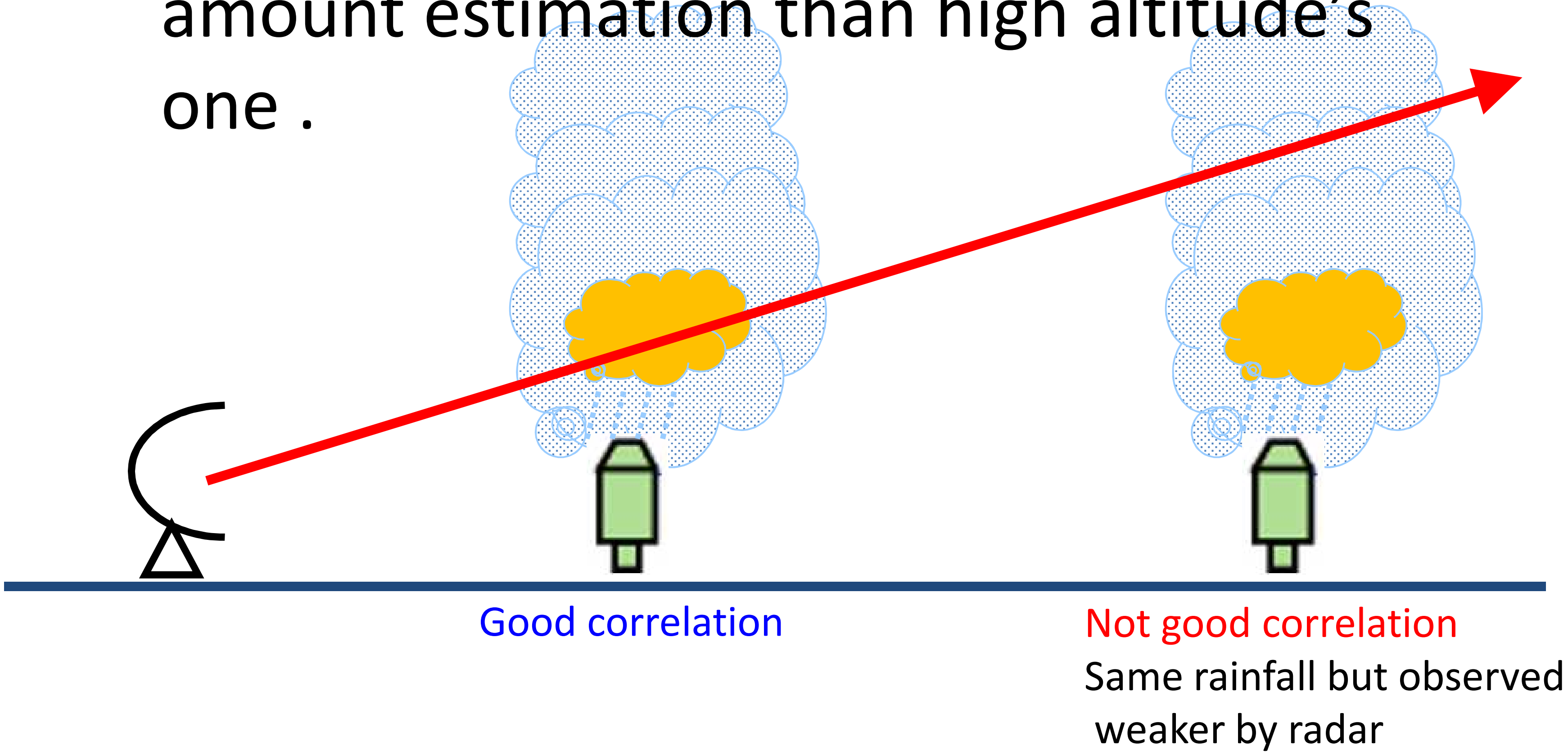
- Range resolution
  1μs of pulse length corresponds to 300m in distance
  → range resolution is 150m
- Azimuth resolution
  Assume the antenna beamwidth is 1.2 degrees.



- Larger antenna allow for smaller beamwidths
- Antenna diameter of 2m for X and 4m for C is required to achieve 1.2 degree beamwidth
  → X can be more compact

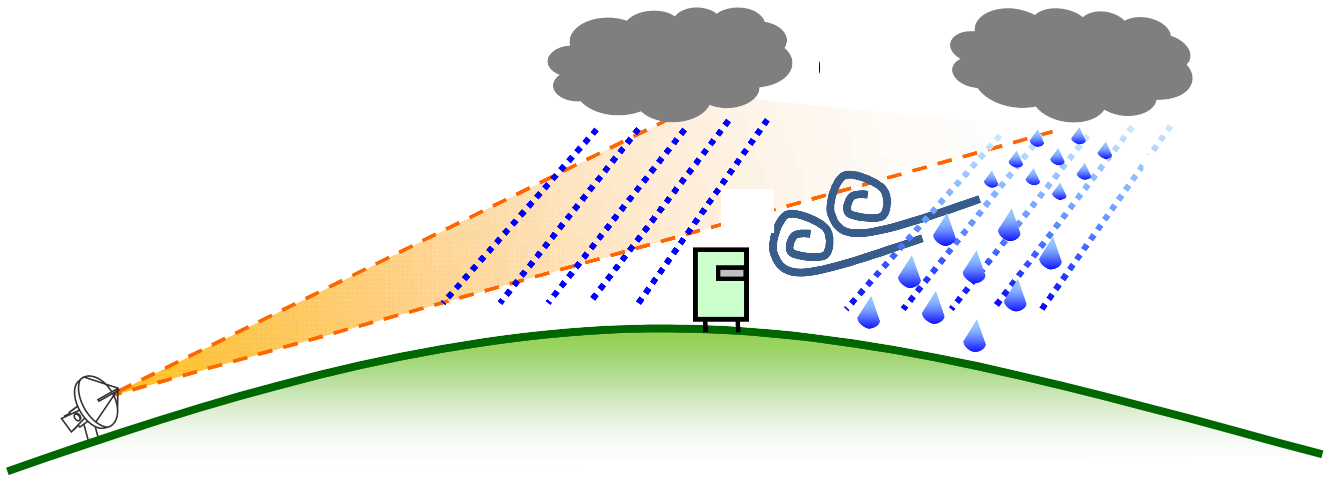
Observation height on radar beam path

- Reflectivity from raindrop around surface has more good correlation on rain fall amount estimation than high altitude's one .



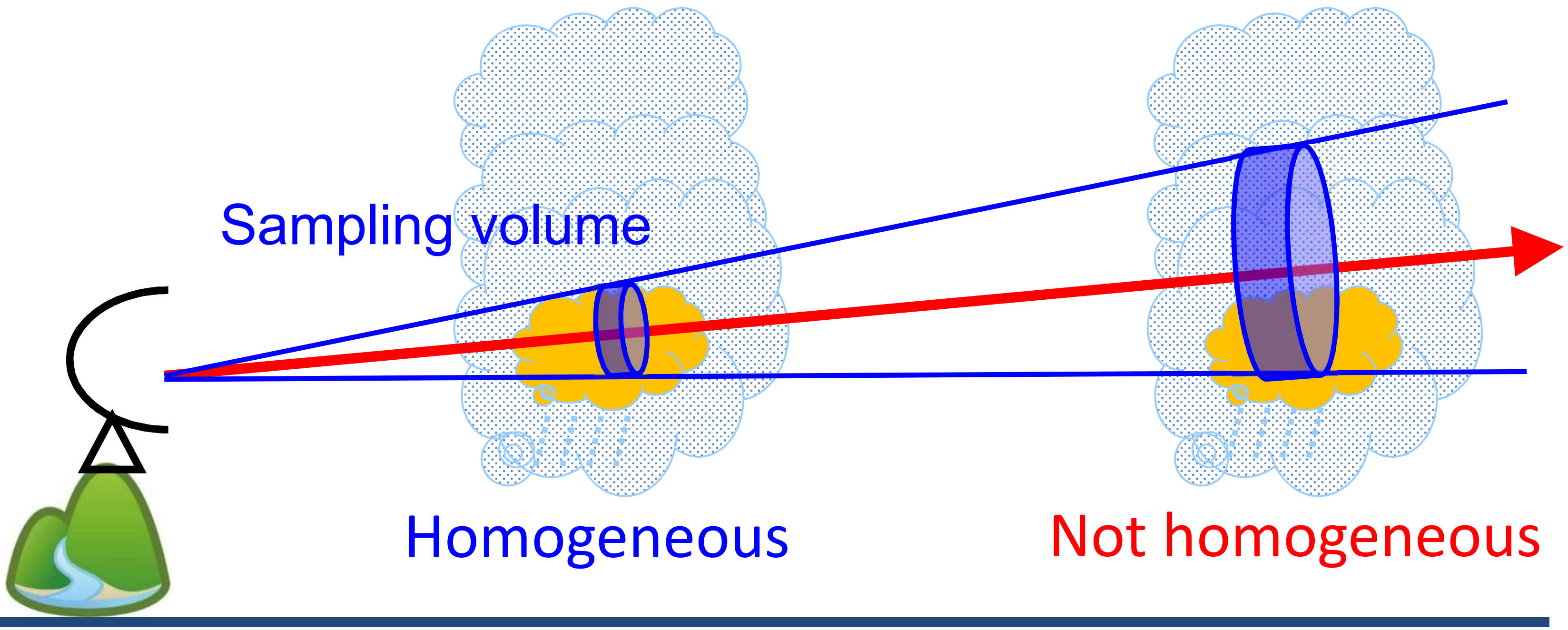
Observation height on radar beam path (cont.)

- At higher observation altitudes, raindrops take longer time to fall, resulting in poor correlation with ground rainfall.
- Correlation with ground rainfall is poor because the size and type of raindrops are different between the sky above and near the ground, where the radar is observing.
- When winds are strong, the correlation with ground rainfall is poor because it does not fall straight to the ground.

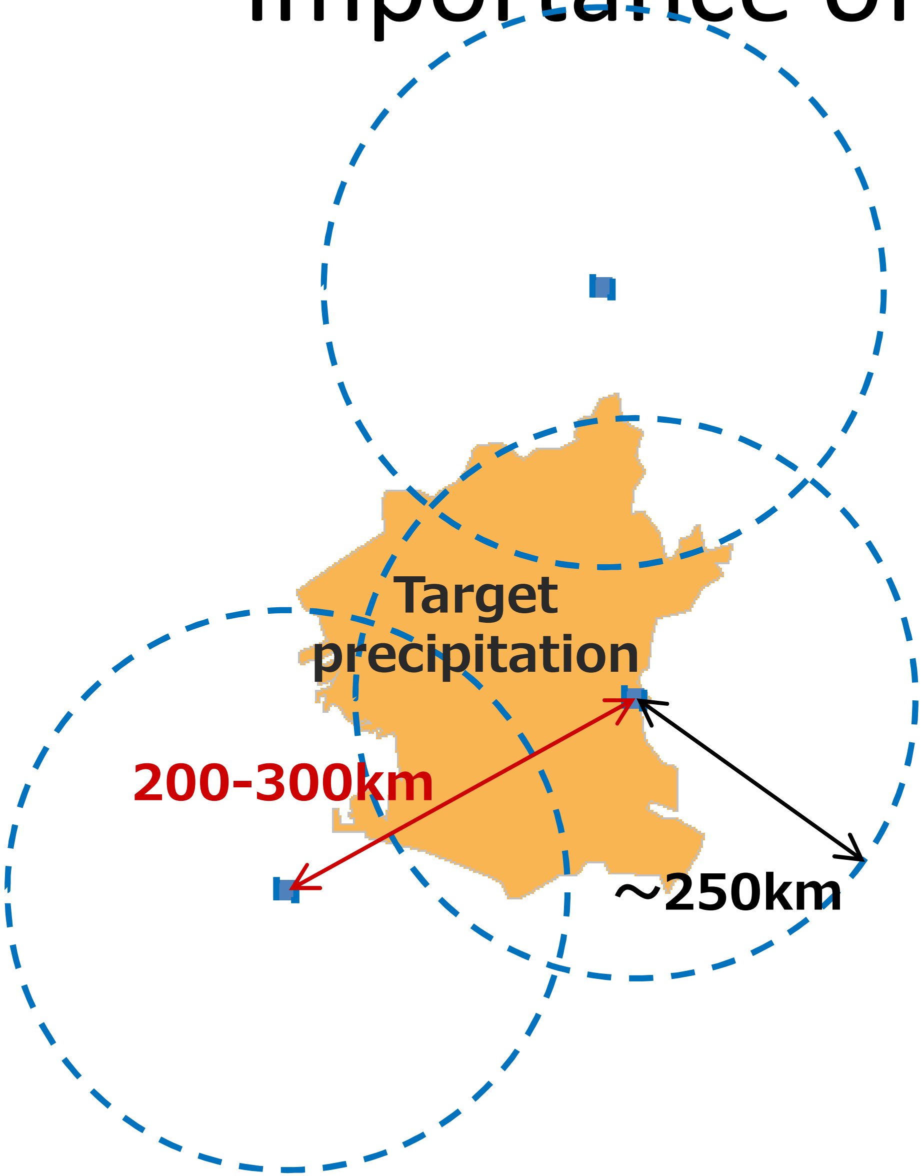


Sampling volume

- Sampling volume get larger with distance from radar
  - If the sampling volume get larger and not homogeneous situation, it generally makes the estimated rainfall intensity weakened.



Importance of radar network



- Azimuth resolution of each radar increases with distance
- Sampling volume also increases with distance
- Beam height increases with distance

⇒ Quantitative characteristics of radar data deteriorate with distance

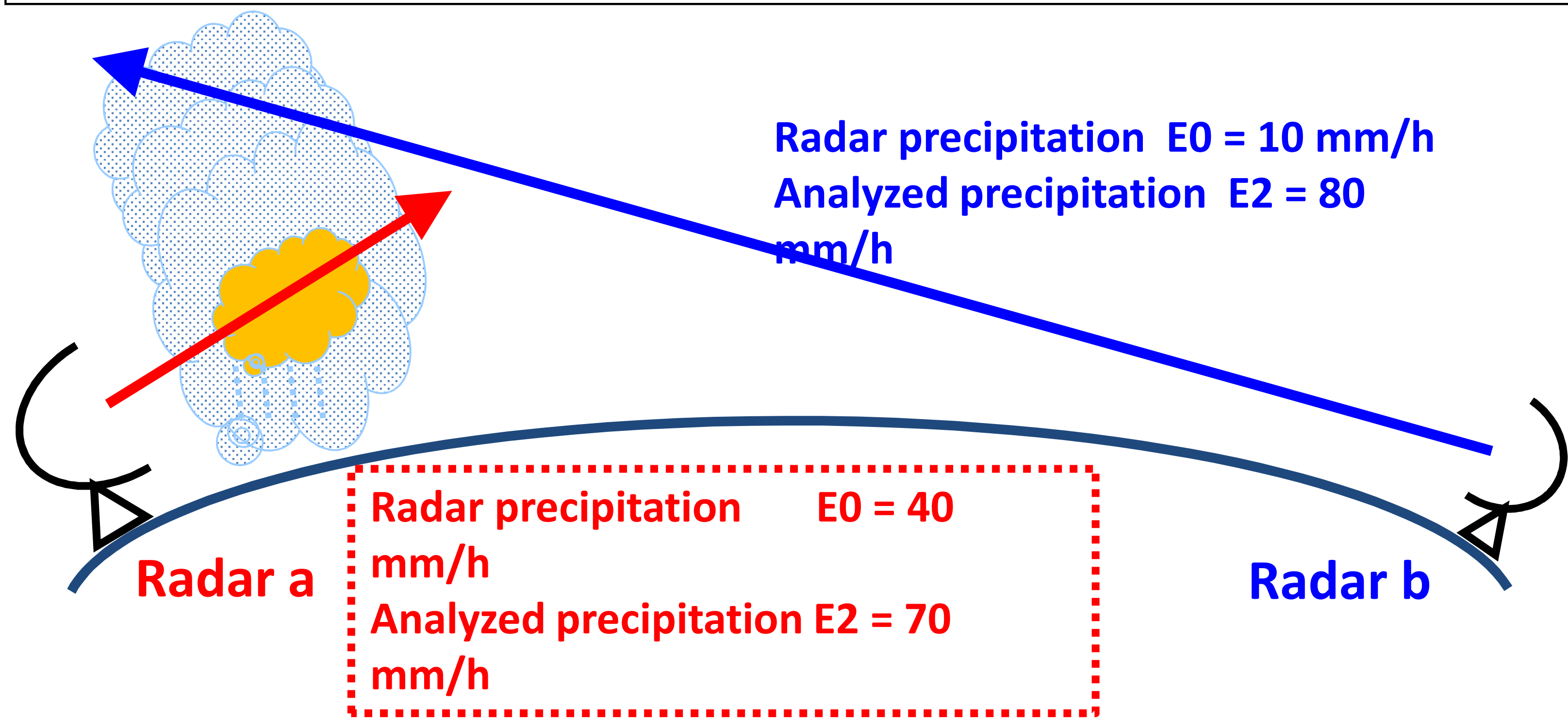
⇒ Multiple radar coverage with overlap area is necessary to derive good quality data

