1. Weather Radar Operation

1.1 History and Current Situation of Weather Radar

1.2 Basics of Weather Radar

1.3 Operation of Weather Radars

5th February 2018

Masahito ISHIHARA

Former Meteorologist/Researcher of Japan Meteorological Agency

Former Professor of Kyoto University

Our issues and targets

- Can we well believe radar observation results?
- Can we issue effective heavy rainfall warning to the public using radar data?
- If not/ if not enough, how can we get the way to improve our job on weather radar?
- Our first target is the Quantitative Precipitation Estimation (QPE).

My brief history

1952 Born in an inland city of Japan

1974-1978 Radar observer at the southernmost Observatory of JMA

1978-1991 Researcher of Meteorological Research Institute (MRI), JMA

1985-1986 Visiting researcher of Oklahoma University and NSSL in Norman, U.S.

1991-2008 Observations Department of the JMA Headquarters

1996-1999 Kansai-airport Met Office

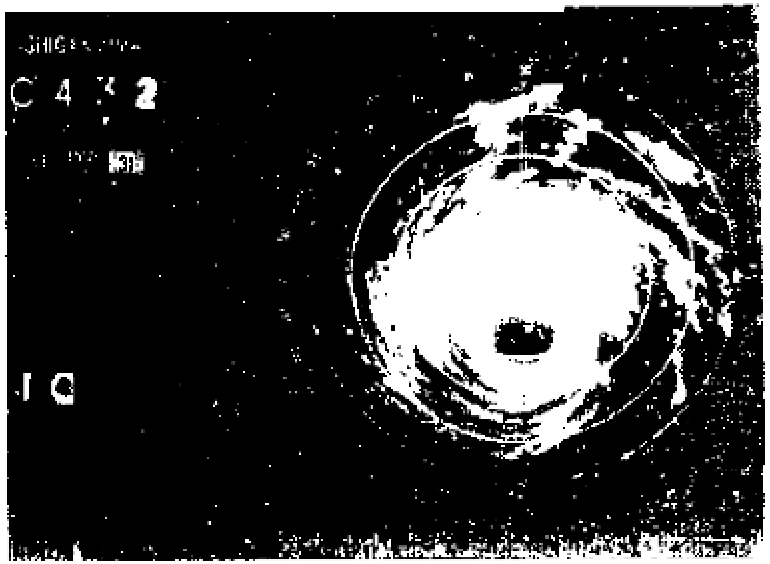
2008- 2011 MRI and Aerological Observatory

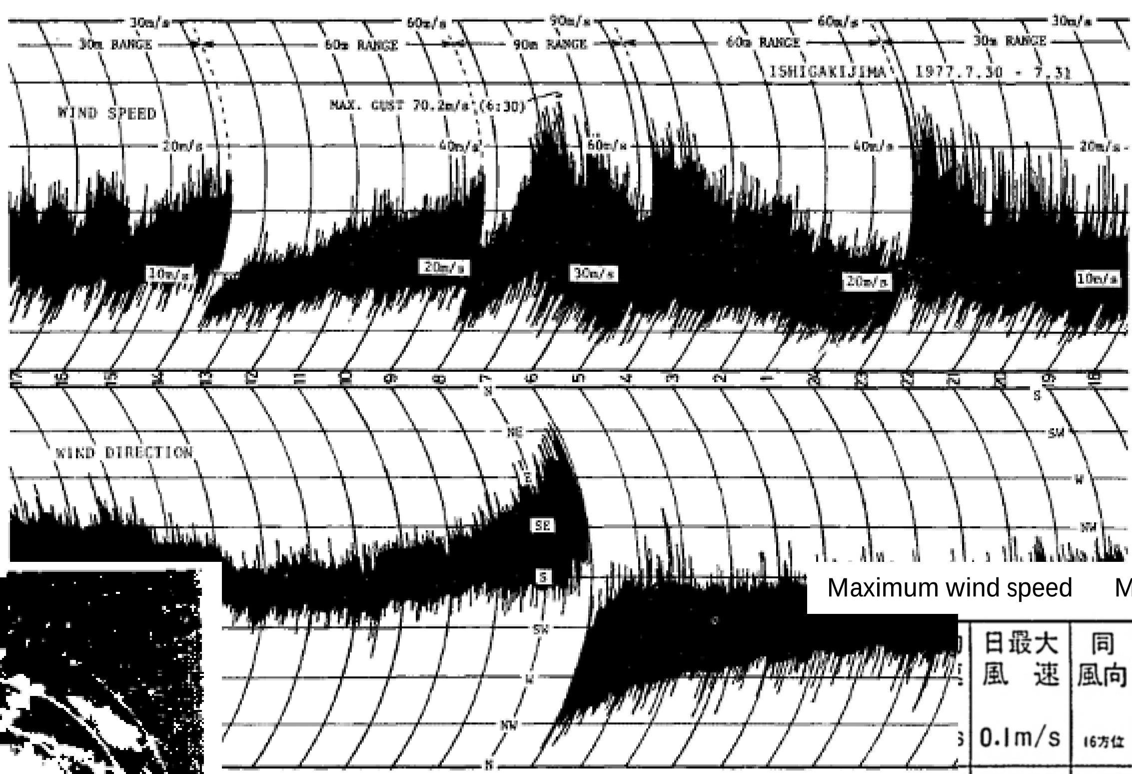
2012- 2017 Kyoto University

2014-2017 Sri Lanka Department of Meteorology (JICA Expert)

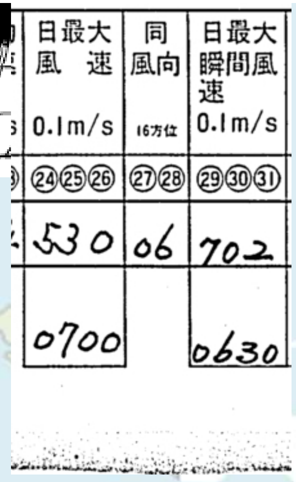
My first impression to natural power

JMA Ishigakijima Radar
04:32 31 July 1977





Maximum wind speed Maximum gust



My footprints concerning weather radar

1. Weather Radar Operation

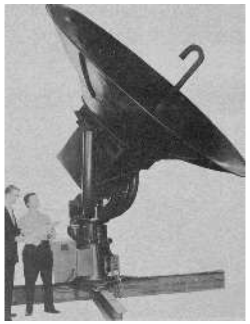
1.1 History and Current Situation of Weather Radar

1.2 Basics of Weather Radar

1.3 Operation of Weather Radars

Brief history of radar

- James Clerk Maxwell (Scotland) gave a set of equation “Maxwell’s Equation” describing electricity and magnetism. Maxwell demonstrated that electric and magnetic fields travel through space as waves moving at the speed of light.
- Heinrich Hertz (German) showed that radio waves were reflected by metallic objects in the late 19th century.
- In the 1934–1939 period, eight nations developed independently, a kind of radar systems: Great Britain, Germany, the United States, the USSR, Japan, the Netherlands, France, and Italy. http://en.wikipedia.org/wiki/History_of_radar
- During World War II, military radar operators noticed noise in returned echoes due to weather elements like rain, snow, and sleet.
- in the late 1940s-early 1950s: pulse Doppler, monopulse, phased array, and synthetic aperture were developed.
- In 1950s, productions of radar systems specially designed for weather monitoring were started.



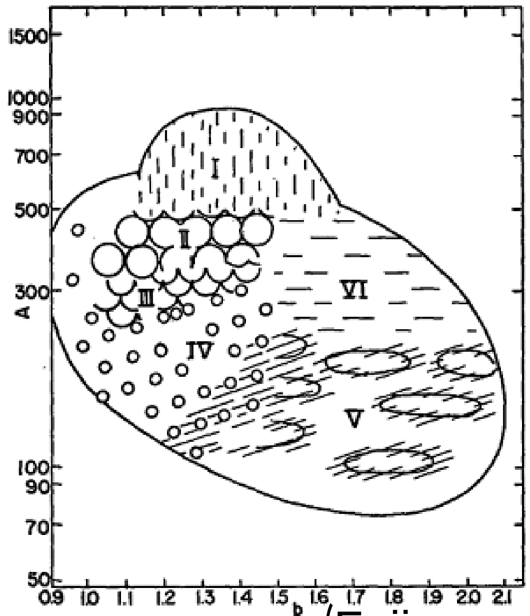
U.S. WSR-57
(S-band)

https://en.wikipedia.org/wiki/WSR-57#Radar_properties

Japanese 1st Weather Radar
(X-band)

Source: JMA

JMA 1st weather radar and measurement of raindrops distribution



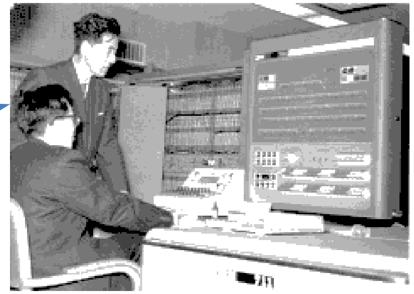
(Fujiwara 1965)

Meteorological Research Institute of JMA in 1960s

History of modernization of weather services in JMA

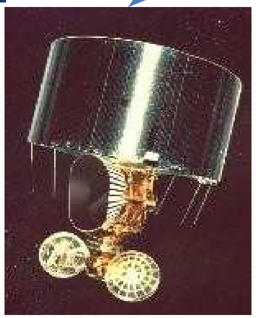
1950	1960	1970	1980	1990	2000	2010

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

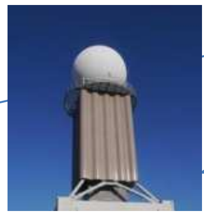


- 1964 Mount Fuji Radar

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



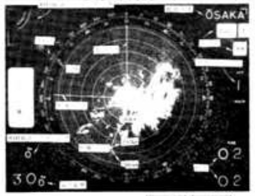
- 1982 Digital Weather Radars
- 1983 Quantitative Precipitation Estimation (Radar-Raingause Composite Map)
- 1987 Quantitative Precipitation Forecast
- Wind Profiler Network
- 2001 Precipitation Nowcast
- Solid-state Dual-polarlization TDWR
- 2016