⇒ Importance of radar network

Composition of Second Precipitation Estimation

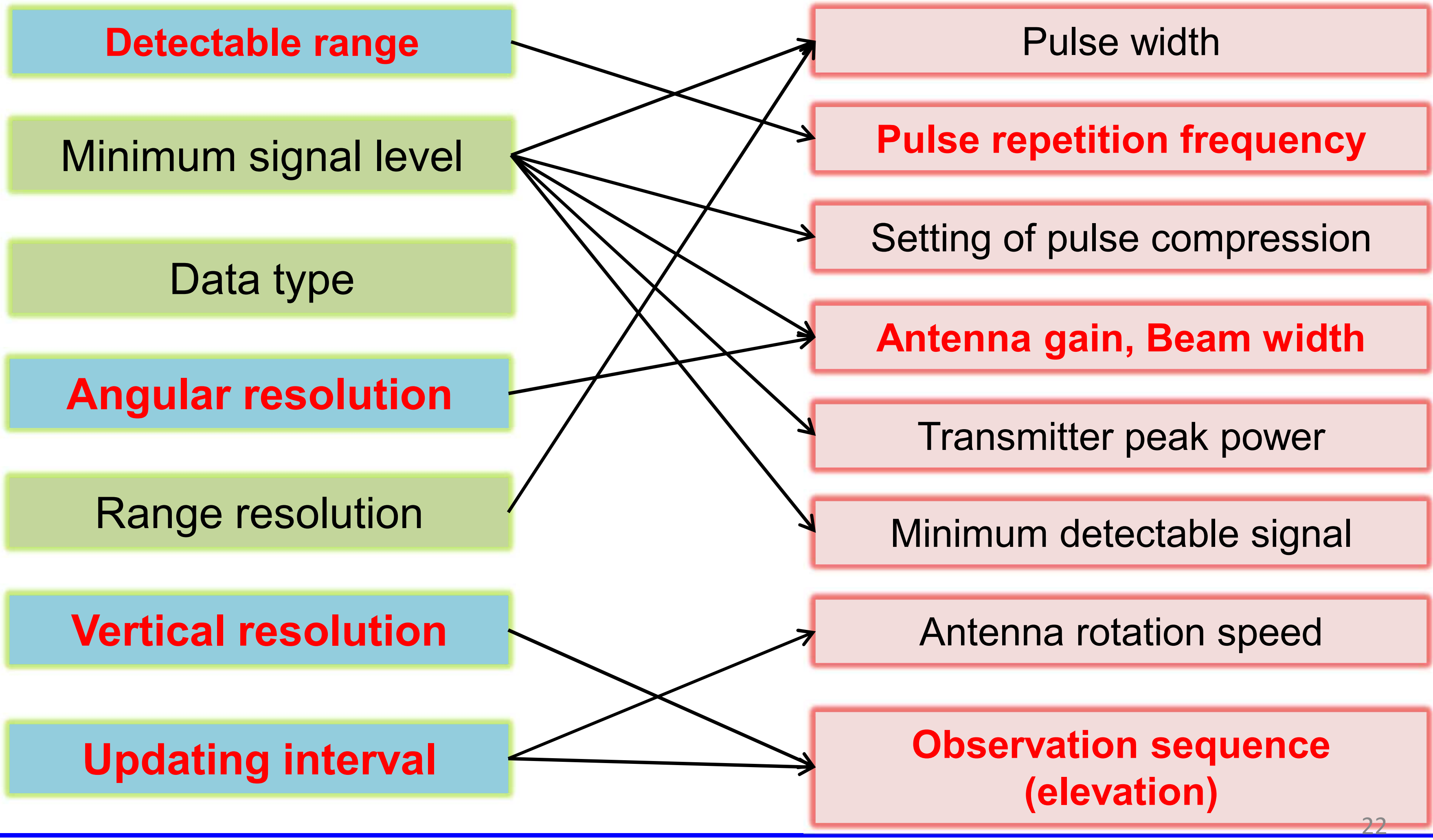
Maximum value method is employed on common observation area of neighboring radar.

Several radars observe the same precipitation at grids of common observation coverage area on composition map, maximum radar precipitation is used as value of QPE.



Consideration of radar parameters

- Expected data specifications
- Needed radar specifications and parameter settings

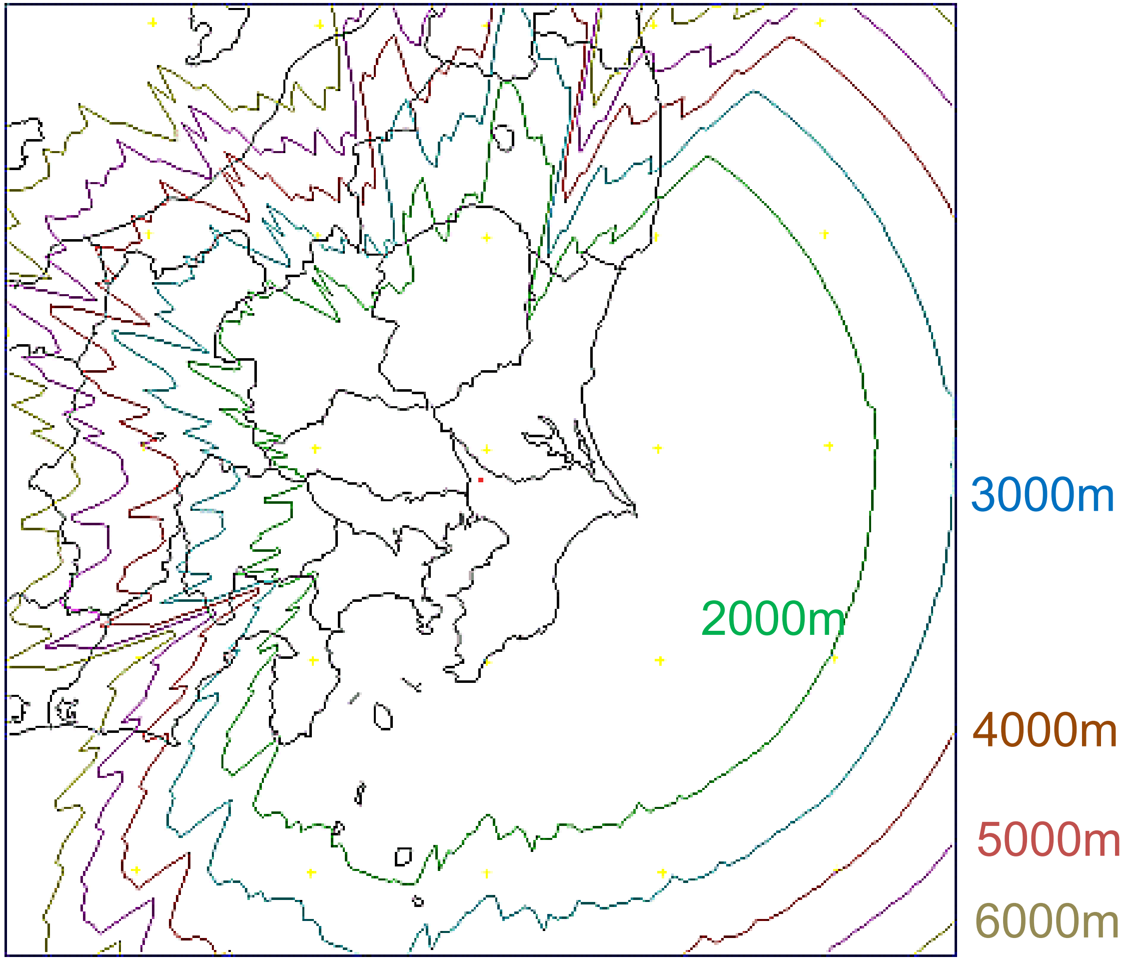


Comparison between S,C,X-band

	Merits	Demerits
S-band	・Less attenuation by rain ・Wide detectable range of Doppler velocity	・Need large antenna to get good angular resolution ・Need much electric power supply ・Need rigid tower ・Costly to initial and maintain
C-band	・Medium attenuation by rain (mitigate attenuation by dual Pol.) ・Medium antenna is enough ・Enough coverage ・Cost-effective	・Attenuation by extremely heavy rain ・Medium detectable range of Doppler velocity
X-band	・Good angular resolution with small antenna ・Good sensitivity for snow / weak rain ・Compact system	・Large attenuation by rain ・Small detection range

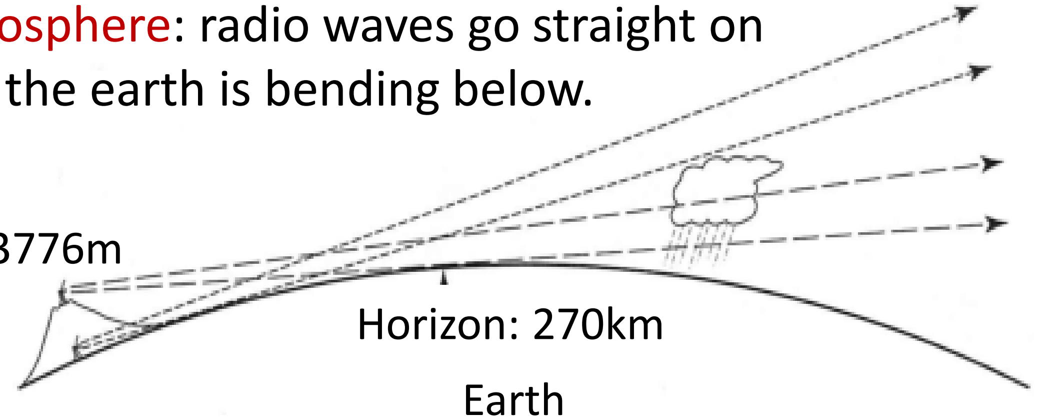
- Making a map of effective beam height
  →Considering installation altitude

Contour of
effective beam height
(detectable area)

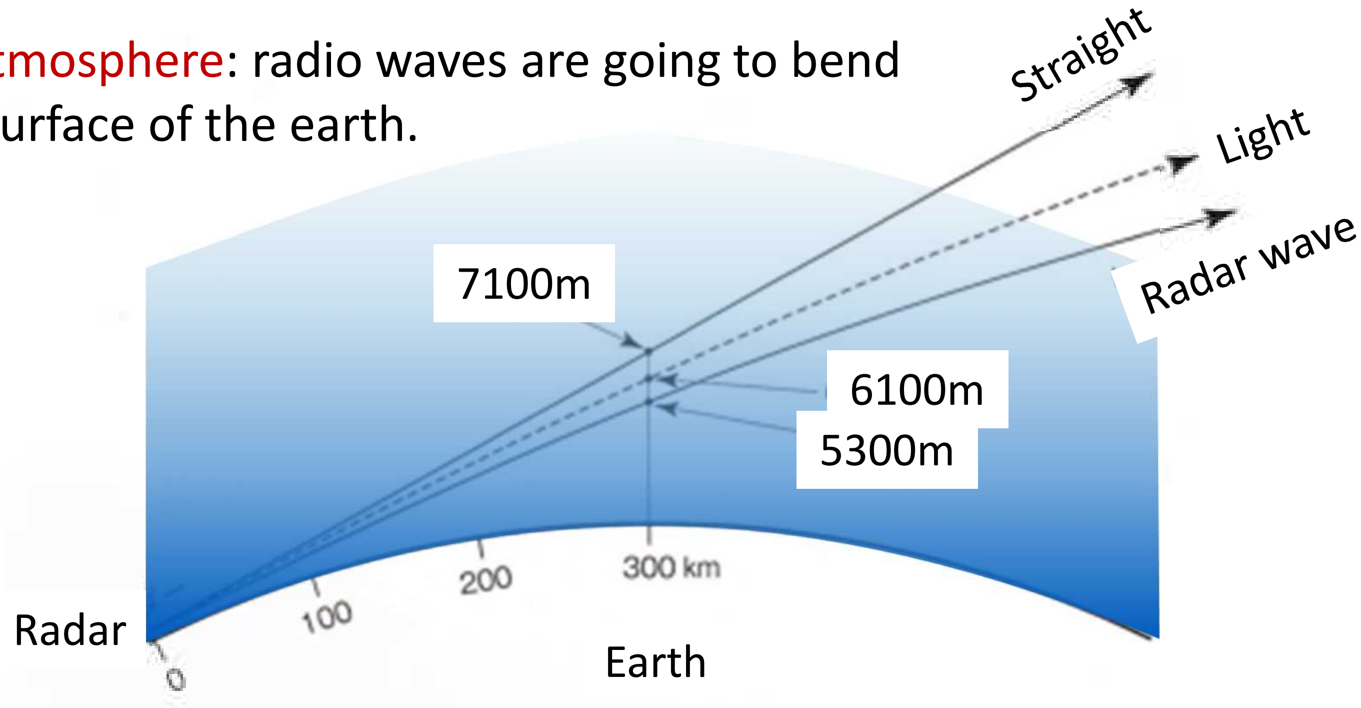


Propagation of radio wave

Earth without atmosphere: radio waves go straight on and the surface of the earth is bending below.



Earth with atmosphere: radio waves are going to bend toward the surface of the earth.



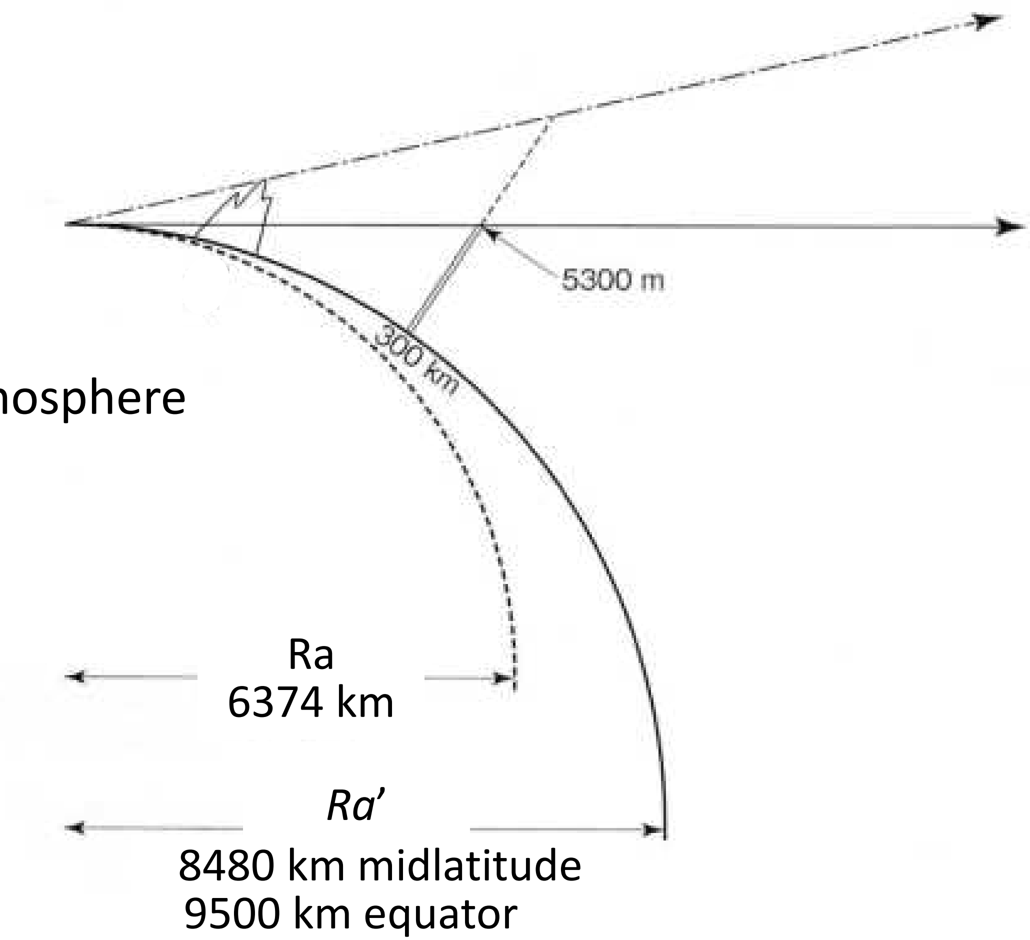
Effective earth radius

Assuming that radio propagation is straight, imaginary earth's radius called "**effective earth radius**" is introduced. The earth radius ***Ra*** and effective earth radius ***Ra'*** are related as,

$$Ra' = \frac{Ra}{1 + Ra\dfrac{dn}{dH}}$$

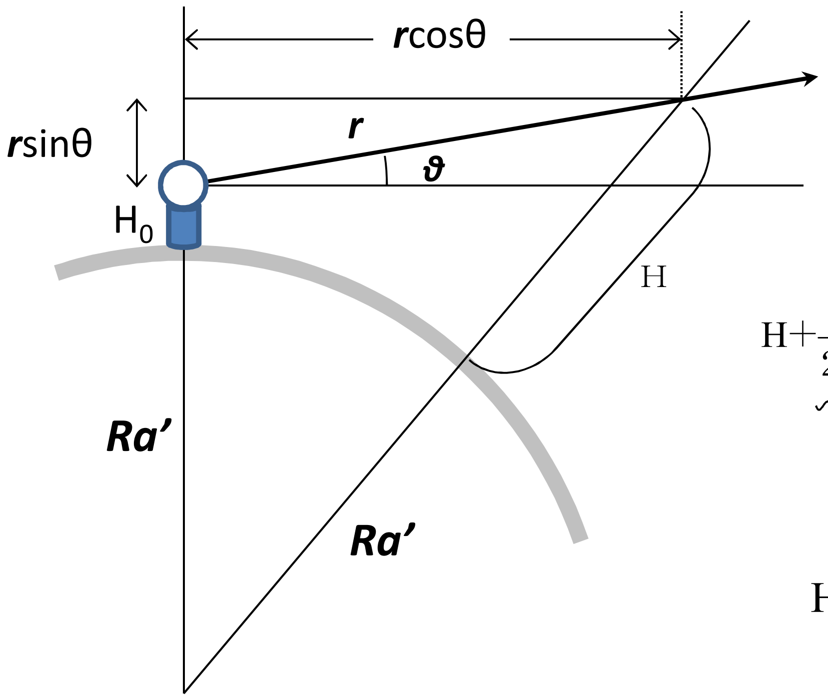
$\dfrac{dn}{dH}$: vertical change rate of refractive index of the atmosphere

Ra' : 4/3R in midlatitudes
3/2R in the equator



Height of a target

When radio waves are transmitted at elevation angle ***ϑ***, from the radar of height H_0 , let's get the height of the target at the range of r using simple geometry.