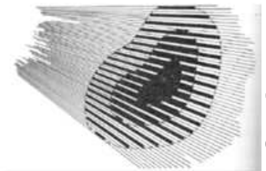


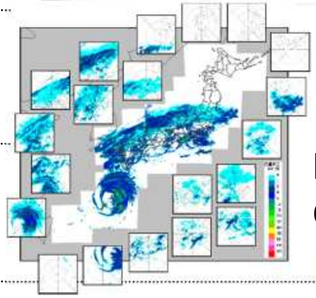
History of radar observation of JMA

- **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

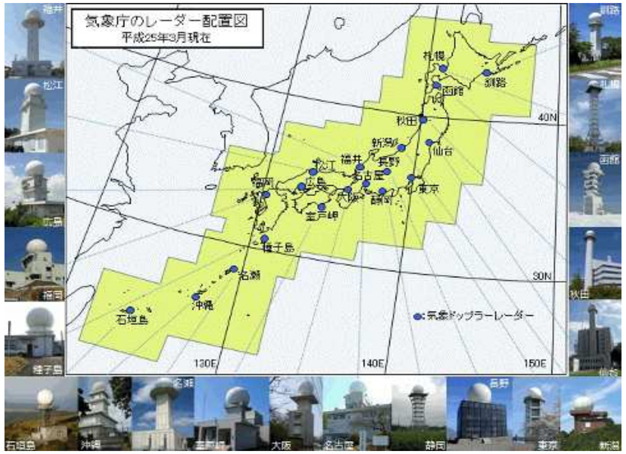

Tokyo


Narita DRAW

Weather Radar Network and Manufactures in Japan

Japan Meteorological Agency (JMA)

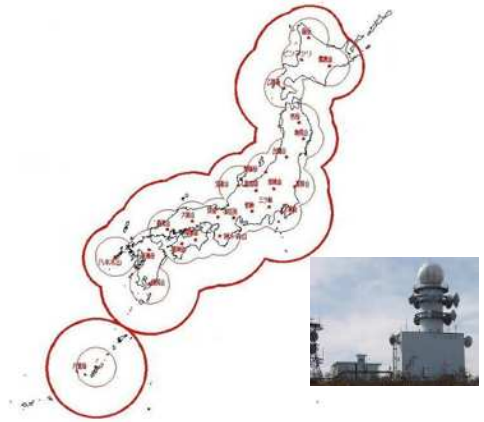
JMA Weather-Radar Network
20 C-band Radars



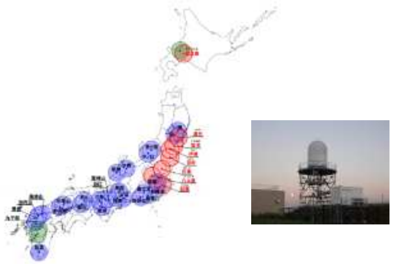
Airport Weather Radar (TDWR)
9 C-band Radars for Aviation Safety

Ministry of Land, Infrastructure & Transport (MLIT)

Radar Rain-gauge Network
26 C-band Radars for Dam and Road Condition Monitoring



XRAIN Network
39 X-band Radars for Urban Flood Monitoring



Major Weather Radar Manufactures

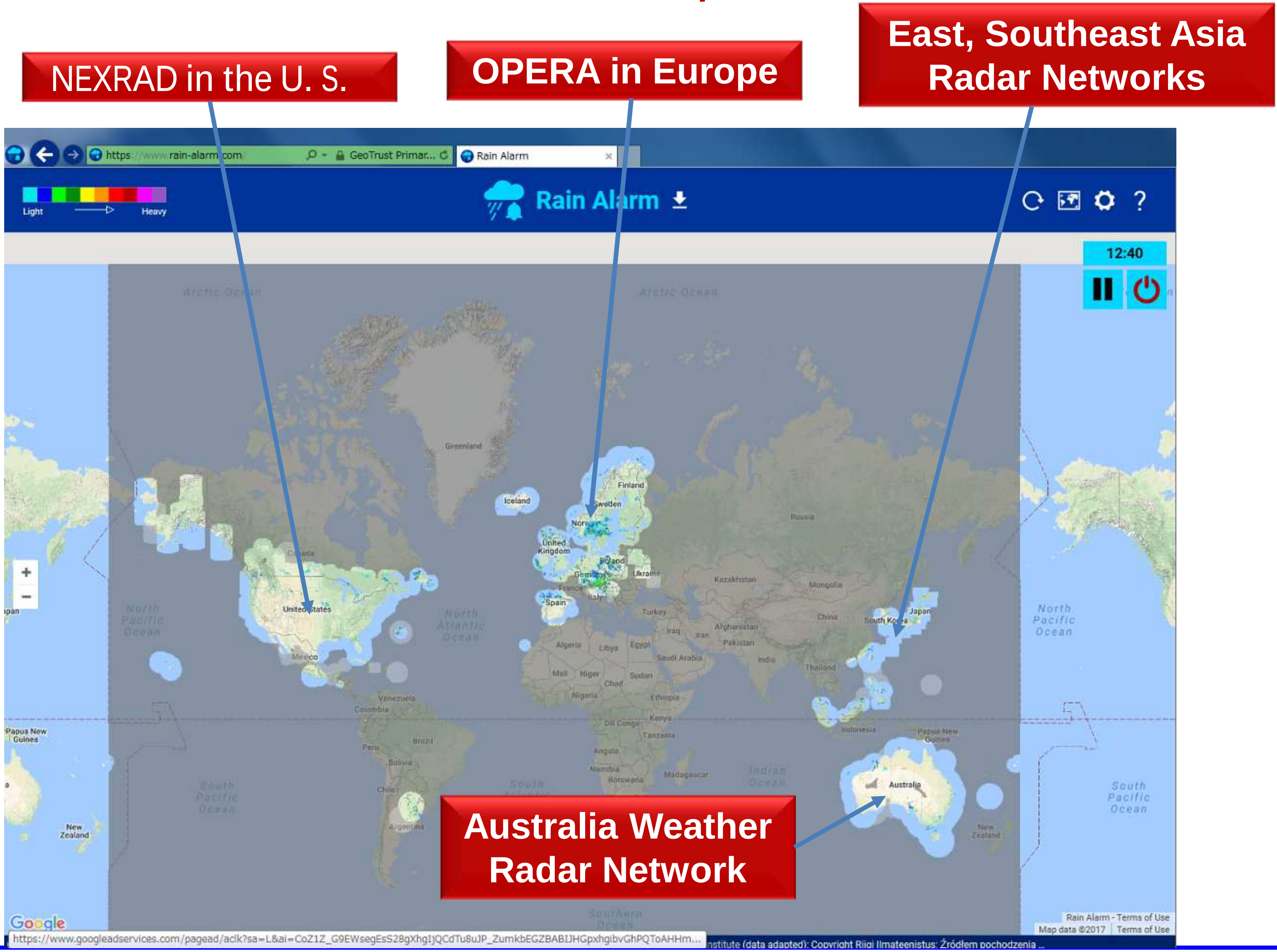
Japan Radio Company
Mitsubishi
Toshiba

Research Institutes and Universities

3 Research Institutes and 11 Universities

MRI: Meteorological Research Institute, JMA
NICT: National Institute of Communication & Technology
NIED: National Research Institute for Earth Science & Disaster Resilience

Weather Radar Networks opened in the World



1. Weather Radar Operation

1.1 History and Current Situation of Weather Radar

1.2 Basics of Weather Radar

1.3 Operation of Weather Radars

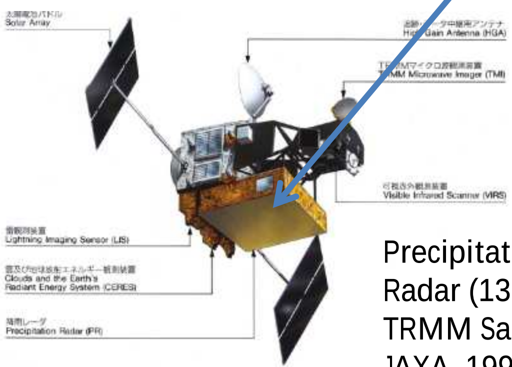
Types of meteorological radars

band designation	frequency	wavelength
HF	3～30 MHz	100～10 m
VHF	30～300 MHz	10～1 m
UHF	300～1000 MHz	1～0.3 m
L	1～2 GHz	30～15 cm
S	2～4 Ghz	15～8 cm
C	4～8 GHz	8～4 cm
X	8～12 GHz	4～2.5 cm
Ku	12～18 GHz	2.5～1.7 cm
K	18～27 GHZ	1.7～1.2 cm
Ka	27～40 GHz	1.2～0.75 cm
W	40～300 GHz	7.5～1 mm