Ra' : effective earth radius
H_0 : height of the antenna center
ϑ : elevation of the antenna

$$(Ra' + H)^2 = (Ra' + H_0 + r\sin\theta)^2 + (r\cos\theta)^2$$

$$H + \underbrace{\frac{H^2}{2Ra'}} = H_0 + \underbrace{\frac{H_0^2}{2Ra'}} + r\sin\theta + \underbrace{\frac{H_0}{Ra'} r\sin\theta} + \underbrace{\frac{r^2}{2Ra'}\sin^2\theta} + \frac{r^2}{2Ra'}\cos^2\theta$$

Because $Ra' \gg H_0, H,$ ﹏ are neglected.

$$H = H_0 + r\sin\theta + \frac{r^2}{2Ra'}\cos^2\theta$$

Using the units of ***H*** and H_0 [m] and that of ***r*** [km]

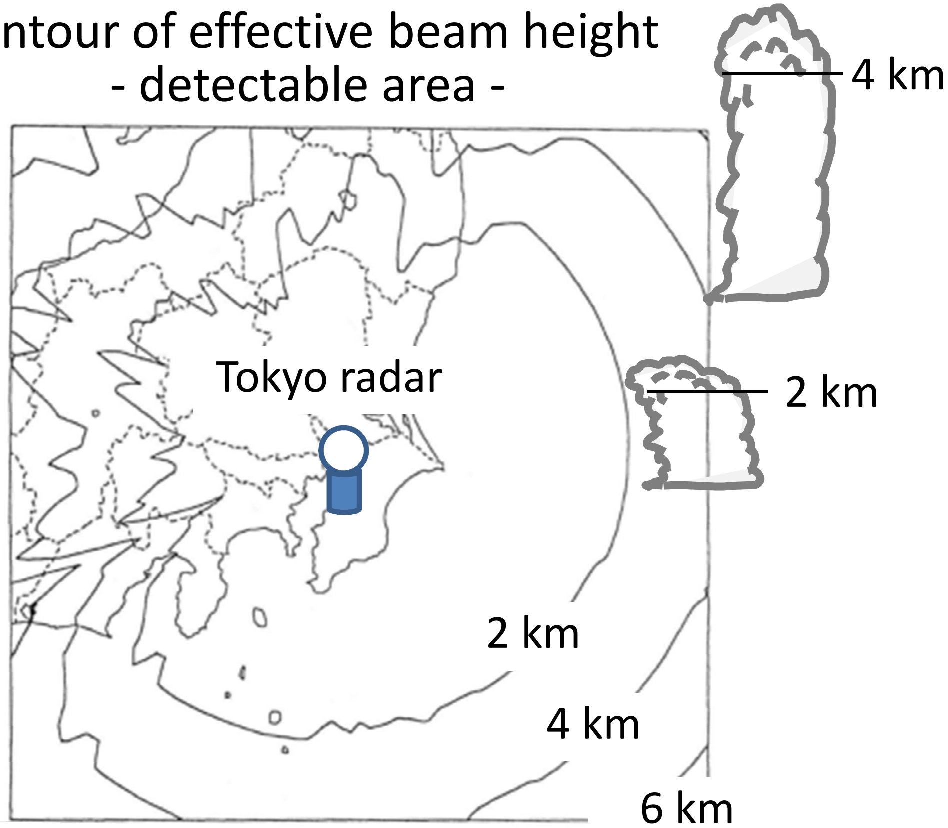
$$H = H_0 + 1000\, r\sin\theta + 0.0589\, r^2\cos^2\theta$$

Effective beam height

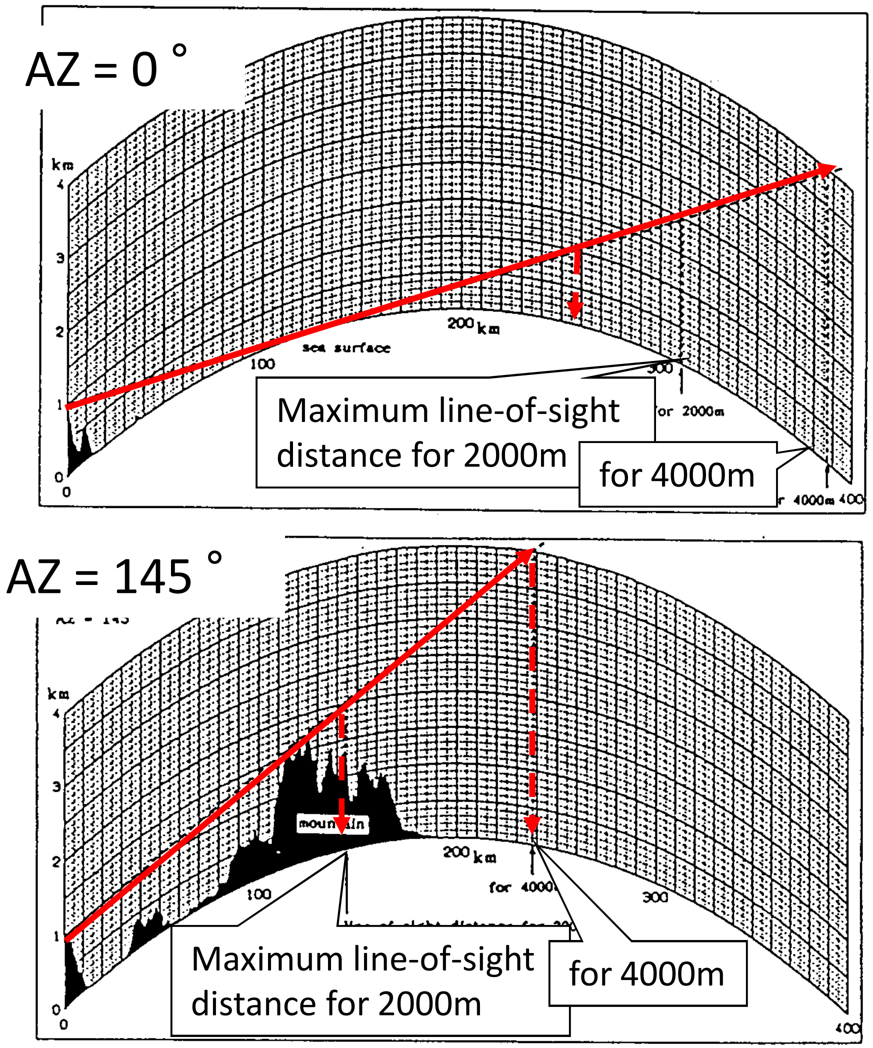
Topographical maps and the effective earth radius give us the "Contour of effective beam height " around a radar. outside the area a effective beam height (e.g. 2 km) contour, precipitation clouds taller than the beam height are detected by the radar.

Google Map

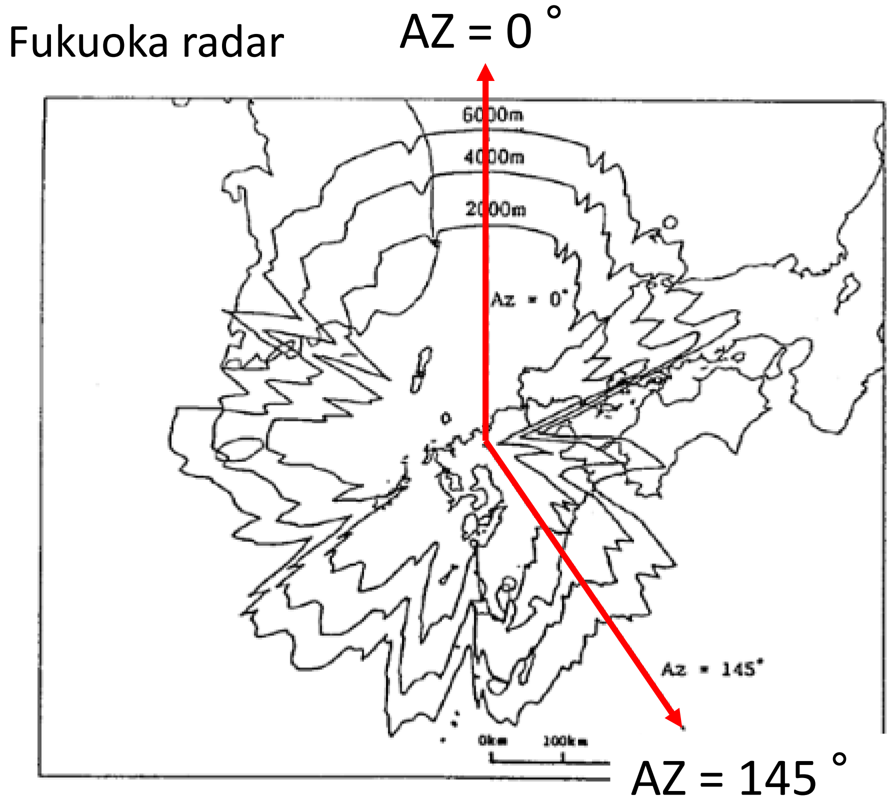
Contour of effective beam height
- detectable area -



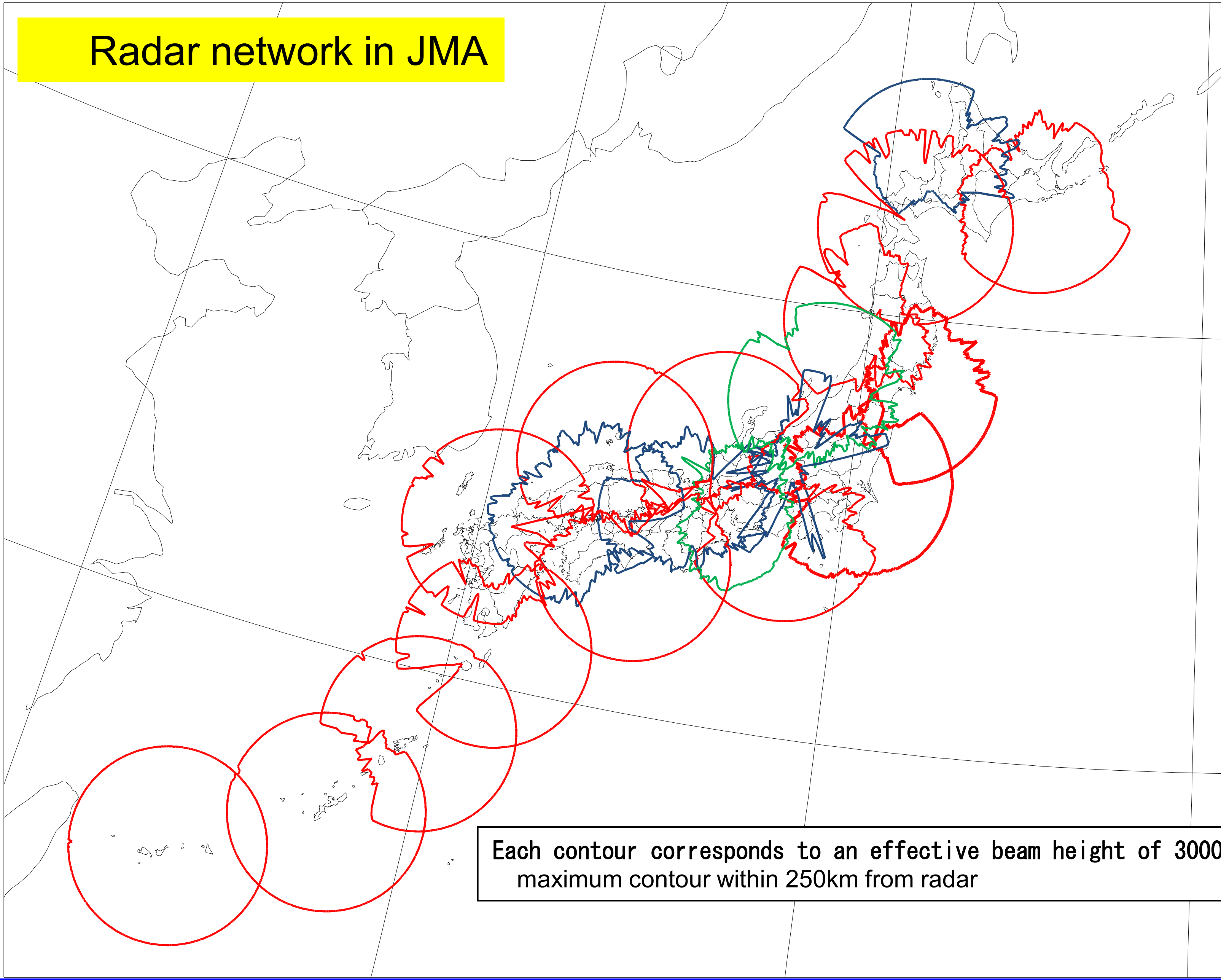
Classical chart to get effective beam height



Now we are easily able to make it using a PC !

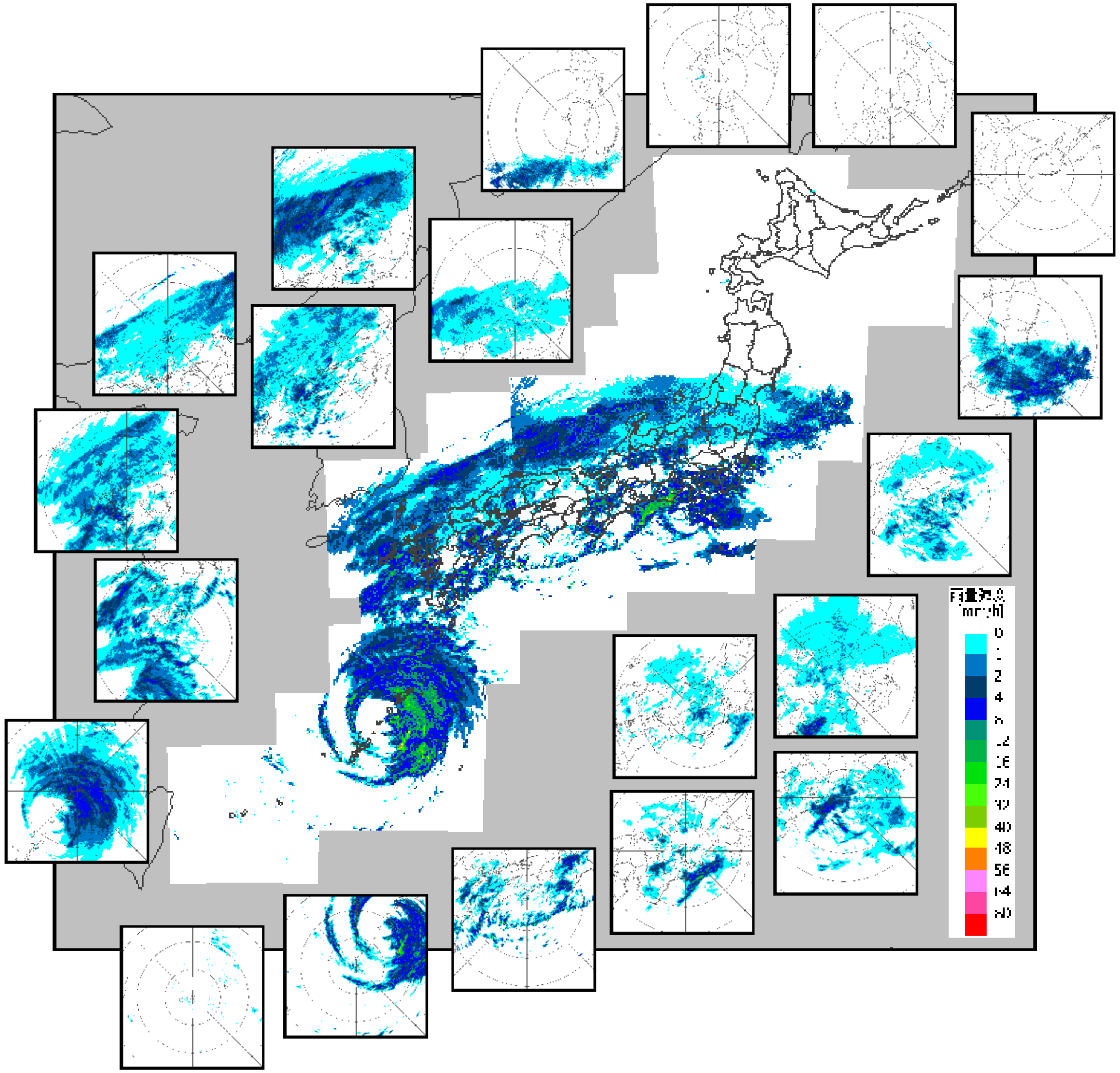


Radar network in JMA



Each contour corresponds to an effective beam height of 3000m
maximum contour within 250km from radar

National composite precipitation map by combining 20 radars



P-CAPPI from 20 radars

Z-R relation ($Z=200R^{1.6}$)

Quality Control

Simple calibration by rain gauge

Calibration coeff. (RAM0→RAM1)

Composite (by maximum)

National composite with 1km mesh

Simple QPE procedure

Way to measure rainfall rate in radars

Transmitted power $\mathbf{P_t}$ [W]
(Known)
Received power $\mathbf{P_r}$ [W]
(measured)

↓ **Radar equation**

Radar reflectivity factor ***Z*** [mm^6/m^3]
(calculated)

↓ ***Z-R* relation**

Rainfall rate ***R*** [mm/h]
(estimated)

Radar equation

Radar equation (full version)

The final form of the radar equation considering attenuation effect is,

$$P_r = \frac{\pi^3 P_t G^2 h \theta^2 |K|^2 \Sigma D^6}{1024 \log_e 2 \, r^2 \lambda^2} \cdot 10^{-0.1L} \cdot 10^{-0.2 k_g \cdot r}$$

Now we learn the relation between transmit power $\mathbf{P_t}$ and received power $\mathbf{P_r}$ at the distance of r, which is back-scattered by precipitation in echoing volume.

P_t: transmit power (peak power) (such as 250000 W)
G: antenna gain (44 dBZ)
h: pulse length (300 m)
θ: beam width (1.2 degree → 3.14/180 radian)
$|K|^2$: dielectric coefficient (0.970 for rain)
λ: wavelength (0.054 m)
L: loss by wave guides
K_g: loss by atmospheric gas (0.01dB/km)

Simpler radar equation

Simplifying Radar equation

All of the parameters associated with a specific radar can be grouped together as constant C_1.

$$C_1 = \frac{\pi^3 P_t G^2 h \theta^2}{1024 \log_e 2 \lambda^2} \cdot 10^{-0.1L} \quad (1)$$

Then the radar equation will be

$$P_r = \frac{C_1 |K|^2 \Sigma D^6}{r^2} \cdot 10^{-0.2 k_g \cdot r} \quad (2)$$

We define a parameter $Z = \Sigma D^6$ as "radar reflectivity factor", and give $|K|^2$ the value of 0.97, and further the attenuation of atmospheric gas is now the outside of consideration,

$$\boxed{P_r = \frac{C_2 Z}{r^2}} \quad (3)$$

The simplest radar equation

Simplest Radar equation

$$P_r = \frac{C_2 Z}{r^2} \tag{3}$$

We are interested in Z to estimate rainfall rate, then change Eq.(3) to ,

$$Z = C_3 P_r r^2 \tag{4}$$

We have now obtained a very simple relation between P_r and Z. Here radar reflectivity factor Z is given the unit of [mm^6/m^3] .

The original definition of Z is given by ΣD^6 , but we get Z from radar observation. Then the radar reflectivity factor obtained from radar observation is called “Equivalent radar reflectivity factor” Ze.

Radar reflectivity factor and “dBZ radar equation”

Logarithmic forms of Z

Ze “Equivalent radar reflectivity factor” shows very wide range from 0.001 mm^6/m^3 in fog to 36,000,000 mm^6/m^3 in hail storms. The follwing logarithmic form of Z is more convenient

$$Z = 10\log_{10}\left(\frac{Ze}{1[\mathrm{mm}^6/\mathrm{m}^3]}\right) \qquad (5)$$

The unit of this Z is dBZ (decibels relative to a reflectivity of 1 mm^6/m^3). Z [dBZ] is ranged from -30 dBZ in fog and +76 dBZ in severe hail storms, and rainfall shows from 10 dBZ to 55 dBZ.

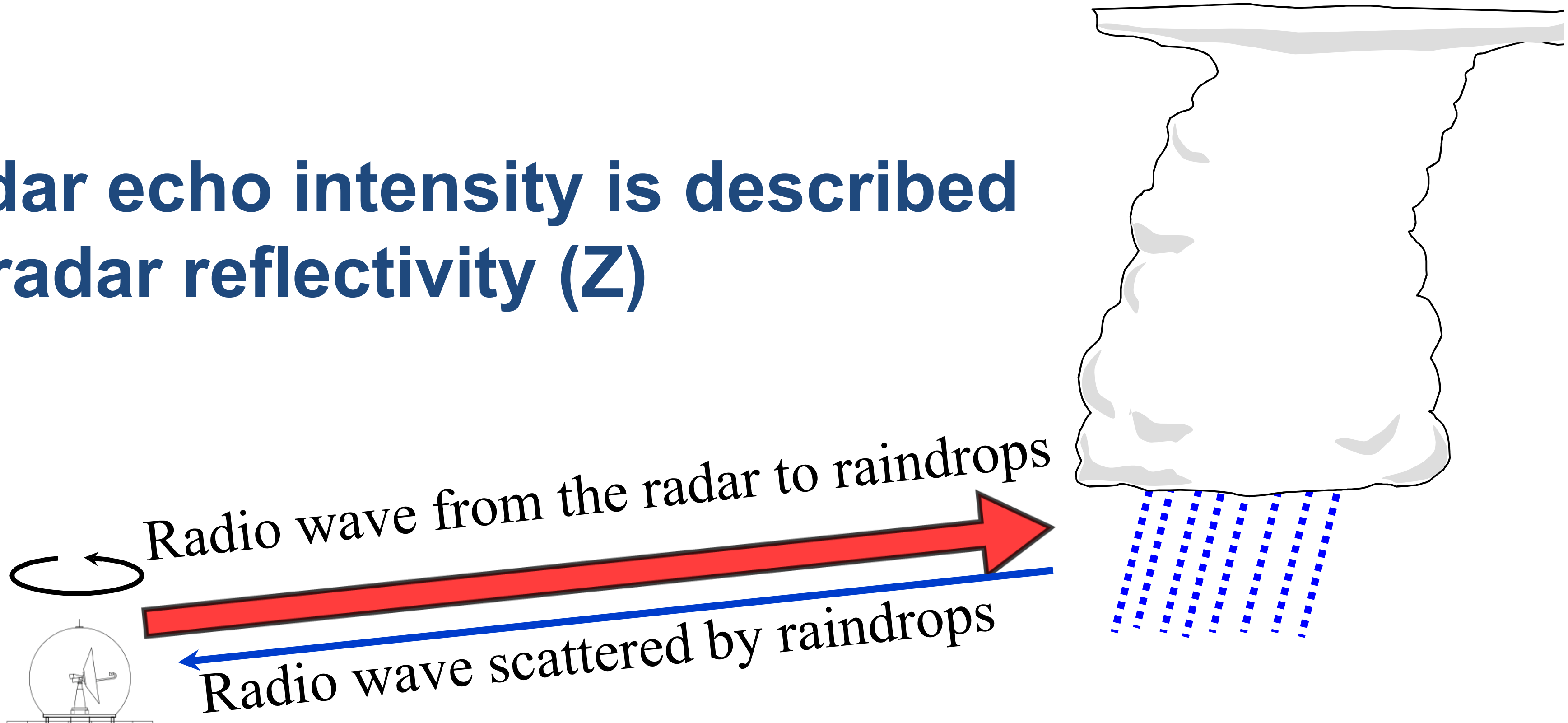
Logarithmic forms of radar equation

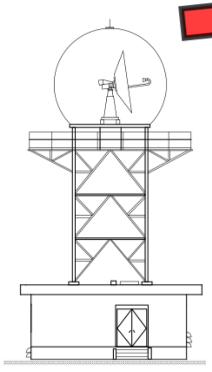
$$Z = C_3 P_r r^2 \qquad (4)$$

$$10\log Z = 10\log C_3 + 10\log P_r + 20\log r$$

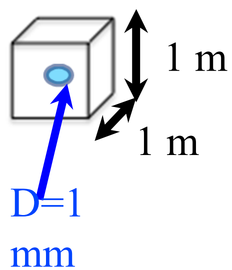
$$Z[\mathrm{dBZ}] = C_4 + P_r[\mathrm{dBm}] + 20\log r[\mathrm{km}] \qquad (6)$$

Radar echo intensity is described as radar reflectivity (Z)





Received signal is converted to radar reflectivity (Z). Z=1 means the situation of one raindrop with 1 mm in diameter per 1m^3 volume.



Radar reflectivity (Z) is usually expressed in the units of dBZ

$Z = \int D^6 N(D) dD$ [mm^6 m^{-3}].

Z=1~1000000 [mm^6 m^{-3}]

dBZ = 10 $\log_{10}$ Z = 0 ~ 60 [dBZ]

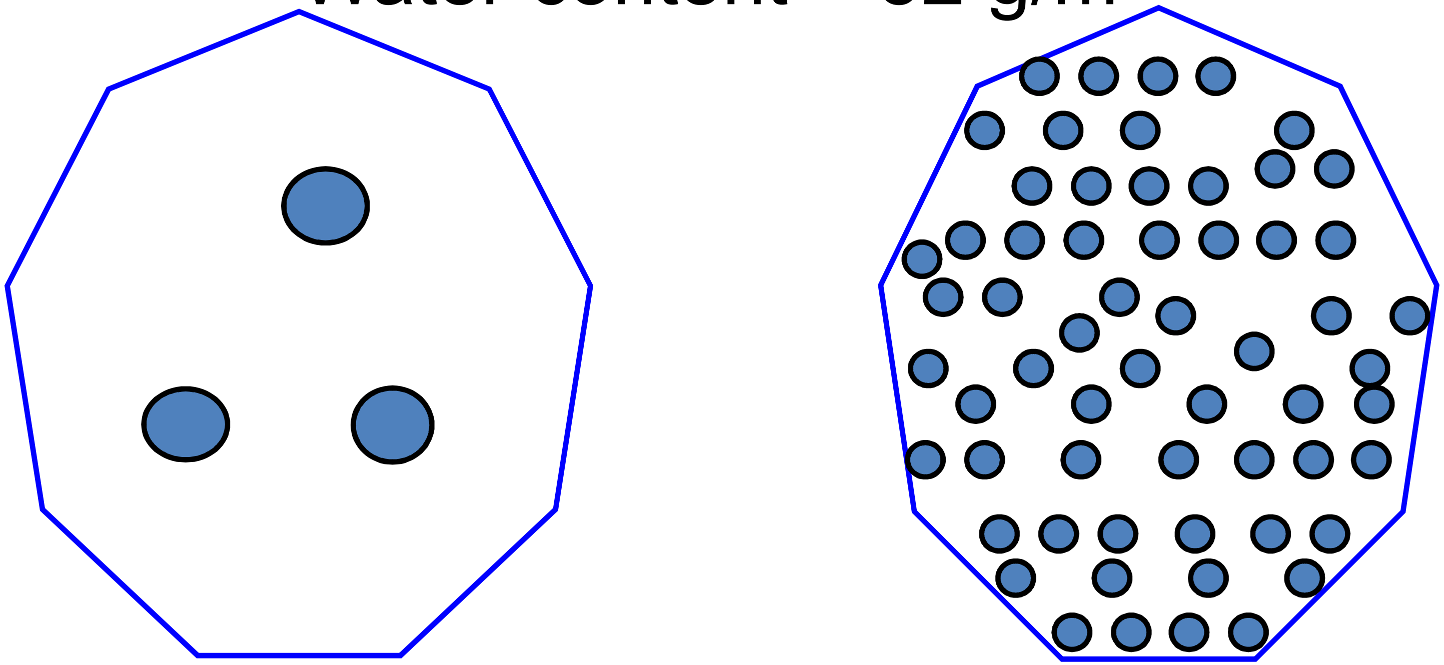
ex.)

$Z[mm^6/m^3]$		dBZ
1	→	0
10	→	10
100	→	20
1000	→	30
10000	→	40

Z is proportional to the sixth power of drops diameter and the number of drops per unit volume and is thus used to estimate the rain or snow intensity.

Large precipitation particles result in large Z

Water content = 52 g/m^3



Small number of large drops
D=3mm, N=3700
Z = 64dBZ

Large number of small drops
D=1mm, N=100000
Z = 50dBZ

Statistical Variability of Z-R relation

Z : radar reflectivity factor

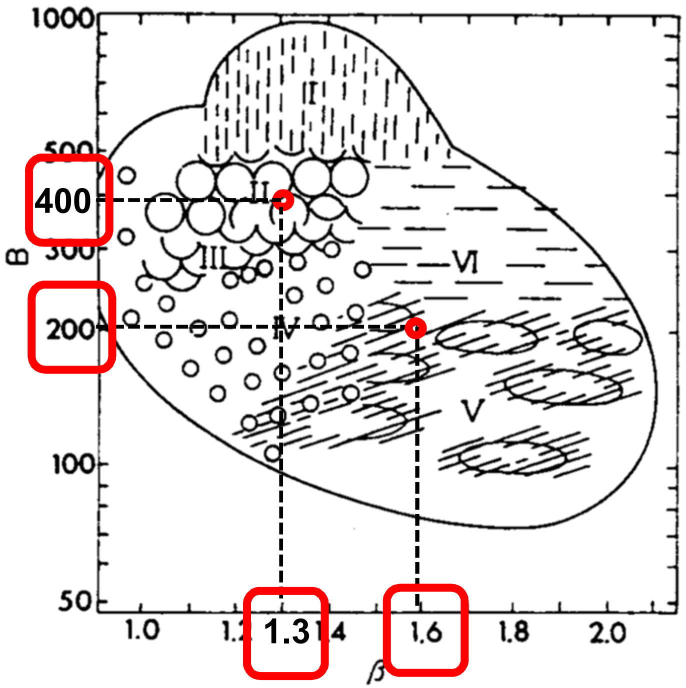
$$Z \equiv \sum D^6$$

D : diameter of rain (mm)

Σ : sum in unit volume (m³)

The relation between ***Z*** and rain rate ***R*** (mm/h) is expressed statistically as follows :

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

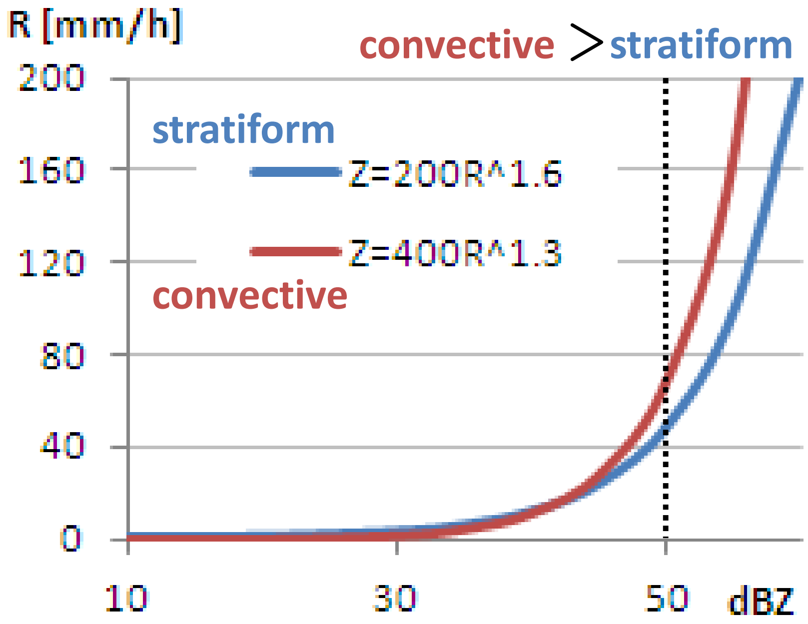


(rain) ***B*** : 80～1000
β : 1.0～2.0

(snow) ***B*** : 500～2000
β : 2.0

Ⅰ : Scattered but somewhat heavy portion of thunderstorm echo, or high, isolated, convective echo in dry atmospheric air (water drops evaporate considerably).
Ⅱ : Center portion where thunderstorm echo is dominant, or strong, massive echo with slightly scattered shape.
Ⅲ : Breaking out or growing stage of the convective cells.
Ⅳ : Small, solid-like, convective echoes scattered or aligned.
Ⅴ : Stratiform echoes uniformly spread, or scattered weak echoes.
Ⅵ : Final stage of thunderstorm completely scattered, or scattered portions.