MU radar (46.5 MHz)
RISH, Kyoto Univ.
1984

475 Yagi-antennas

Wind Profiler
(1.3 GHz)
WINDAS, JMA, 2001



Precipitation
Radar (13.8 GHz)
TRMM Satellite
JAXA, 1997-2015

Cloud radar (34.75 GHz)
RISH, Kyoto Univ.,

Air-borne Cloud Radar (95 GHz)
NICT

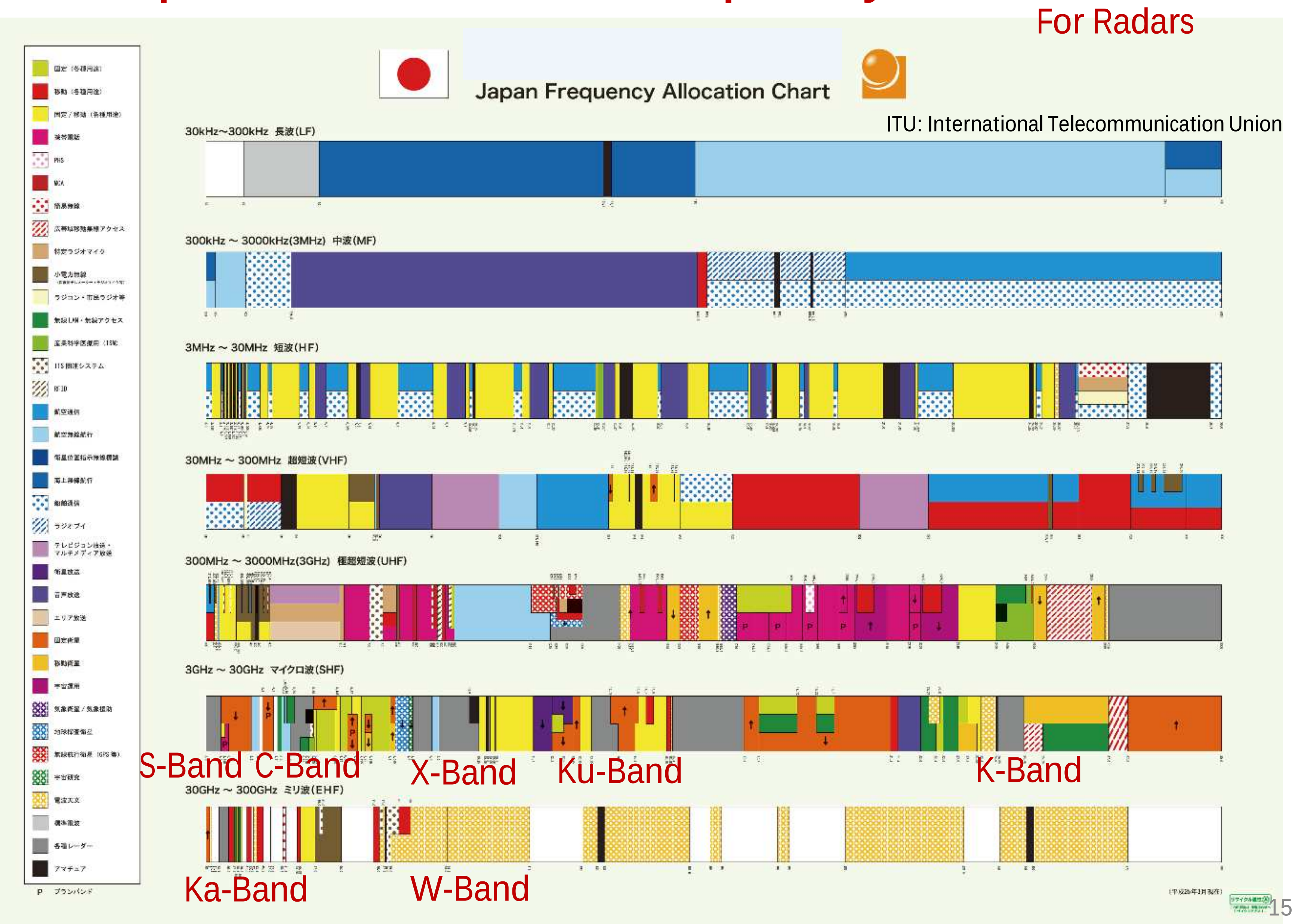
S-band Doppler Radar
(2.7-3.0 GHz)
WSR-88D (NEXRAD) NWS, 1988

Weather radars

C-band Doppler Radar (5.3 GHz)
JMA Standard Radar, 2006

X-band Research
Doppler Radar
(9.8 GHz)
MRI, JMA, 1982

Example of radio wave frequency allocation

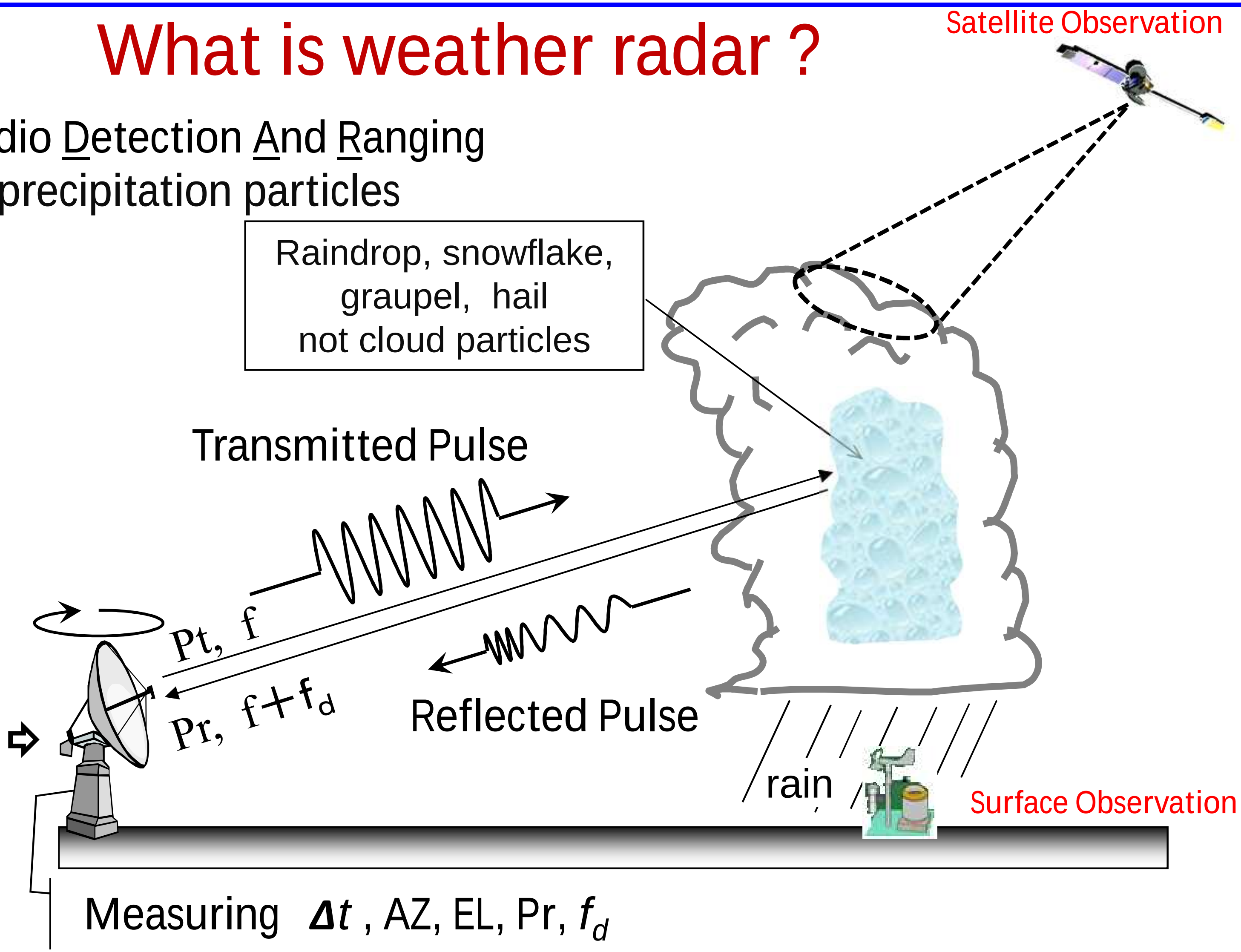


How radar observations are useful ?

Systems	JMA	Cooperative Organizations	Monitoring Products	Nowcast / Forecast Products
Raingauge Network	AMeDAS 1,300 stations	More than 5,000 raingauge stations MLIT, & local Govs.	Radar Echo Composite Precipitation Analysis (1hr/3hr/24hr)	1-hr Precipitation Nowcast 6-hr Pecipitation Forecast Soil Water Index Runoff Index
Radar Network	20 C-band Doppler Radars 9 C-band DRAW (TDWR)	26 C-band & 39 X-band weather radars MLIT	3D Reflectivity Dataset Doppler velocity Dataset	Mesocyclone Detection and Tornado Watch Microburst Detection at airports 4D Variational Data Assimilation to Numerical Forecast
Wind Profiler Network	WINDAS 33 1.3GHz wind profilers	50MHz, 400Mhz Wind profilers (NICT)	Time-height profile of winds	4D Variational Data Assimilation to Numerical Forecast

What is weather radar ?