Estimate R from Z by different Z-R relation

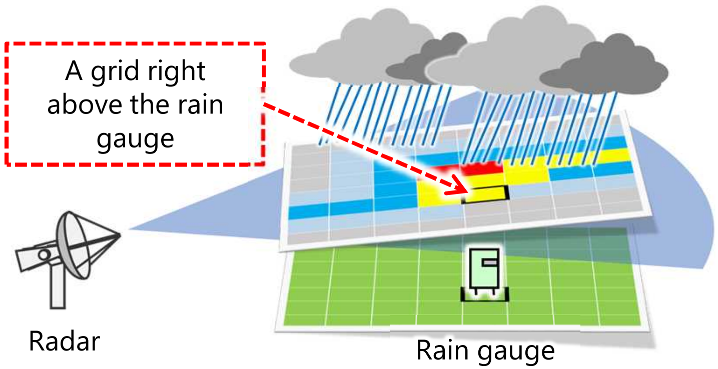


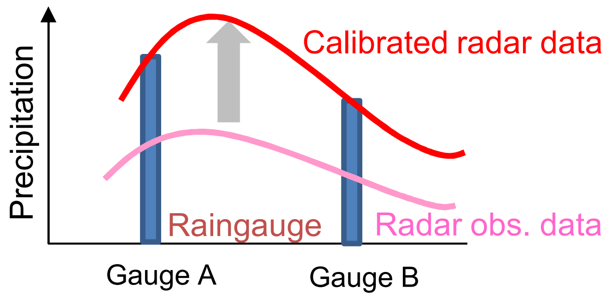
Z [dBZ]	Rain Rate (stratiform)	Rain Rate (convective)
30 dBZ	3 mm h^{-1}	2 mm h^{-1}
40 dBZ	12 mm h^{-1}	12 mm h^{-1}
45 dBZ	24 mm h^{-1}	30 mm h^{-1}
50 dBZ	50 mm h^{-1}	70 mm h^{-1}

Quantitative Precipitation Estimation (QPE)

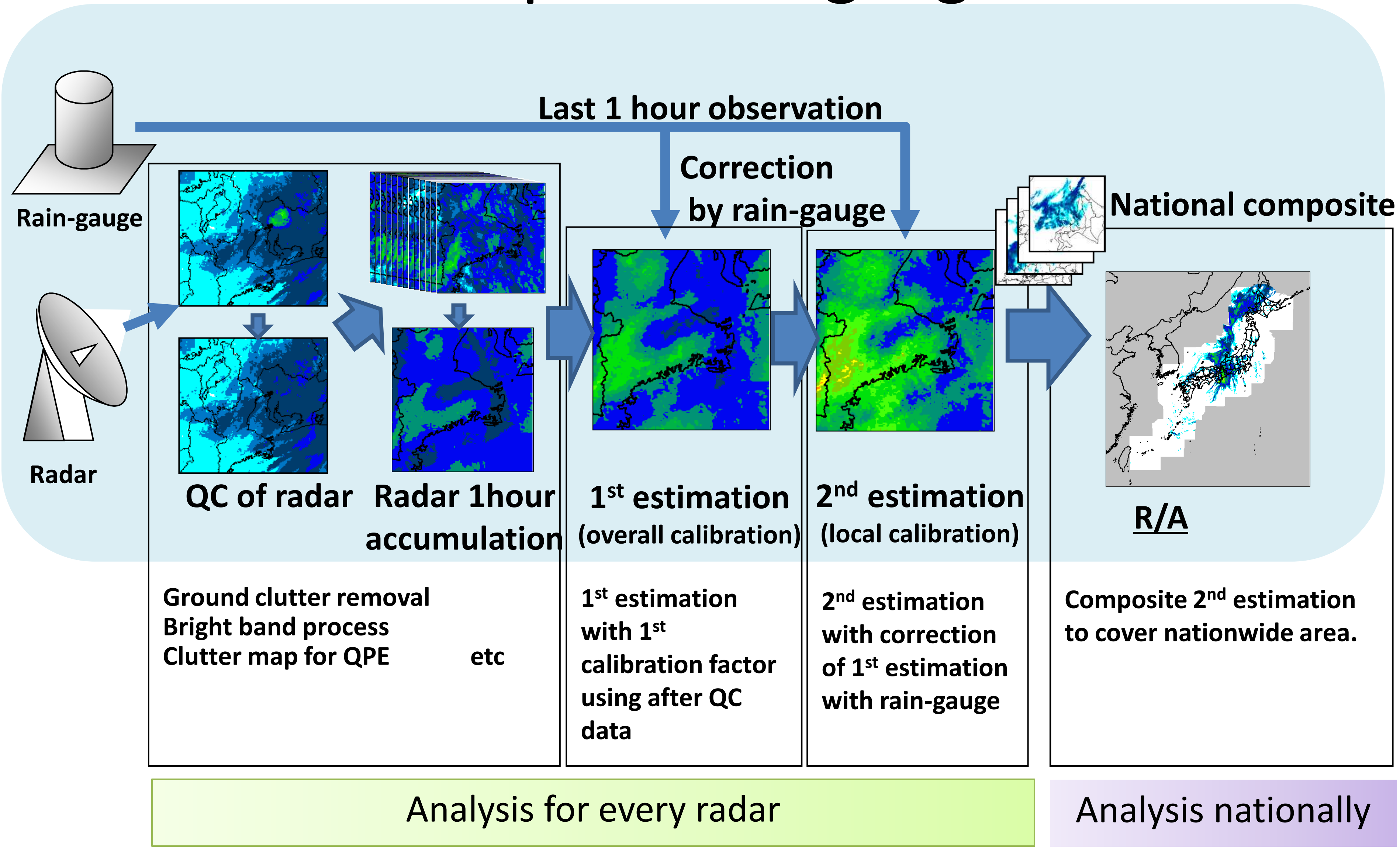
Radar data is adjusted to the value of raingauge for bias correction.
Therefore, the value of raingauge is the absolute standard in the QPE calculation.

- To calculate the amount of rainfall from Single-pol radar, we set assumptions on how reflectivity is related to the raindrop amount and sizes.
- Form of rain is different in every moment, so this assumption makes the bias in the actual estimation process from reflectivity only.



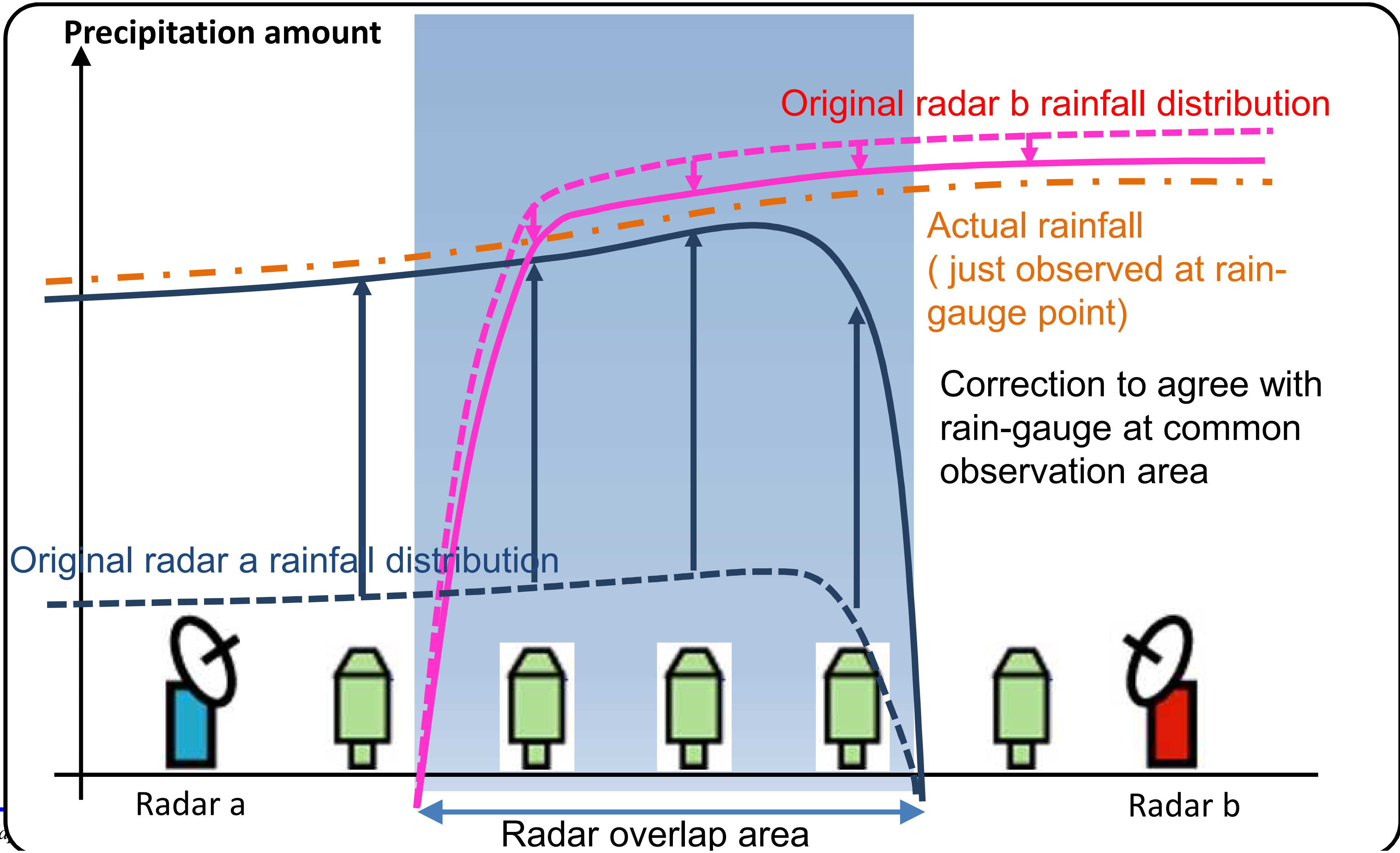


JMA QPE processing algorithm



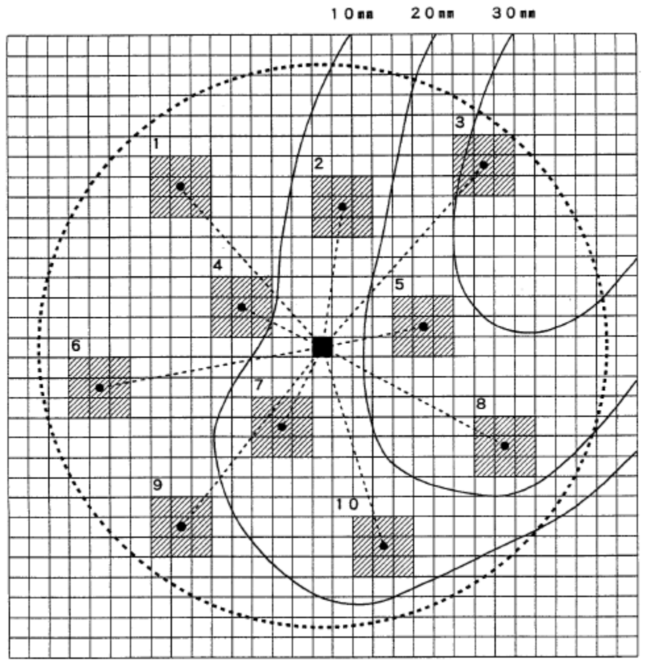
First calibration of radar precipitation

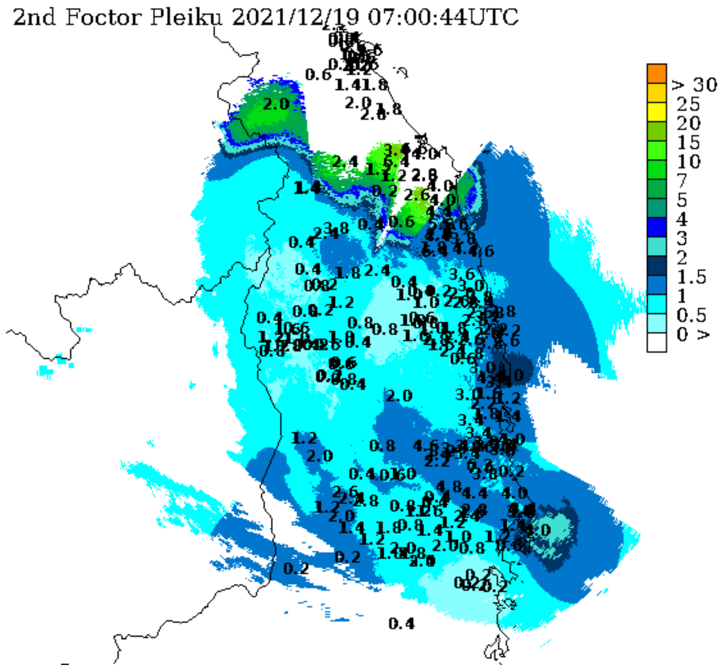
- Correction to agree with radar and rain-gauge



Second calibration (Point to grid comparison)

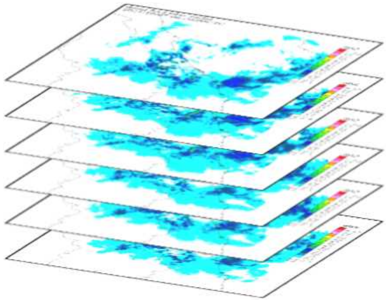
In the 1st calibration, the calibration was done with the average amount, but in the local view, the 1st calibrated precipitation of the radar and the 1hour rainfall of the rain gauge do not fit.
Therefore ,2nd calibration is performed to match the raingauge locally.



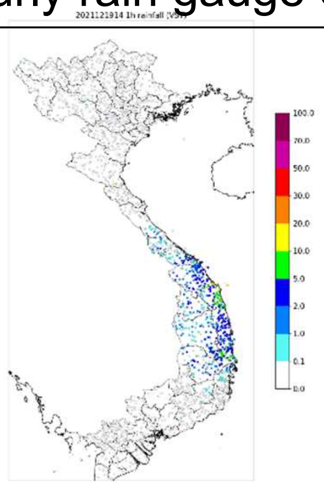


JMA-QPE algorithm applying to Vietnam

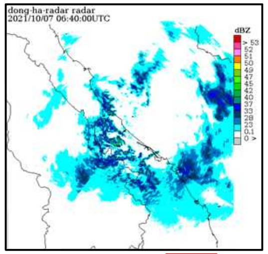
1 hour accumulation
Add the data of past hour



Hourly rain gauge data

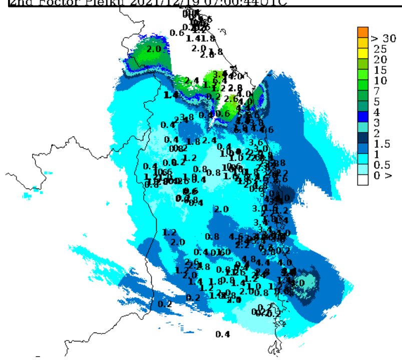


1st calibrarion
Calibration for the entire area

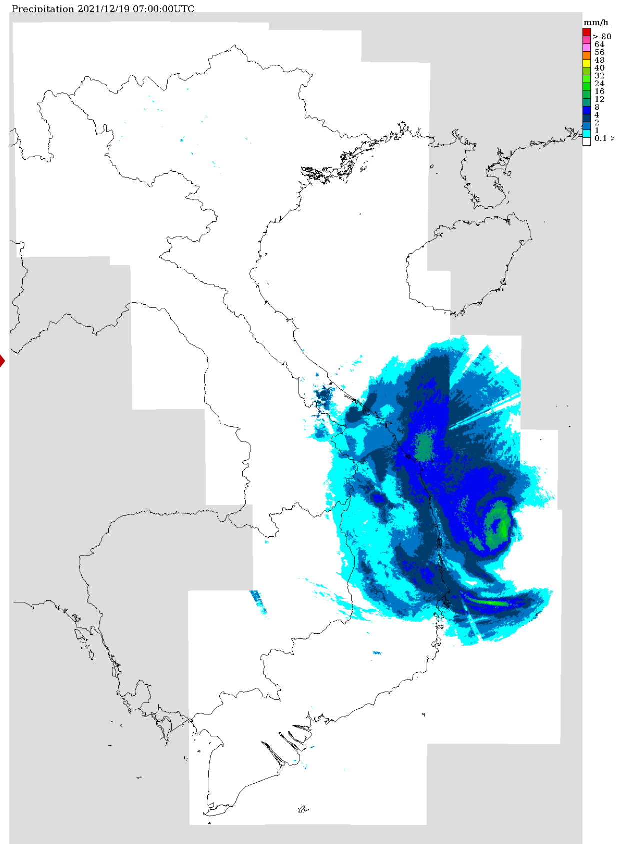


$\times \sigma$

2nd calibrarion
Local calibration with raingauge



Nationwide Composite
Composite all 2nd estimation data to cover all Viet Nam



Error sources on weather radar observation

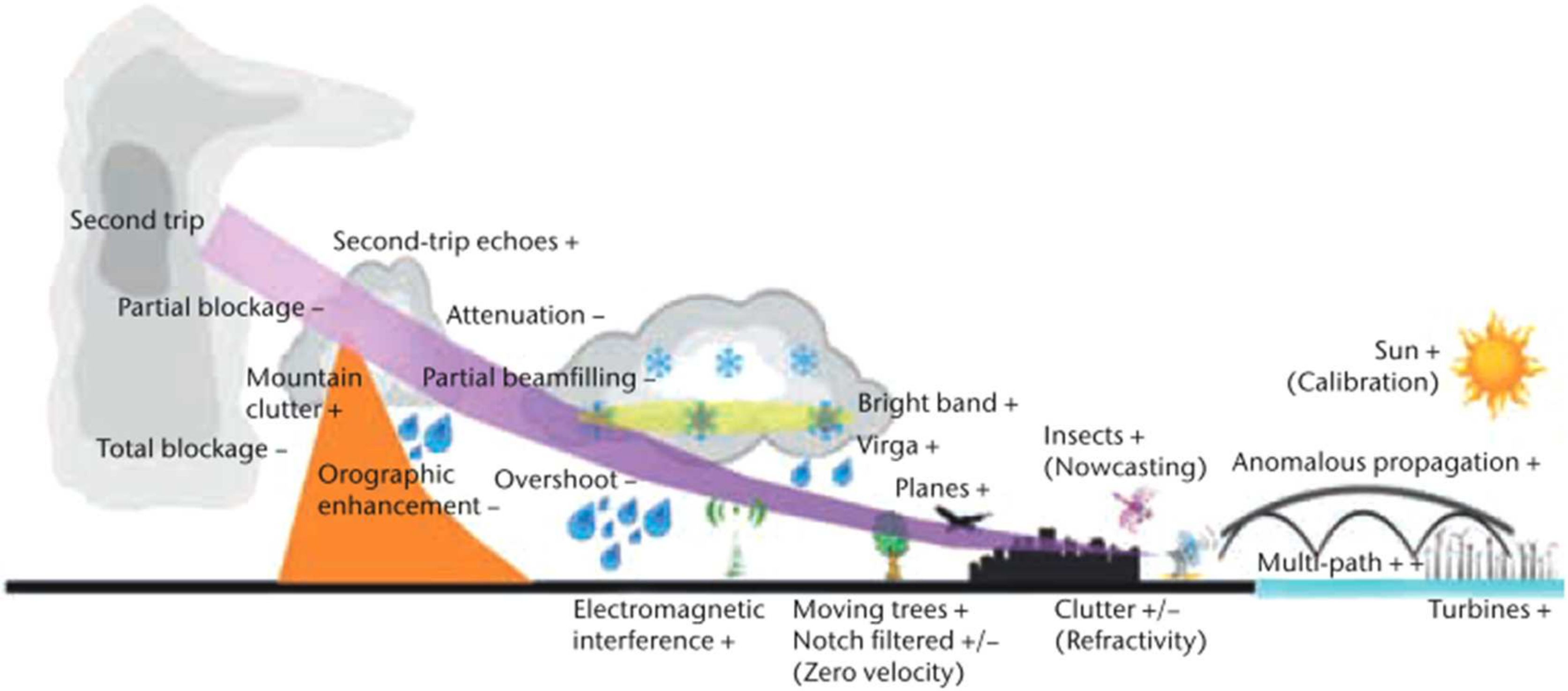


Figure 7.2. The weather radar can detect many things besides weather targets. This schematic illustrates many of these features. The + or – signs indicate whether the radar reflectivity is augmented or diminished by the feature. These artefacts need to be removed for quantitative applications.