RADAR : Radio Detection And Ranging
Targets are precipitation particles



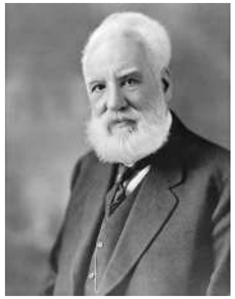
Measuring Δt , AZ, EL, Pr, f_d

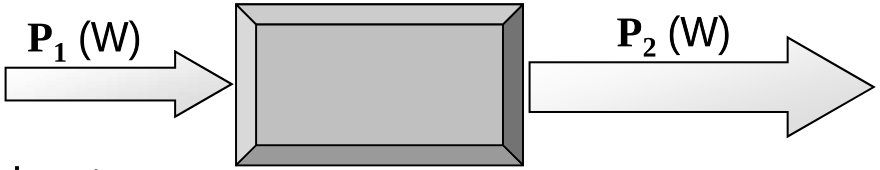
Distribution of Precipitation	Precipitation Intensity	Air flow in Precipitation Area

Why do we use dB (decibel) ?

dB : unit of gain and attenuation (of electric power)

Alexander Graham Bell
1847-1922, Scotland





ratio of input to output

P_1 P_2

definition

$$[\mathrm{dB}] = 10 \cdot \log_{10}\left(\frac{P_2\,[\mathrm{w}]}{P_1\,[\mathrm{w}]}\right)$$

Multiplication
→ Addition

reference

$$10^x = y \Rightarrow x = \log_{10} y$$

$$\log 1 = 0$$

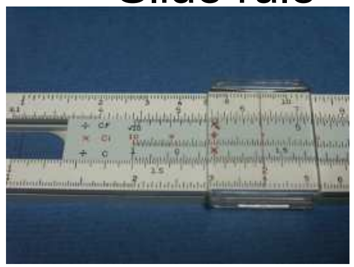
$$\log a^p = p \cdot \log a$$

$$\log(xy) = \log x + \log y$$

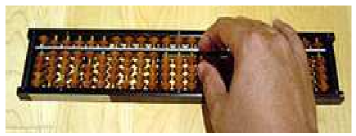
$$\log\left(\frac{1}{x}\right) = \log x^{-1} = -\log x$$

$$\log\left(\frac{x}{y}\right) = \log\left(x \cdot \frac{1}{y}\right) = \log x + \log\left(\frac{1}{y}\right) = \log x - \log y$$

Slide rule

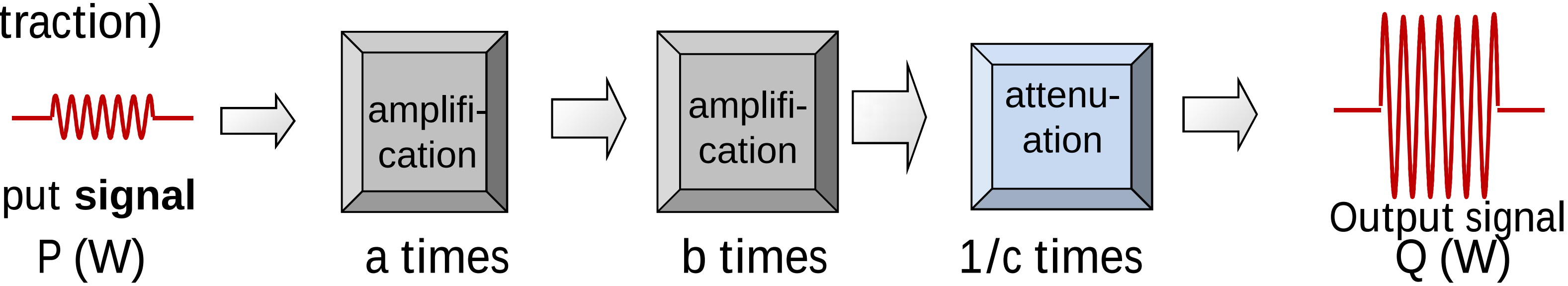


Abacus



"Power" of dB

"Power" or "Magic" of dB unit is that multiplication (division) is changed to addition (subtraction)



Example ×10 ×100 × 1/2

dB	power ratio
100	10 000 000 000
90	1 000 000 000
80	100 000 000
70	10 000 000
60	1 000 000
50	100 000
40	10 000
30	1 000
20	100
10	10
6	3.981
3	1.995 (~2)
1	1.259
0	1
-1	0.794
-3	0.501 (~1/2)
-6	0.251
-10	0.1
-20	0.01

$$Q = P \times a \times b \times (1/c)$$

$$\log Q = \log (P \times a \times b \times (1/c))$$

$$\log Q = \log P + \log a + \log b - \log c$$

Example

$$Q = P \times 10 \times 100 \times (1/2) \longrightarrow Q/P = 500$$

$$\log Q = \log (P \times 10 \times 100 \times (1/2))$$

$$= \log P + \log 10 + \log 100 + \log (1/2)$$

$$10\log Q - 10\log P = 10\log 10 + 10\log 100 + 10\log (1/2)$$

$$10\log Q/P = 10 + 20 - 3$$

$$10\log Q/P = 27 \text{ [dB]}$$

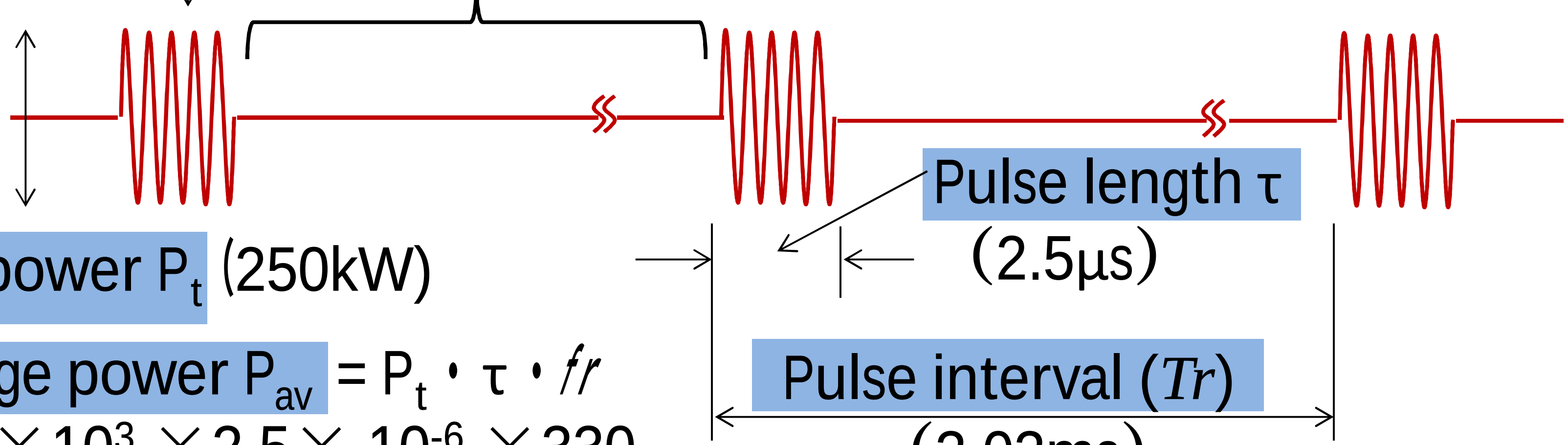
$$Q/P = 10^{(27/10)} = 501.18$$

What is radar pulse ?

Numerals: JMA C-band radar

Transmitted pulse
(frequency 5300MHz)

Period for receiving signals



Pulse length τ
(2.5μs)

Peak power P_t (250kW)

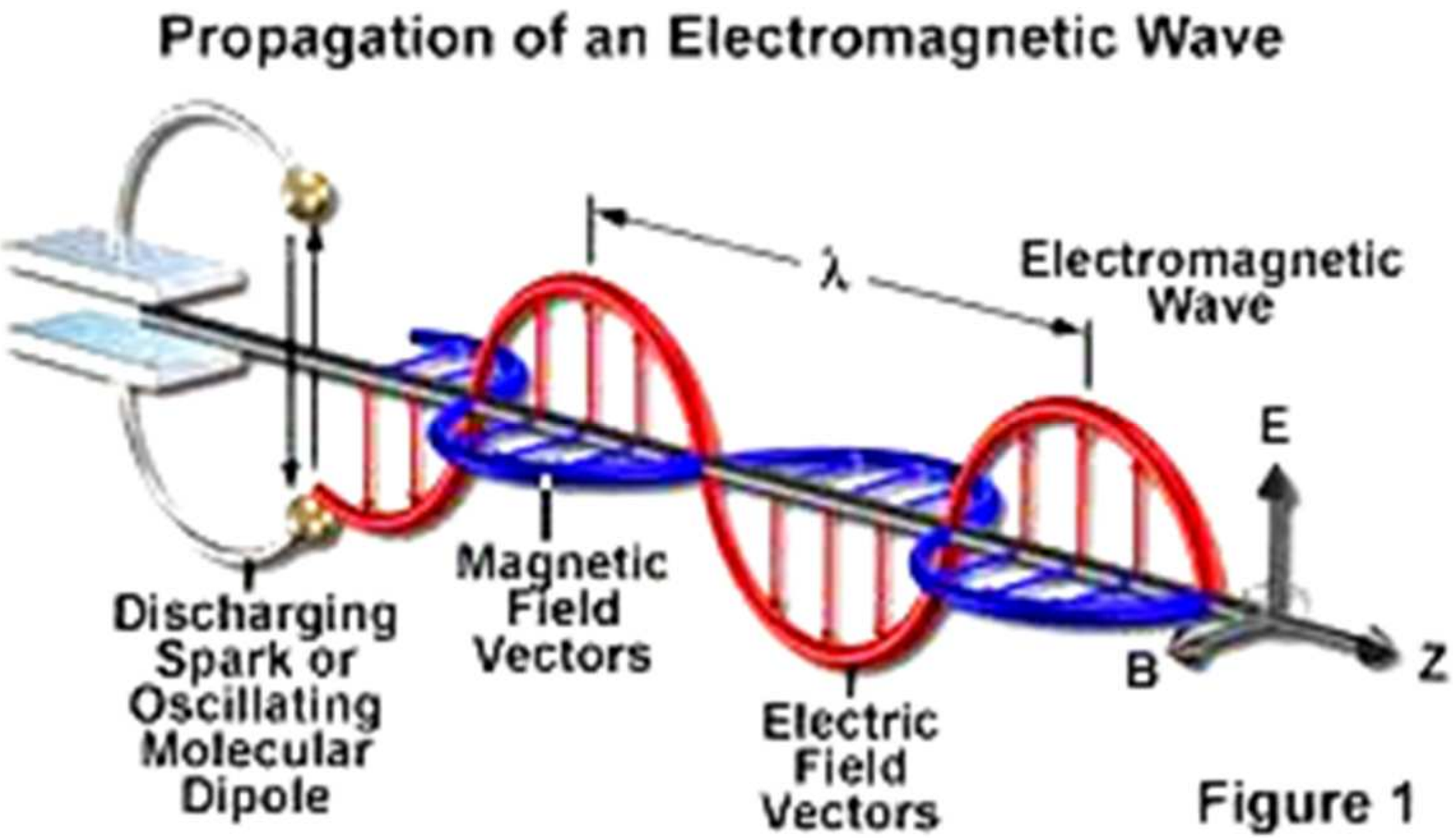
Average power P_{av} = $P_t \cdot \tau \cdot fr$
= 250 × 10^3 × 2.5 × 10^{-6} × 330
= 206 (W)

Pulse interval (Tr)
(3.03ms)

PRF (Pulse Repetition Frequency)

$$fr = \frac{1}{Tr} = 1/\ 0.00303 = 330\ (\mathrm{Hz})$$

What is antenna ?