Source: Guide to Meteorological Instruments and Methods of Observation, 2014, WMO

The cause of Quality Loss

- Data quality can be poor when,
  - some errors occur in an observational equipment.
  - non-precipitation target exists.
  - specific environmental condition occurs.

---Reference

CIMO Guide, (2021), Volume III：Observing Systems; Chapter 7 Radar Measurements; Section 7.9 Sources of Error

Quality Loss by equipment error

- Stability error of transmitted radiowave
  - transmitted power, frequency, pulse width, pulse repetition frequency
- Accuracy error of antenna direction
  - azimuth and elevation angle
- Antenna side lobes
- Waveguide error
  - Reflection coefficient, return loss
- TR limiter error
- Receiver error
  - Input-Output characteristics
- Signal processor error (explained later)

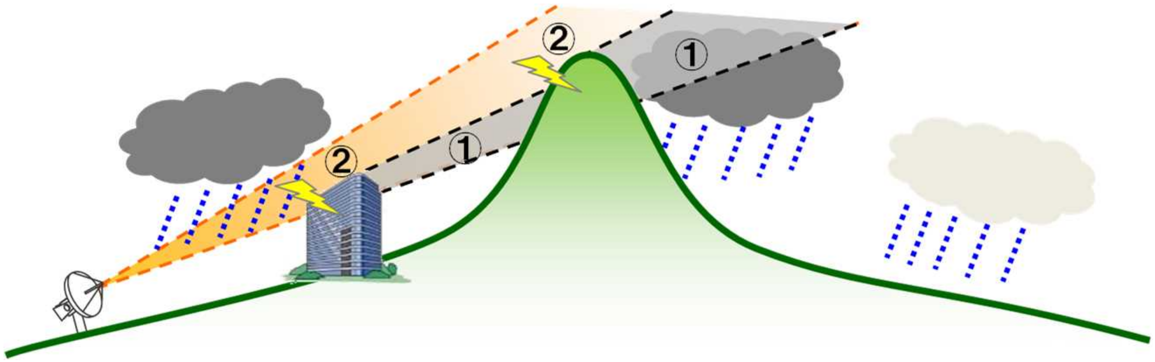
Quality Loss by non-precipitation target

- Ground clutter
- Sea clutter
- Insects, Birds (clear air echo)
- Anomalous propagation
- Wind farm (windmill)
- Electromagnetic interference from other radars or devices
- Chaff
- Sun noise

Ground clutter

① Observation accuracy is degraded by blocking from buildings and mountains

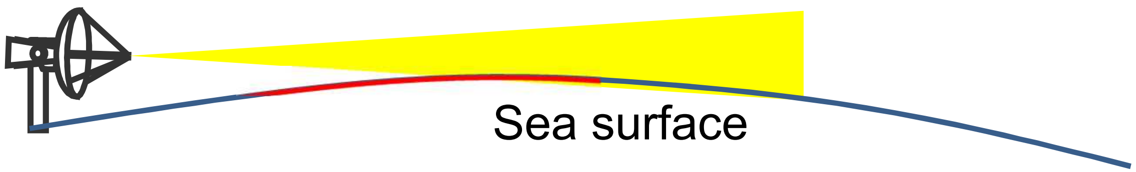
② Noise is generated mainly due to reflective objects near the ground surface, which reduces observation accuracy

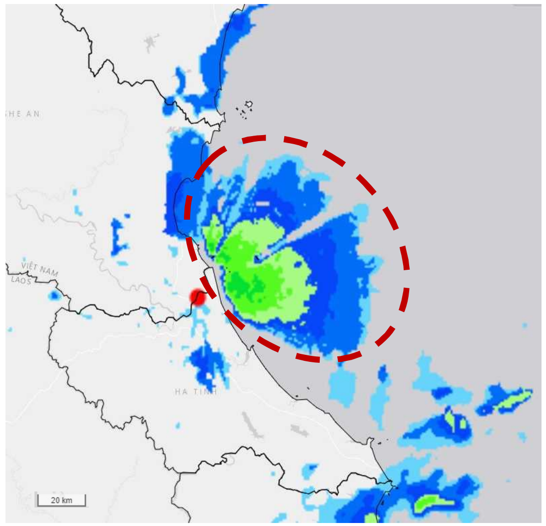


- Ground clutters are the noise from mountains, buildings, towers, windmills, power lines, etc.
- Process for ground clutter remover (non-coherent MTI, coherent MTI, combined both MTI) is working, but does not remove clutters completely.
- Coherent MTI is a method by identifying non-moving targets. If the echo is determined as non-moving target, it will be removed in a certain way, but sometimes MTI may degrade precipitation data excessively.

Sea clutter

- Sea clutter is a noise from sea surface caused by sea wave or sea spray. Because of the sea wave motion, removing sea clutter by MTI does not work well.
- Especially in low elevations, sea water sprays (especially in windy condition) appears as radar echo. To remove the sea clutter, CAPPI (or PCAPPI) mode observations which use higher angle in near range are used.

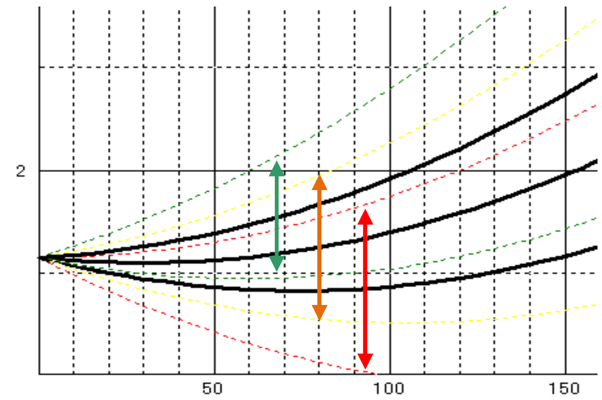


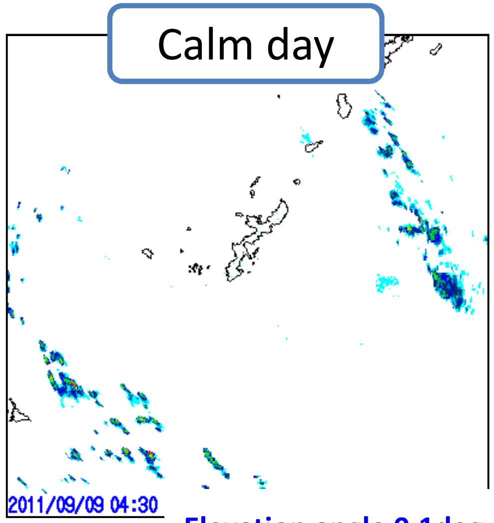


Radar is located close to sea shore

Sea clutter

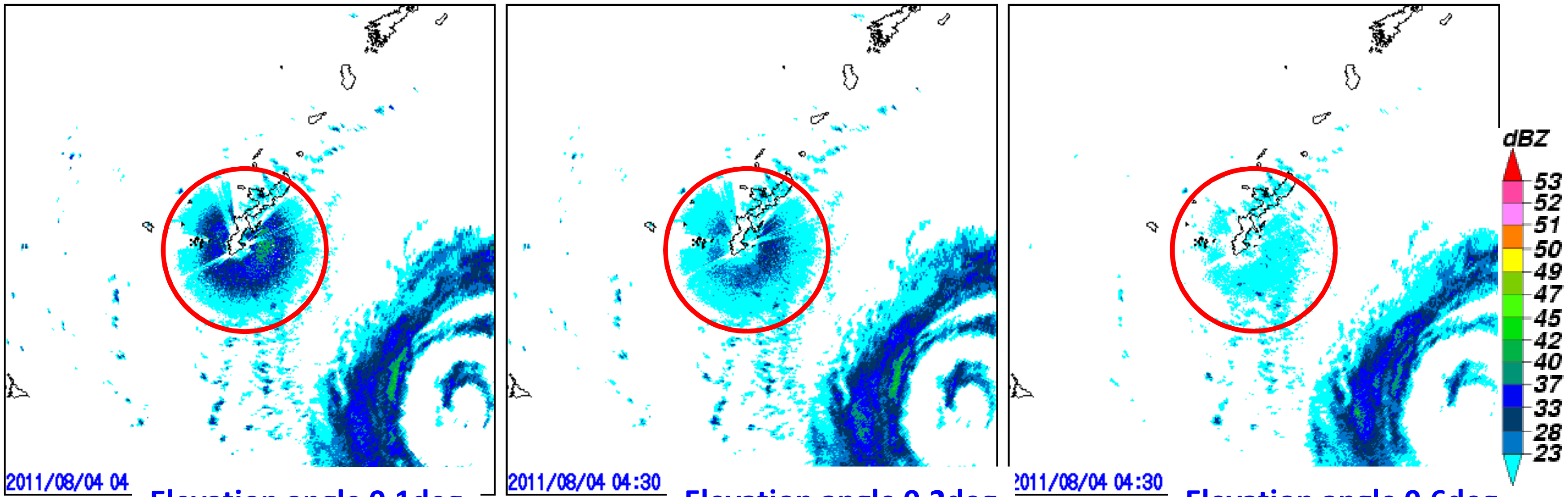
2011/08/04
Typhoon MUIFA (1011)





Elevation angle 0.1deg

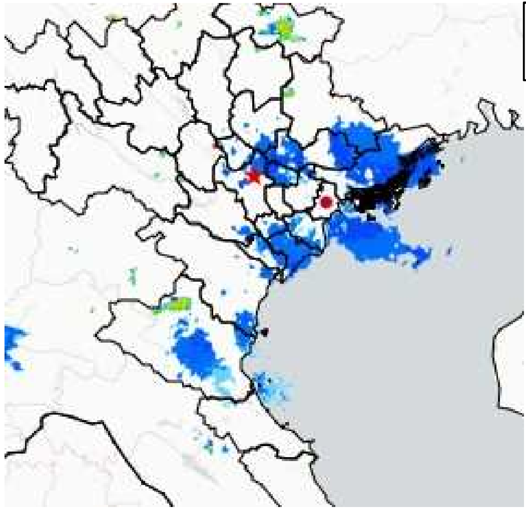
Okinawa radar



Elevation angle 0.1deg Elevation angle 0.2deg Elevation angle 0.6deg

- **In windy situations, the sea spray may be observed at low elevation angles.**

Two types of non-precipitating clear air echo

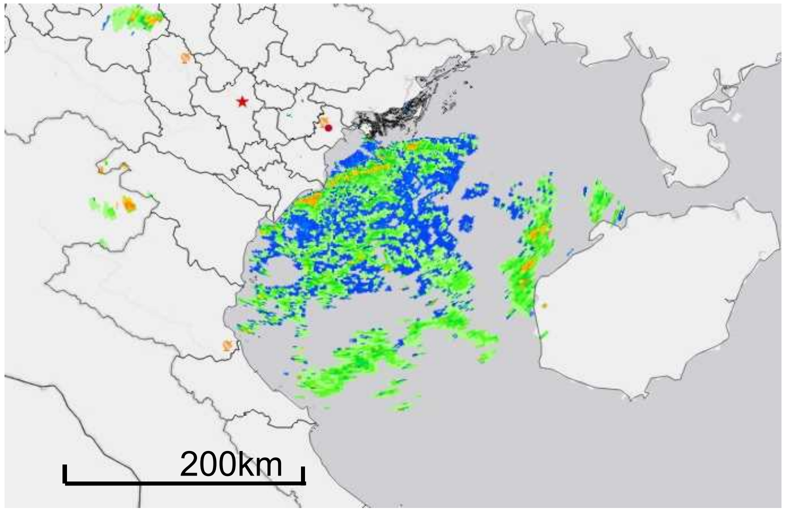


Clear air echo (type1)

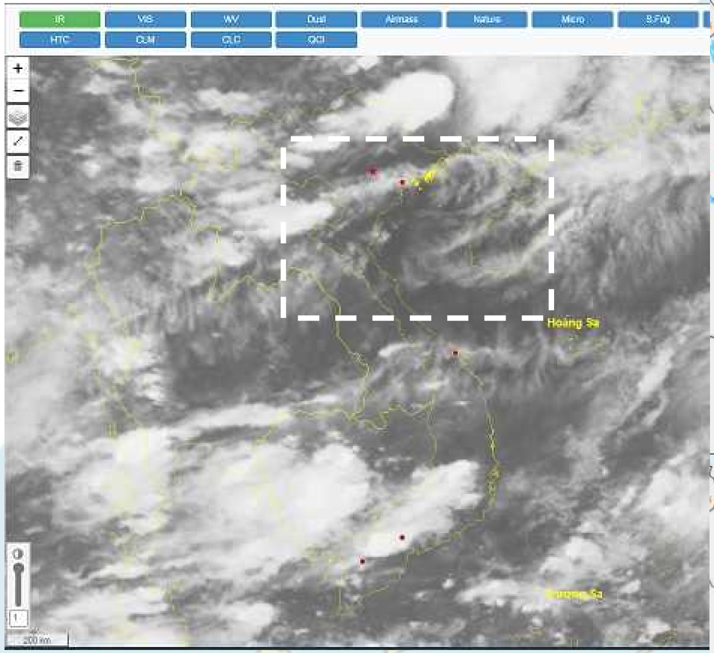
Frequently appear from evening to early morning in spring and autumn when calm situation
Biological targets or atmospheric vortex are reflectors

Clear air echo (type2)

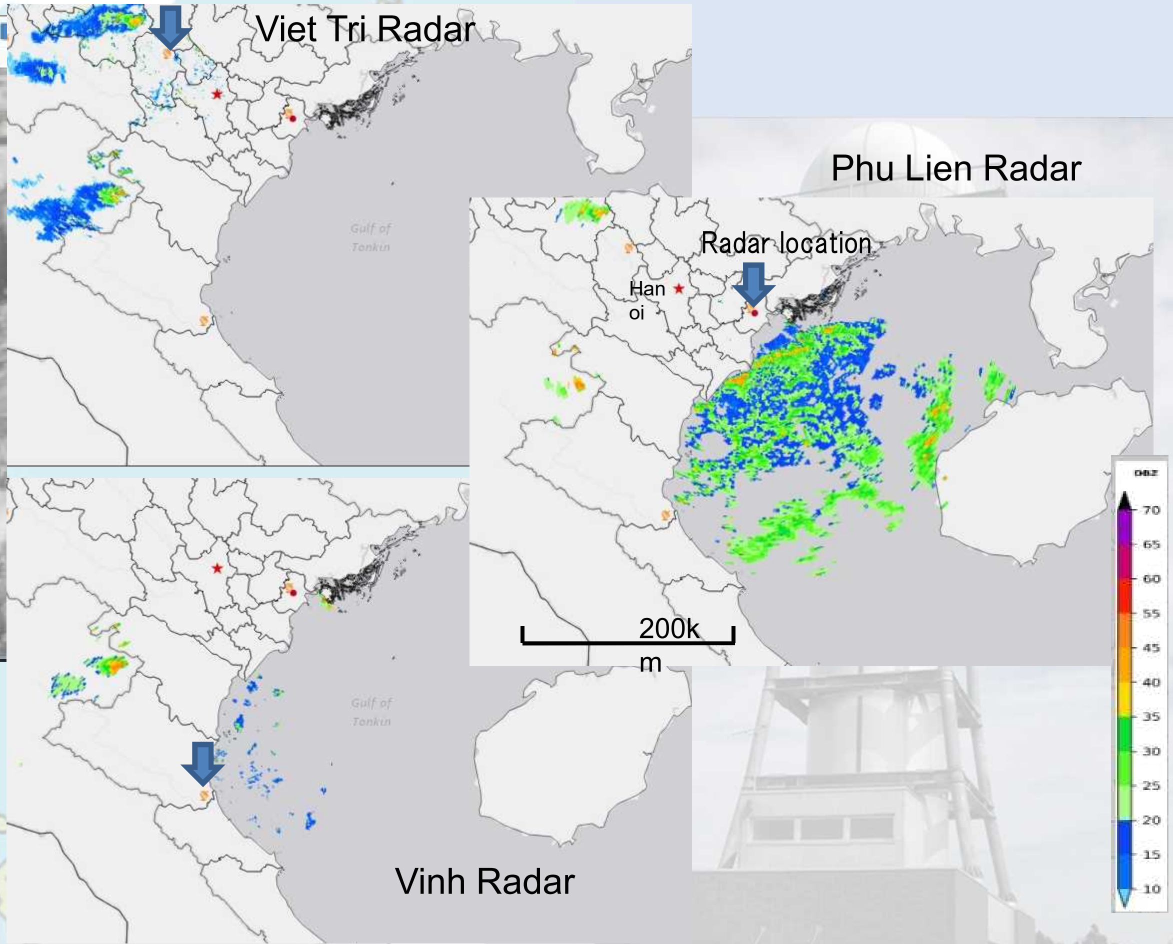
Frequently appear from evening to early morning during May to July when calm situation
Anomolous propagation plays an important role