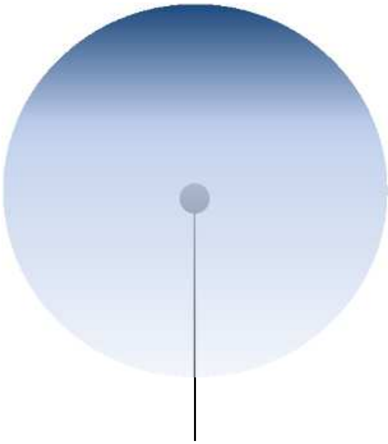


http://micro.magnet.fsu.edu/primer/java/polarizedlight/emwave/

What is antenna gain ?

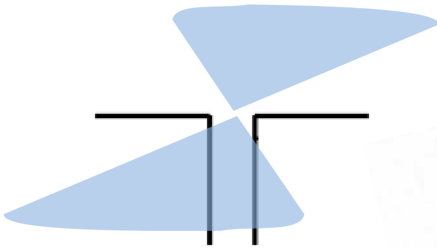
Antenna gain is the factor how much radio wave power is concentrated toward a direction

Point antenna



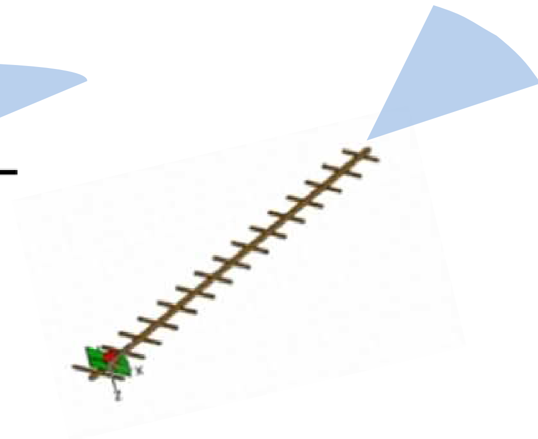
0dB
1W
360 degree

Dipole antenna



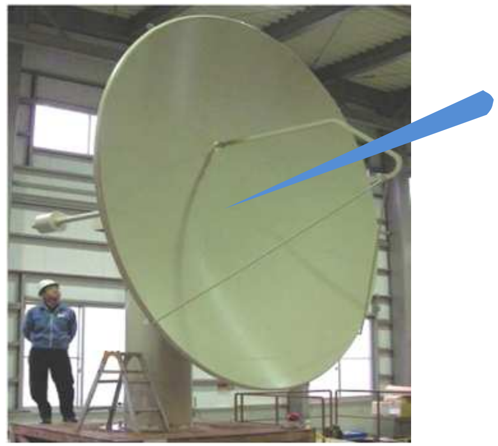
2.14dB
1.6W
72 degree

Yagi-Uda antenna



15dB
40W
36 degree

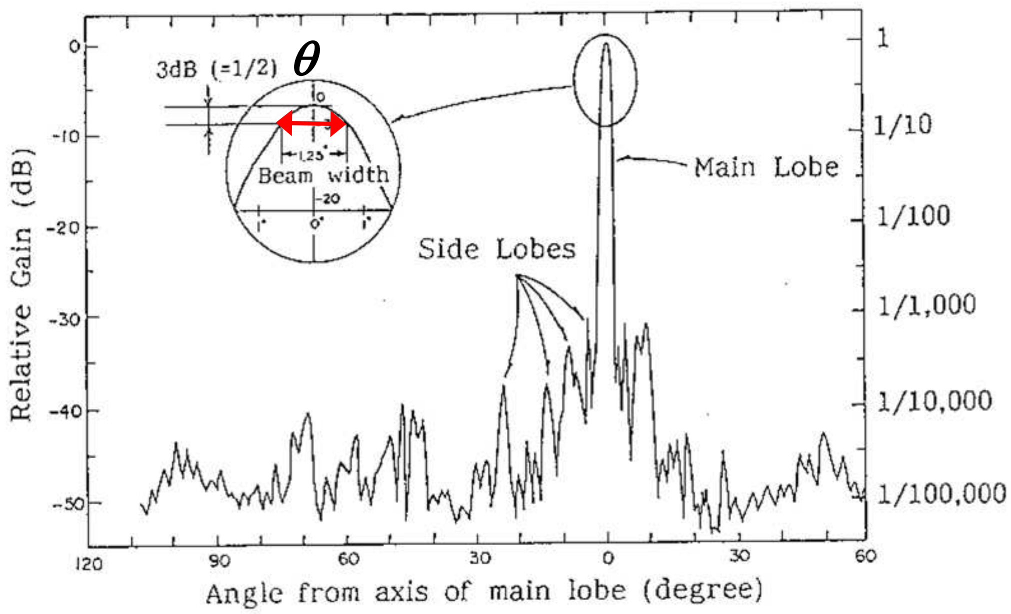
Parabolic antenna



44dB
25000W
1.0 degree

Antenna gain (dB)
Beam Power (W)
Beam width

Antenna pattern of a parabolic antenna



3D Beam pattern

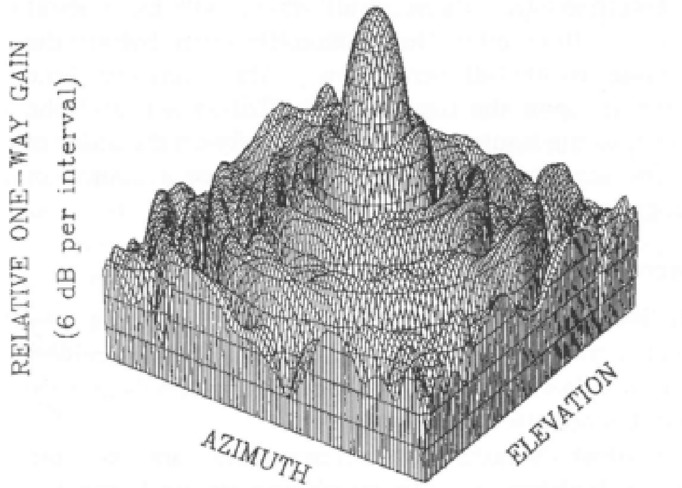


Figure 2.9 Antenna beam pattern of the NCAR CP2 X-band antenna. The elevation and azimuth angles extend about 5° either side of the mainlobe (0.1° per interval for both elevation and azimuth). The horizontal contours are at 6-dB intervals. From Rinehart and Frush, 1983.

Beam width θ (degree) is expressed approximately as follows:

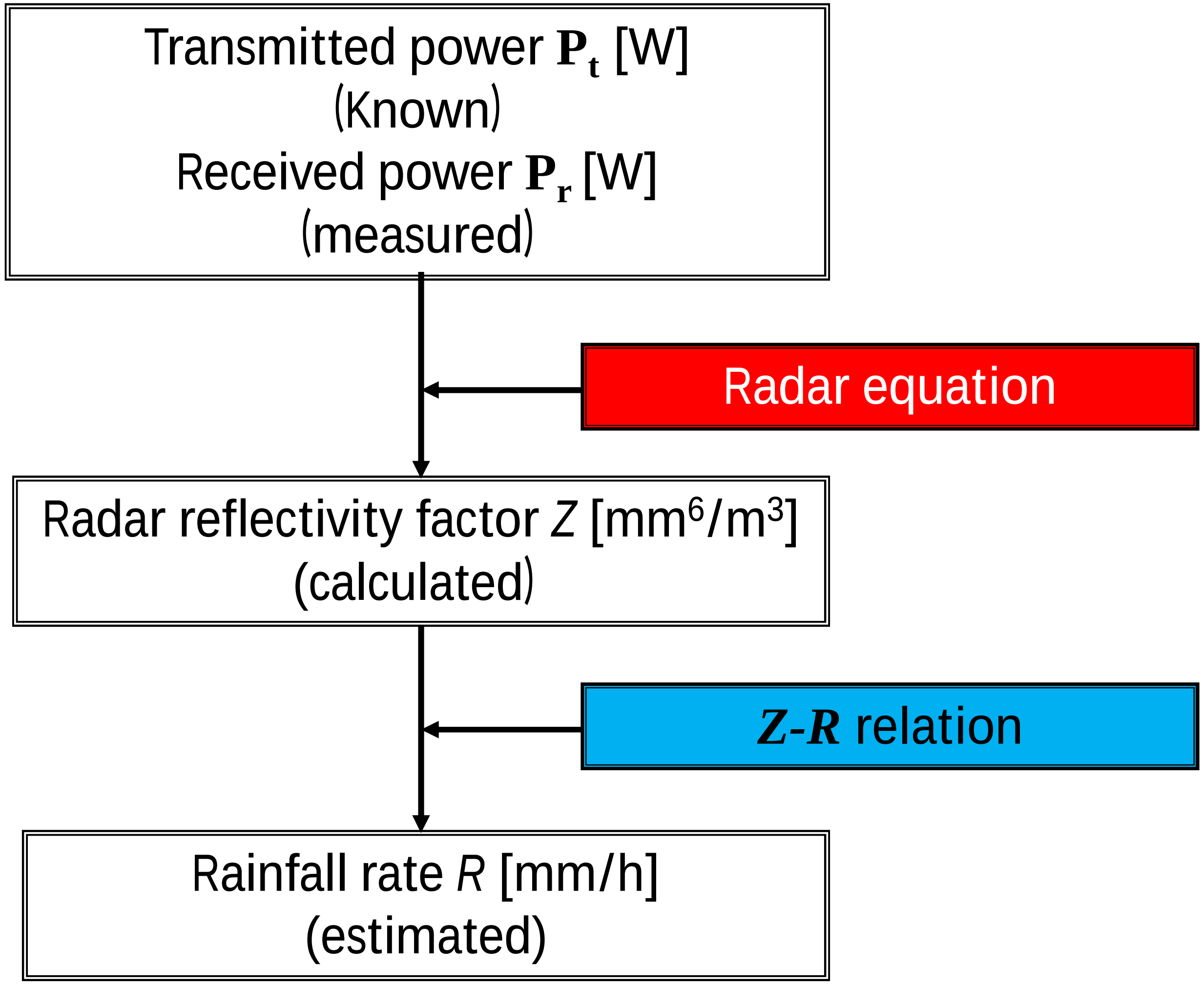
$$\theta = \frac{70\lambda}{d}$$

λ: wave length, d: antenna diameter

Beam width θ (radian) is related to antenna gain *G* as follows :

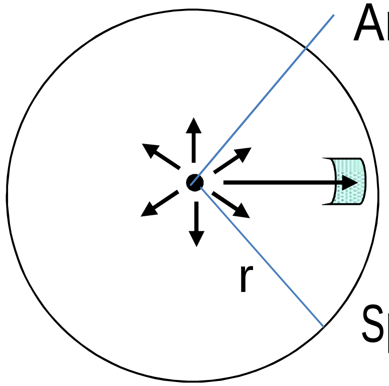
$$G \cdot \theta^2 \quad 8$$

Way to measure rainfall rate in radars



Let's derive radar equation

1. Propagation of radio waves from non-directional antenna



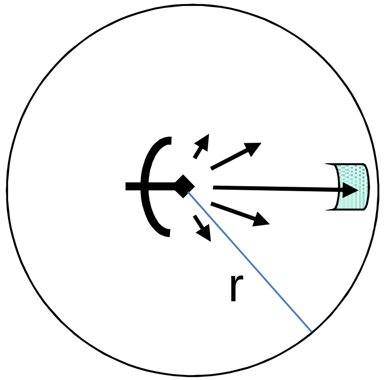
Antenna transmitting power P_t

incident power per unit area P_i

$$P_i = \frac{P_t}{4\pi r^2} \quad (1)$$

Sphere of radius r

2. Propagation from directional antenna



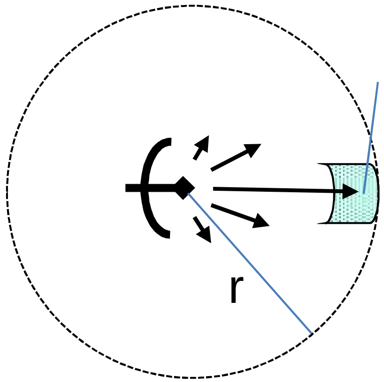
incident power per unit area P_i

$$P_i = \frac{P_t}{4\pi r^2} G \quad (2)$$

G : antenna gain
(not dB unit)

Let's derive radar equation

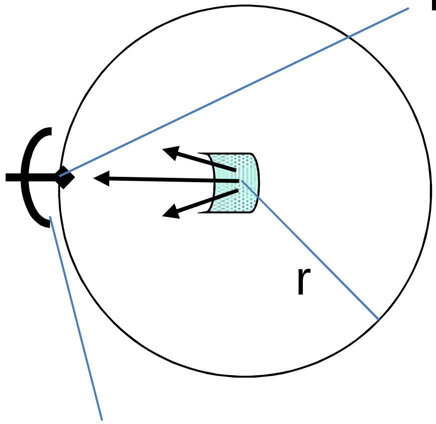
3. Power intercepted by a target of an area A_σ



a target of an area A_σ

$$P_\sigma = \frac{P_t}{4\pi r^2} G A_\sigma \qquad (3)$$

4. The target re-radiate its energy and detected by the radar

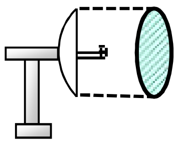


Detected power by the radar P_r

$$P_i = \frac{P_\sigma}{4\pi r^2} A_e$$

$$= \frac{P_t}{(4\pi)^2 r^4} G A_\sigma A_e$$

$$= \frac{P_t G^2 \lambda^2 A_\sigma}{64\pi^3 r^4} \qquad (4)$$



Effective area of the antenna A_e $\quad A_e = \frac{G\lambda^2}{4\pi}$

Let's derive radar equation

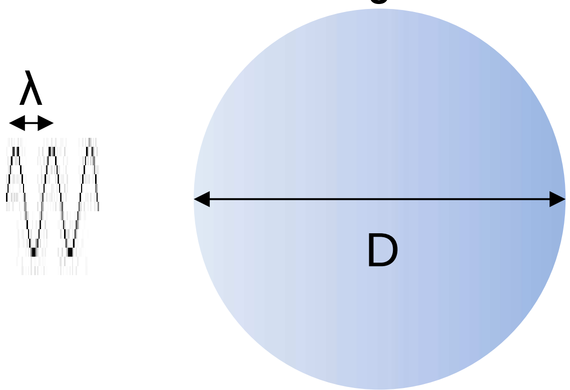
5. Backscattering cross-section area **σ** is introduced

There are many kinds of targets. Some kinds of targets show different sizes from their physical sizes. To overcome this problem, Backscattering cross-section area σ is introduced instead of A_σ.

$$P_i = \frac{P_t G^2 \lambda^2 A_\sigma}{64\pi^3 r^4} \longrightarrow P_i = \frac{P_t G^2 \lambda^2 \sigma}{64\pi^3 r^4} \qquad (5)$$

6. **σ** for spherical target

When diameter of a sphere D is enough large than the wavelength λ of the radar: D > 10λ , σ is the geometric area of the sphere.

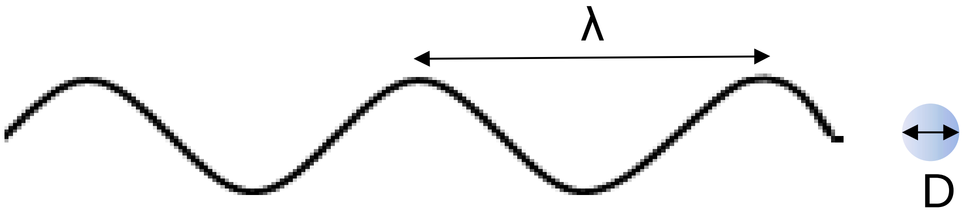


$$\sigma = \pi r^2 \qquad (6)$$

Let's derive radar equation

7. Rayleigh scattering of a one target

When diameter of a sphere D is enough small than the wavelength λ of the radar (D < 0.1λ : Rayleigh region), σ is proportional to the sixth power of D.



$$\sigma = \frac{\pi^5 |K|^2 D^6}{\lambda^4} \quad (7)$$

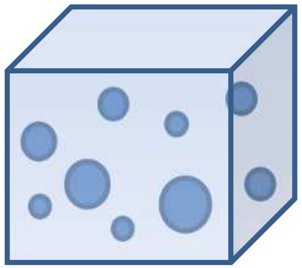
$|K|^2$ is dielectric coefficient and the parameter related to the complex index of refraction of the material. we here simply think $|K|^2$ as degree of reflection of radio wave at the material. In case of water (raindrop) $|K|^2$ is 0.930, and 0.197 for ice (snow).

Lord Rayleigh
1842-1919 England

Going on deriving radar equation

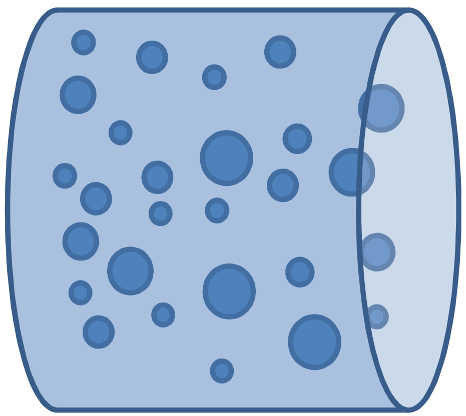
11. Rayleigh scattering of many targets in a volume V

Next we consider the condition of scattering from many targets. The total amount of backscattering from many targets in a unit volume (that is, 1m^3) is described as $\sum \sigma$.