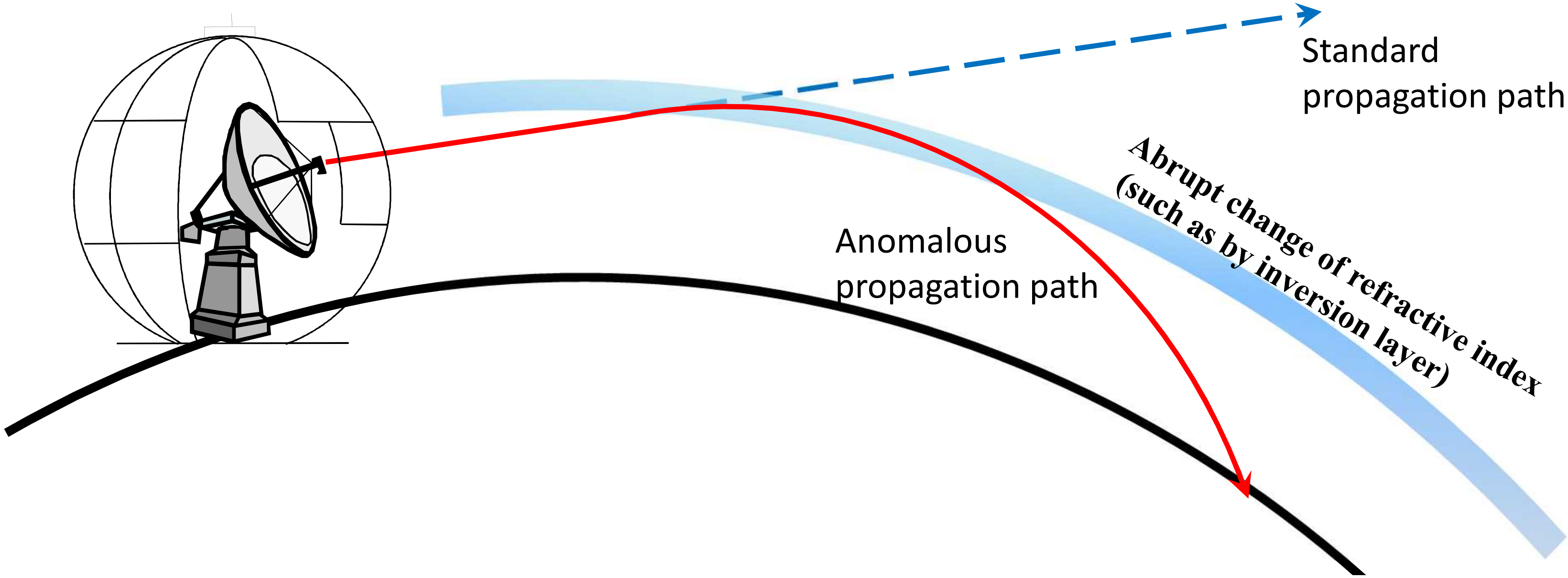
Clear air echoes over Ton Kin bay（18LST 21 June 2022）



Satellite IR image
Dashed area corresponds to the radar area



Non-precipitating echo caused by anomalous propagation



The position of the radar echoes depend heavily on the standard decrease of temperature hypothesis. However, the real atmosphere can vary greatly from the norm. Anomalous Propagation (AP) refers to false radar echoes usually observed when calm, stable atmospheric conditions, often associated with super refraction in a temperature inversion, direct the radar beam toward the ground. The processing program will then wrongly place the return echoes at the height and distance it would have been in normal conditions.

Artificial non-precipitation target:

- air planes, chaff, wind turbine, sky lift -

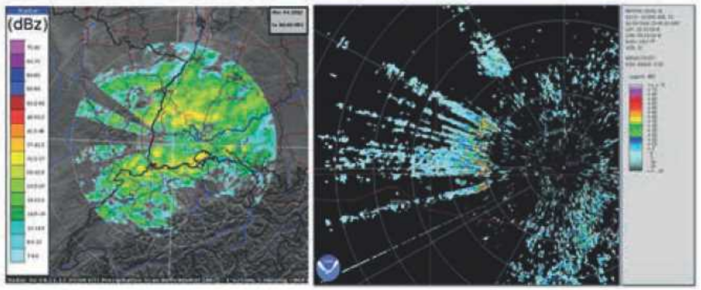


Figure 7.23. The image on the left (courtesy of Deutscher Wetterdienst) shows blocking (west of the radar) by wind turbines, and the image on the right shows interference and multiple scattering effects of the turbines (courtesy of the National Oceanic and Atmospheric Administration).

Source: Guide to Meteorological Instruments and Methods of Observation, 2014, WMO

Range	*Potential impact*	*Guideline*
0–5 km	The wind turbine may completely or partially block the radar and can result in significant loss of data that cannot be recovered.	Definite impact zone: Wind turbines should not be installed in this zone.
5–20 km	Multiple reflection and multi-path scattering can create false echoes and multiple elevations. Doppler velocity measurements may be compromised by rotating blades.	Moderate impact zone: Terrain effects will be a factor. Analysis and consultation is recommended. Reorientation or resiting of individual turbines may reduce or mitigate the impact.
20–45 km	Generally visible on the lowest elevation scan groundlike echoes will be observed in reflectivity Doppler velocities may be compromised by rotating blades.	Low impact zone: Notification is recommended.
> 45 km	Generally not observed in the data but can be visible due to propagation conditions.	Intermittent impact zone: Notification is recommended.

Interference with Radio Local Area Networks (RLANs)

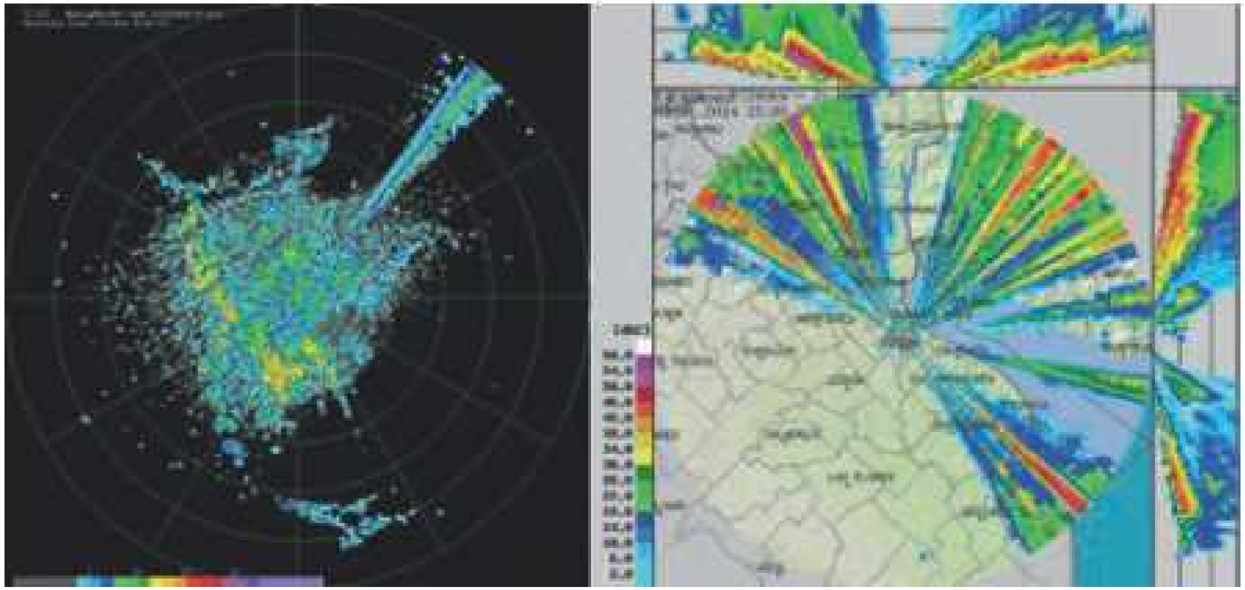


Figure 7.19. The image on the left demonstrates the type of expected interference from a Radio Local Area Network located 6.4 km away at 0.42° elevation angle. The image on the right is from an operational weather radar, courtesy of Claudia Campetella of the Servicio Meteorológico Nacional (Argentina).

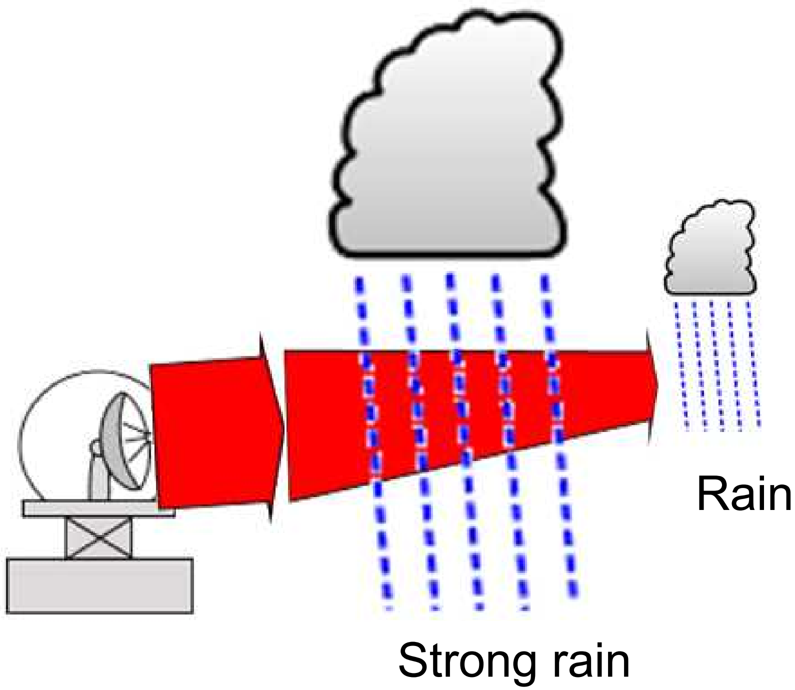
Source: Guide to Meteorological Instruments and Methods of Observation, 2014, WMO

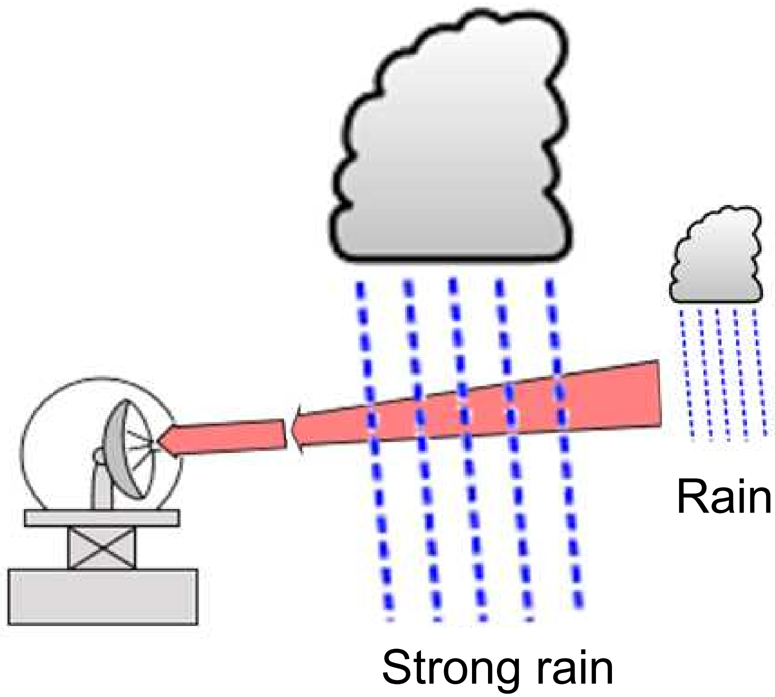
Quality Loss by specific environmental condition

- Attenuation by intervening precipitation
- Attenuation due to a wet radome
- Bright band
- Radar beam filling
- Non-uniformity of the vertical distribution of precipitations
- Beam blocking (partly or completely)

Example of the quality loss

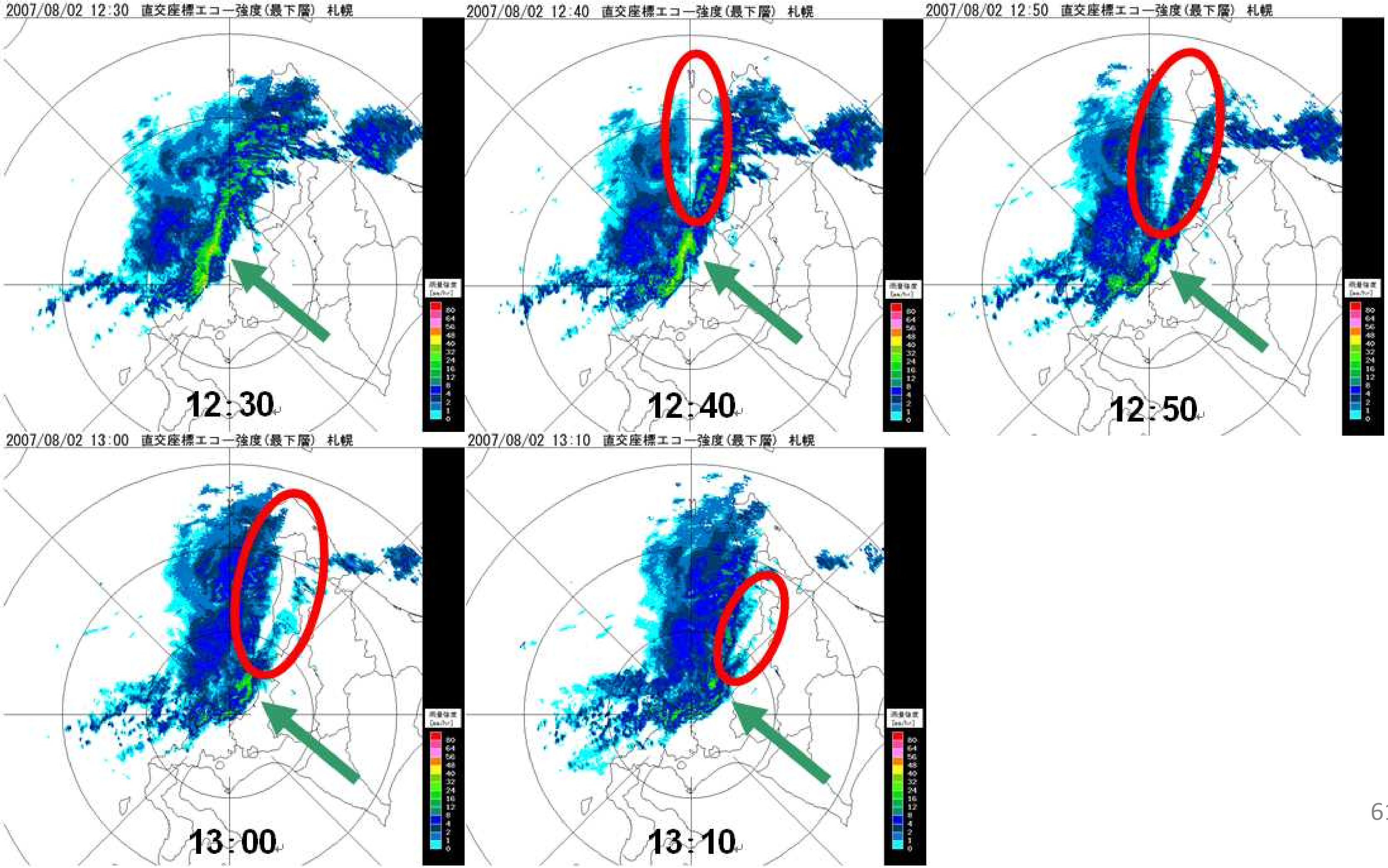
- Attenuation by intervening precipitation