$$\Sigma\sigma = \frac{\pi^5 |K|^2 \Sigma D^6}{\lambda^4} \qquad (8)$$

When there are many targets in a volume V, from Eq.5 received power P_i is



$$P_i = \frac{P_t G^2 \lambda^2 V \Sigma\sigma}{64\pi^3 r^4}$$

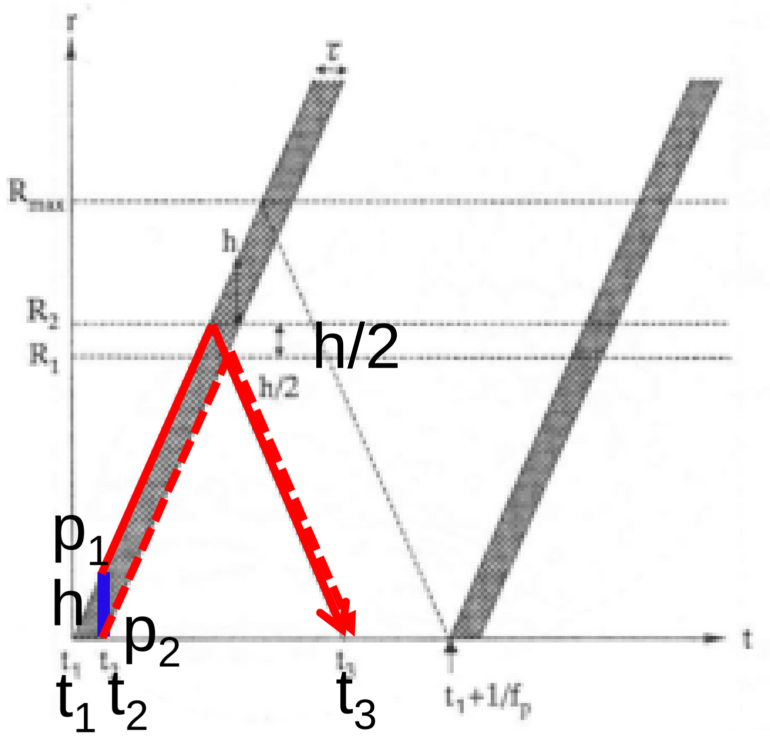
$$P_i = \frac{P_t G^2 \lambda^2 V}{64\pi^3 r^4} \frac{\pi^5 |K|^2 \Sigma D^6}{\lambda^4}$$

$$P_i = \frac{P_t G^2 \lambda^2 |K|^2 \pi^2 V \Sigma D^6}{64 r^4 \lambda^4} \qquad (9)$$

Why range resolution is h/2 rather than h ?

12. Range resolution

The reason why the range resolution of a radar is half the pulse length is that the front edge of the pulse p_1 and the trailing edge p_2 come back to the radar at time t_3. τ is duration time of the transmitted pulse and h = C τ , here C is the speed of radio wave (300,000,000m).



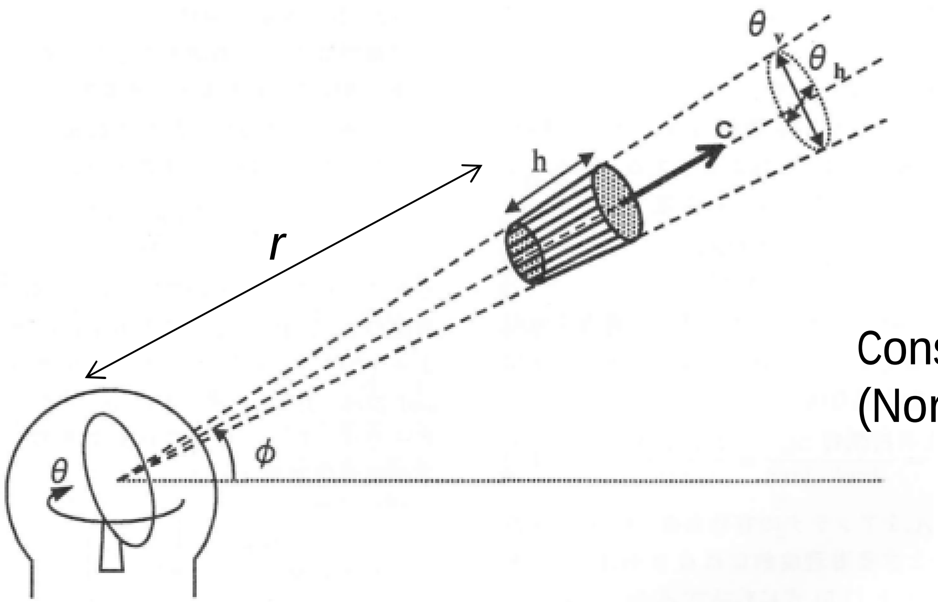
In the JMA radar, τ is 2.5 μs, and then h is $3 \times 10^7 \times 2.5 \times 10^{-6} = 750$ (m), and then the range resolution is 375 m.

This figure also shows the maximum range of observation R_{max} is $C/(2 f_r)$, here f_r is Pulse Repetition Frequency. Fp of the JMA radar is 330 Hz, and R_{max} is 455 km.

Back to deriving radar equation

13. Radar sampling volume V

A volume of a radar pulse in space is shown as below. The radar receives the power of radio wave returning from the half of the volume. The volume is called as “sample volume V_{ol}”.



$$V_{ol} = \pi \frac{r\theta}{2} \frac{r\theta}{2} \frac{h}{2}$$

$$= \pi \left(\frac{r\theta}{2} \right)^2 \frac{h}{2} \qquad (10)$$

Considering the beam pattern is Gaussian (Normal) shape,

$$V_{ol} = \pi \left(\frac{r\theta}{2} \right)^2 \frac{h}{4\log_e 2} \qquad (11)$$

Here h is the pulse length [m], θ is the beam width [radian : π/180✕[degree]].
Be careful that the length of the sample volume is (h/s), because (h/s) is the range resolution. $\mathrm{Log}_e(2)=0.693$

We have been arriving at **radar equation**

13. Radar equation

The radar equation will be obtained to put V_{ol} described by Eq.11 into Eq.9,

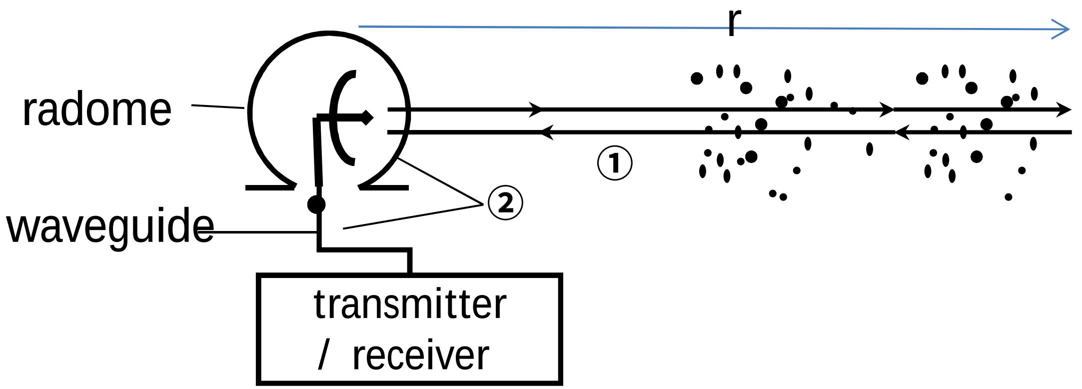
$$P_i = \frac{P_t G^2 \lambda^2 |K|^2 \pi^2 V_{ol} \Sigma D^6}{64 r^4 \lambda^4}$$

$$= \frac{P_t G^2 \lambda^2 |K|^2 \pi^2 \Sigma D^6}{64 r^4 \lambda^4} \pi \left(\frac{r\theta}{2} \right)^2 \frac{h}{4 \log_e 2}$$

$$= \frac{\pi^3 P_t G^2 h \theta^2 |K|^2 \Sigma D^6}{1024 \log_e 2 \, r^2 \lambda^2} \qquad (12)$$

We are arriving at **radar equation**

14. Effect of attenuation



Loss due to atmospheric gases (mainly oxygen and water vapor) : k_g (dB/km) → $10^{-0.2\, k_g \cdot r}$ (round trip)

Loss due to wave-guide and radome : L (dB) → $10^{-0.1L}$ (transmitter and receiver)

The final form of the radar equation considering attenuation effect is

$$P_r = \frac{\pi^3 P_t G^2 h \theta^2 |K|^2 \Sigma D^6}{1024 \log_e 2\, r^2 \lambda^2} \cdot 10^{-0.1L} \cdot 10^{-0.2 k_g \cdot r} \qquad (13)$$

We are now on final **radar equation**

15. Radar equation

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

$$P_r = \frac{\pi^3 P_t G^2 h \theta^2 |K|^2 \Sigma D^6}{1024 \log_e 2 \, r^2 \lambda^2} \cdot 10^{-0.1L} \cdot 10^{-0.2 k_g \cdot r} \qquad (13)$$

Now we learn the relation between transmit power P_t and received power P_r ,which is back-scattered by precipitation in echoing volume.

P_t: transmit power (peak power) (JMA radar: 250000 W)
G: antenna gain (44 dBZ)
h: pulse length (750 m)
θ: beam width (1.0 degree → 3.14/180 radian)
$|K|^2$: dielectric coefficient (0.970 for rain)
λ: wavelength (0.057 m)
L: loss by wave guides
K_g: loss by atmospheric gas (0.01dB/km)

Simpler radar equation

16. Simplifying Radar equation

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

$$C_1 = \frac{\pi^3 P_t G^2 h \theta^2}{1024 \log_e 2 \lambda^2} \cdot 10^{-0.1L} \quad (14)$$

Then radar the radar equation will be

$$P_r = \frac{C_1 |K|^2 \Sigma D^6}{r^2} \cdot 10^{-0.2 k_g \cdot r} \quad (15)$$

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,

$$P_r = \frac{C_2 Z}{r^2} \quad (16)$$

The simplest radar equation

17. Simplest Radar equation

$$P_r = \frac{C_2 Z}{r^2} \qquad (16)$$

We are interested in Z to estimate rainfall rate, then change Eq.16 to ,

$$Z = C_3 P_r r^2 \qquad (17)$$

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"

18. Logarithmic forms of Z

Ze "Equivalent radar reflectivity factor" shows has 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

$$Z = 10\log_{10}\left(\frac{Ze}{1[mm^6/m^3]}\right) \quad (18)$$

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.