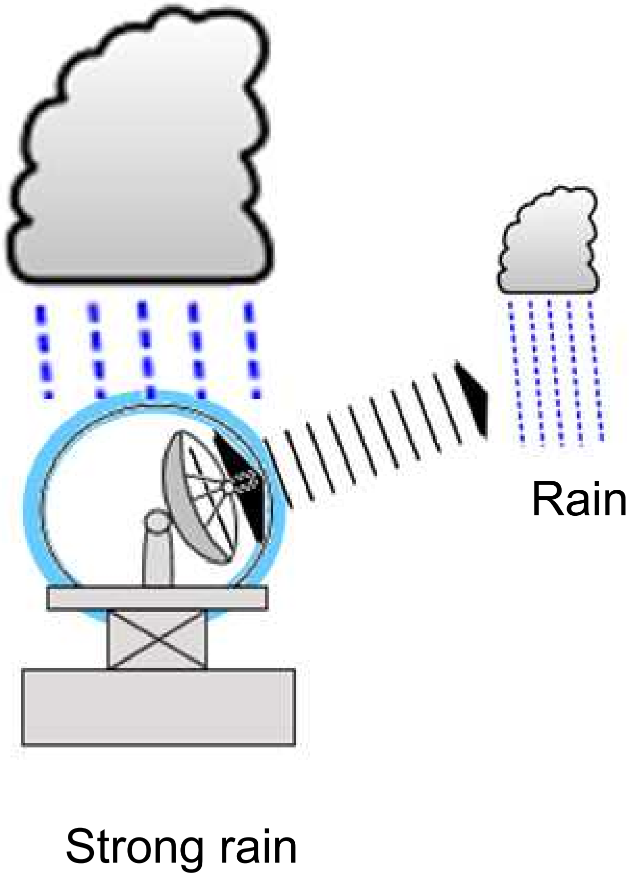
Example of the quality loss

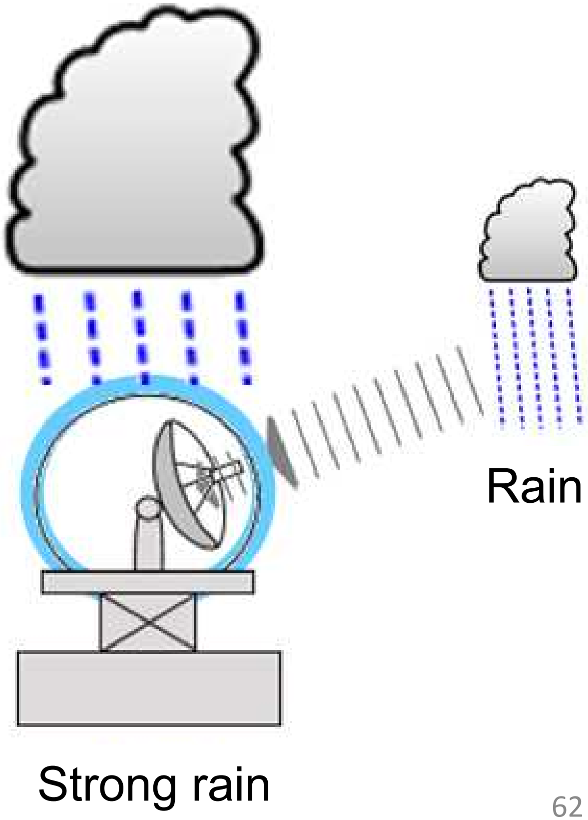
- Attenuation by intervening precipitation



Example of the quality loss

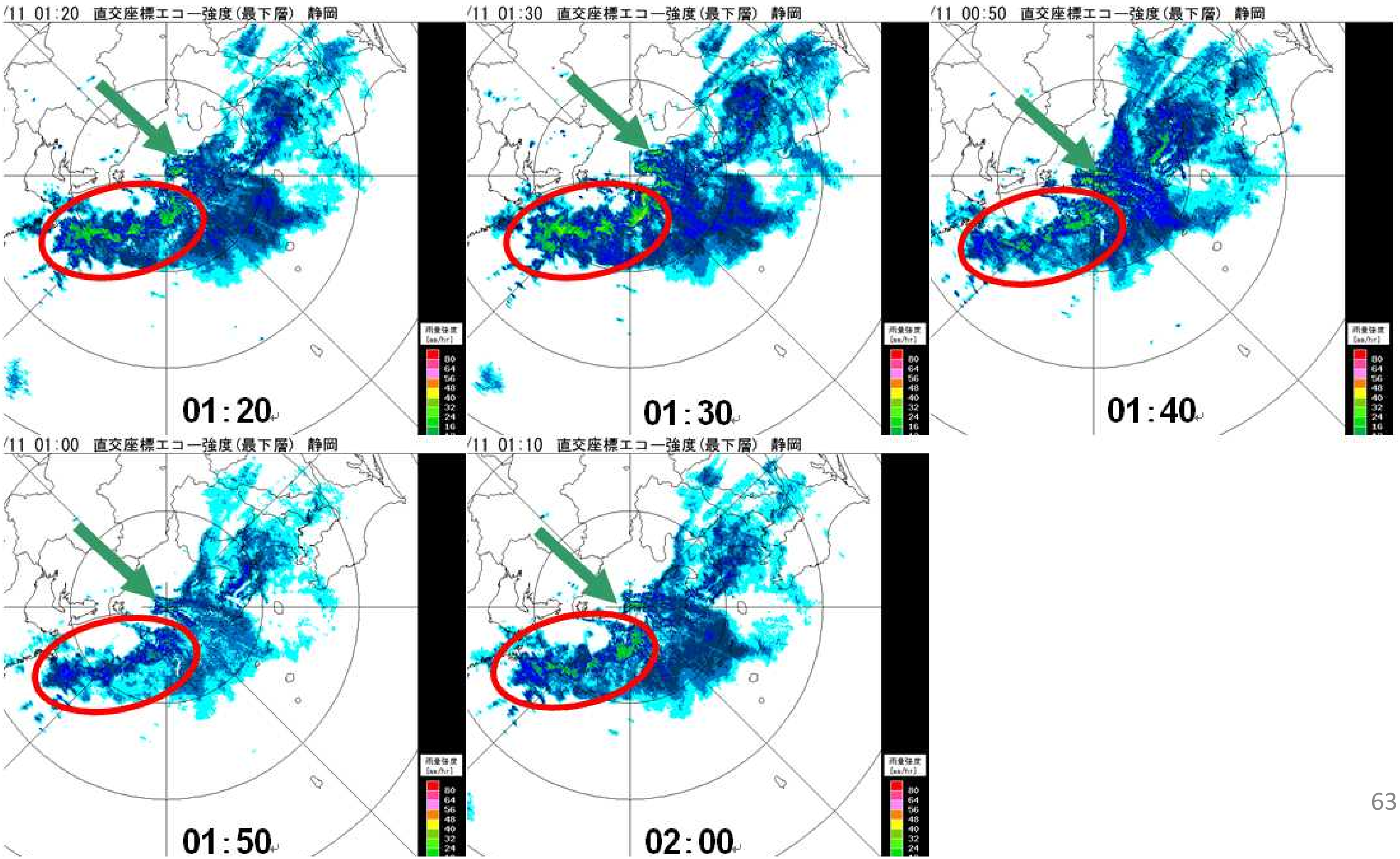
- Attenuation due to a wet radome



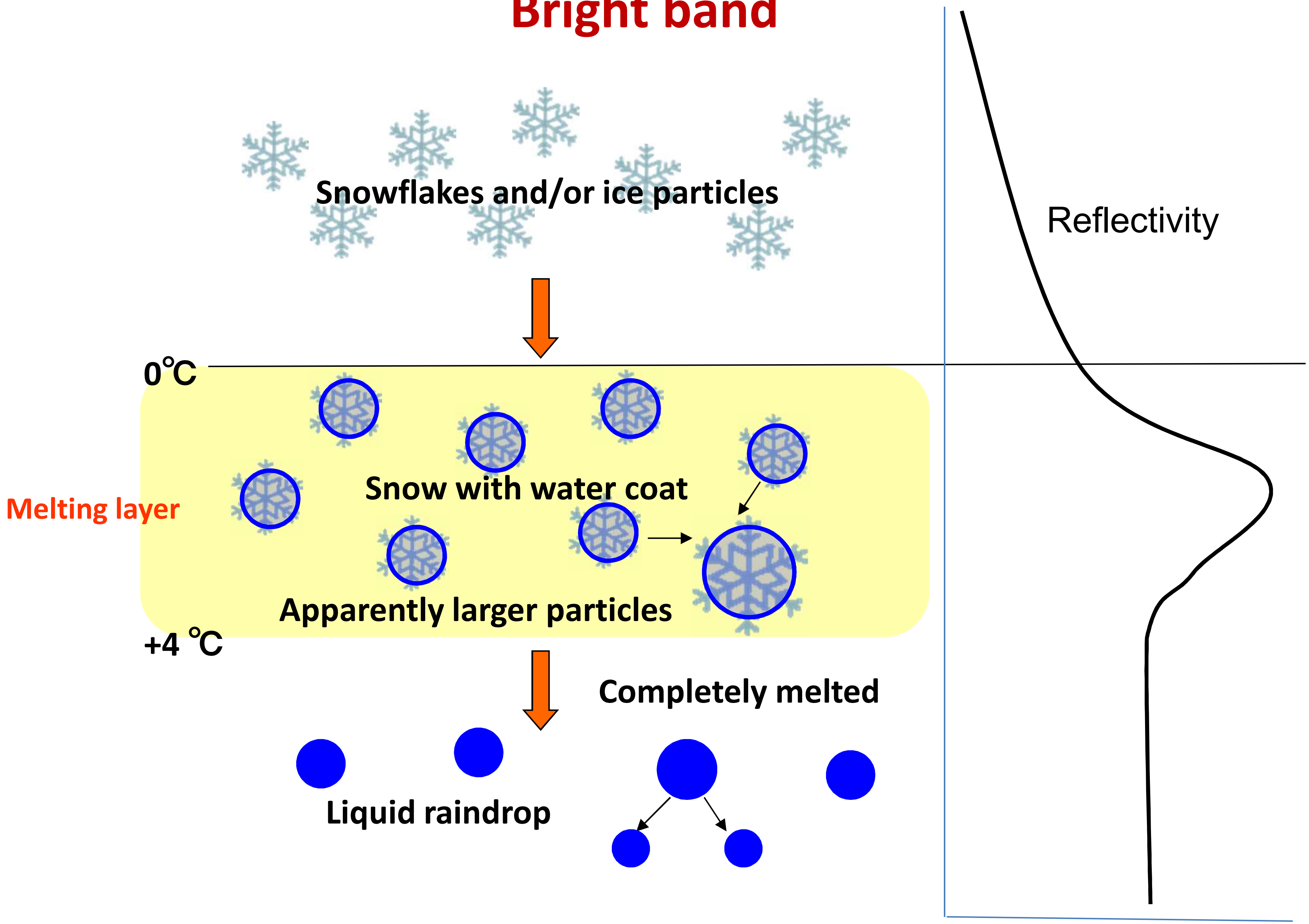


Example of the quality loss

- Attenuation due to a wet radome

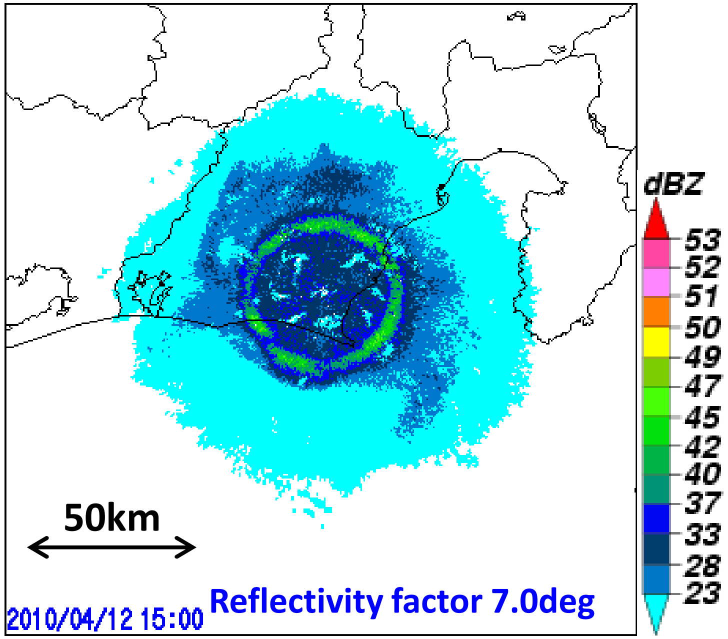


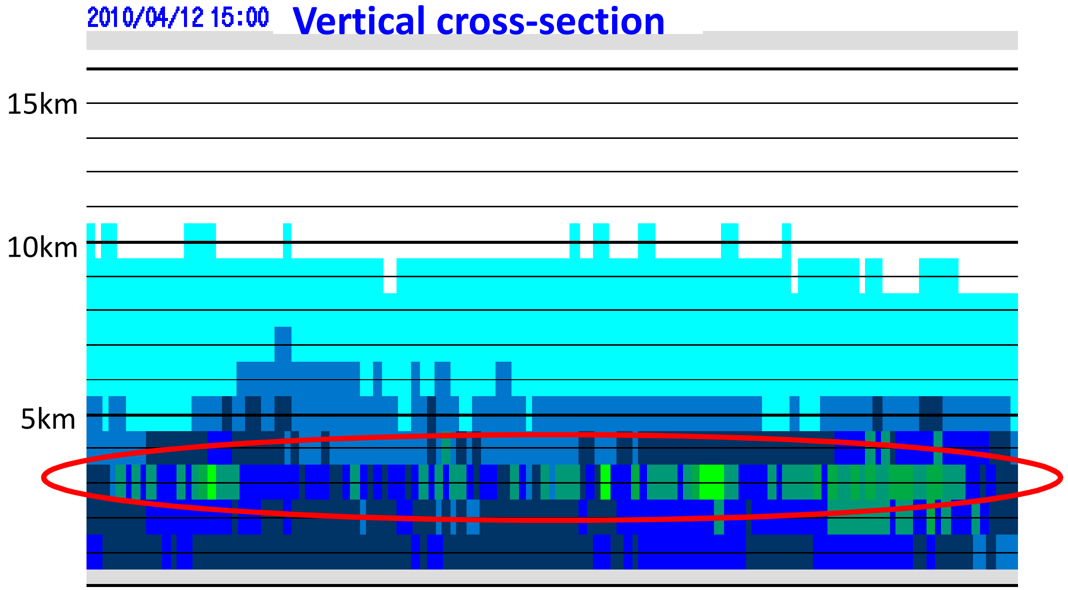
Bright band


Snowflakes and/or ice particles
Reflectivity
0℃
Melting layer
Snow with water coat
Apparently larger particles
+4 ℃
Completely melted
Liquid raindrop

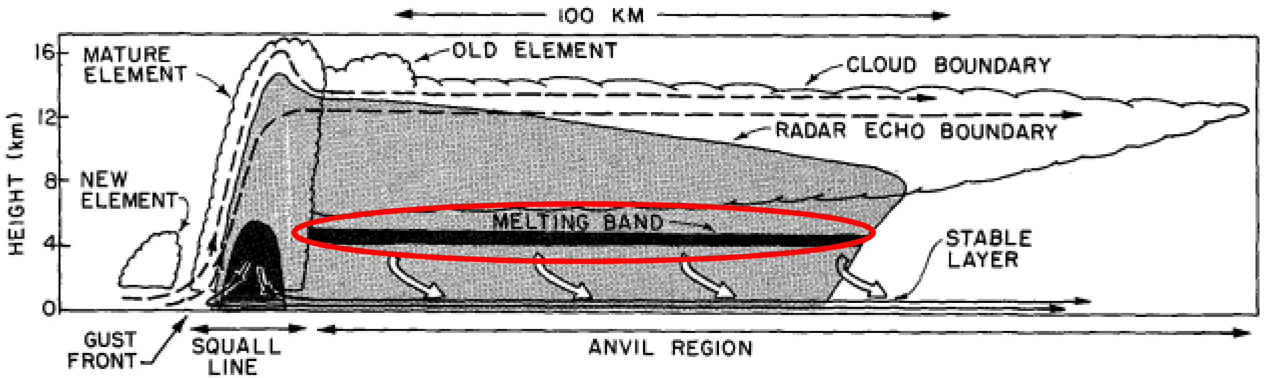
Bright band

JMA Shizuoka radar





Vertical cross-section a tropical squall line (Houze, 1977)



Processing Flow of Signal Processor

- JMA Method
  - Interference Filters
  - Removal of 2nd trip echo
  - Ground clutter Filtering
  - Reflectivity calculation
  - Thresholding (LOG, CSR, SNR)
  - Speckle Filters (isolated point, singular point)
  - Rain rate estimation (Z-R relation)

Quality Loss by Signal Processor Error

- Data quality decreases mainly by following causes. The cause depends on the processing conditions of each radar.
  - ✓ Clutter filter cannot eliminate grand clutter fully.
  - ✓ Because of strong ground clutter, invalid value is filled by the quality check.
  - ✓ When a variation of the reflectivity is large, invalid value is filled.
  - ✓ When a variation of the doppler velocity is large, invalid value is filled.
  - ✓ Equation is not appropriate to convert from reflectivity to rain rate.

Method of Quality Control

- Inspection (Maintenance) of radar equipment
- Automatic quality control
- Manual quality control
- Statistical quality control

Inspection of radar equipment

- Operation of Periodic inspection (Regular maintenance)
- Making checklist (clarifying inspection items and criteria)
- Making inspection manual (documentation of inspection method)
- Preparation of measuring instruments
- Review of inspection results
  - What would we do if wrong point found?
  - Is there any differences between this results and last results?

Automatic quality control

- We should understand following contents for operating better quality control.
  - Processing items
  - Processing algorithms
  - Parameter settings
  - Secondary effects

Manual quality control

- To find an error from observation results, we should check following things.
  - Is the movement of rain cloud continuous?
  - How is the 3-dimensional echo distribution?

- To conduct manual quality control successfully, we should prepare beforehand as follow.
  - Understanding the cause of quality loss
  - Understanding the mechanism of meteorological phenomena
  - Accumulating a lot of case study and making a manual (a document paper)
  - Conducting a training program

Statistical quality control

(1) Problems	(2) Statistics	(3) Improvements
Extremely strong echo Continuous weak echo	Appearance count of echo	Is it a precipitation echo or a non-precipitation echo (clutter)?
Clutter inside the rain area	Summation of rainfall amount	Is the parameter setting adequate? Should we tune them again?
Unnatural rainfall distribution		Is the elevation angle composite table adequate? Should we change it?
Quantitatively inadequate rain rate	Comparison between radar and rain gauge	Is the conversion equation adequate? For example, should we change B, β in Z-R relation?

Reference

WMO/CIMO guide (2021)

https://library.wmo.int/viewer/68661/download?file=8_III_2021_en.pdf&type=pdf&navigator=1

Volume III Chapter 7 Radar Measurements

Thank you