(19)

19. Logarithmic forms of radar equation

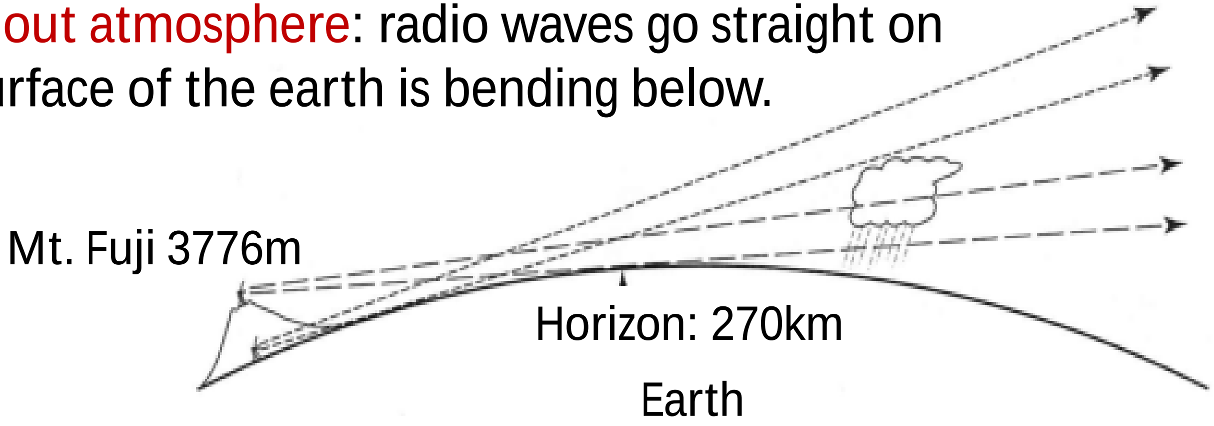
$$Z = C_3 P_r r^2 \quad (17)$$

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

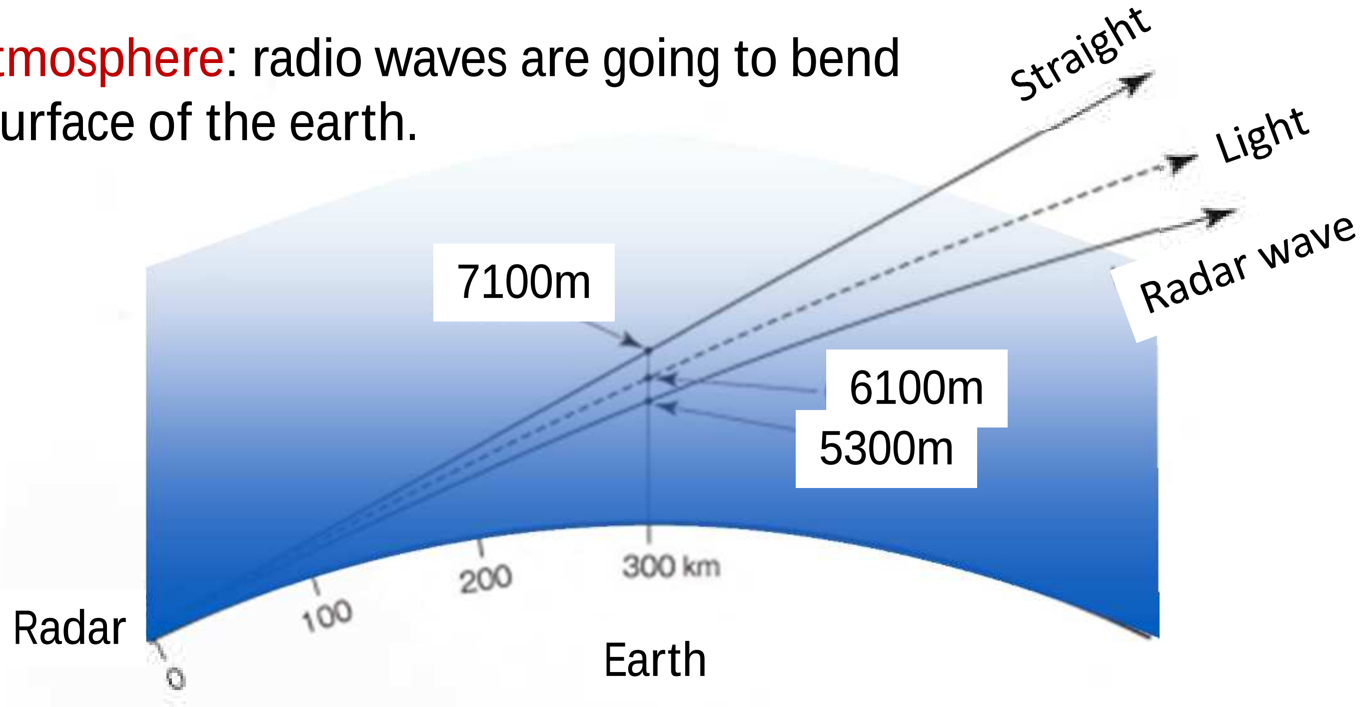
$$Z[dBZ] = C_4 + P_r[dBm] + 20\log r[km] \quad (20)$$

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.



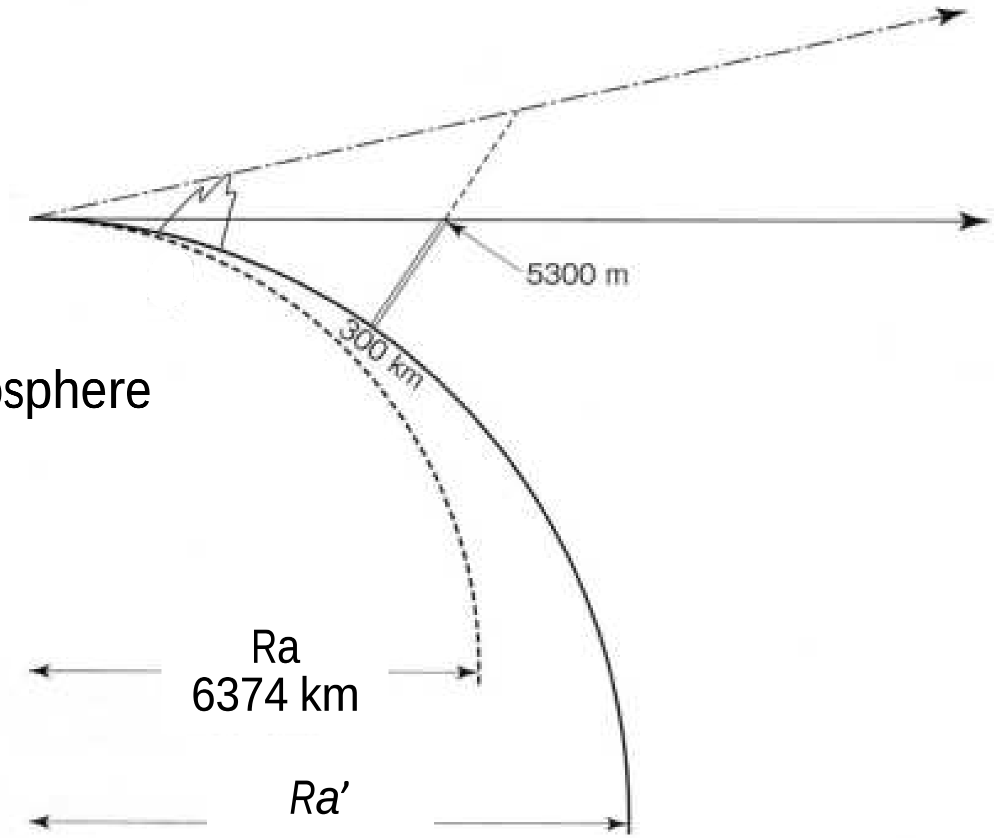
Effective earth radius

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,

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

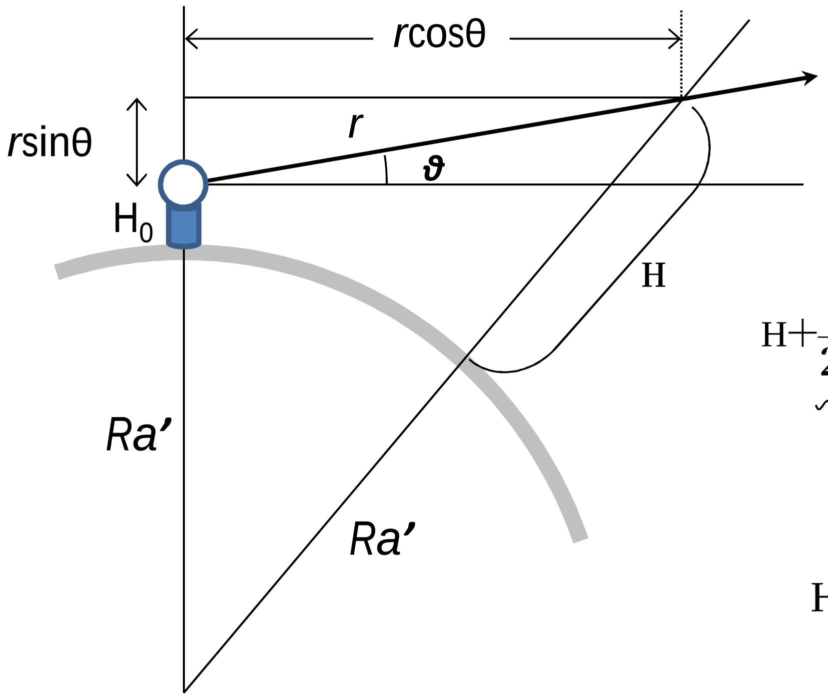
$\dfrac{dn}{dH}$: vertical change rate of refractive index of the atmosphere

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

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

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

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]

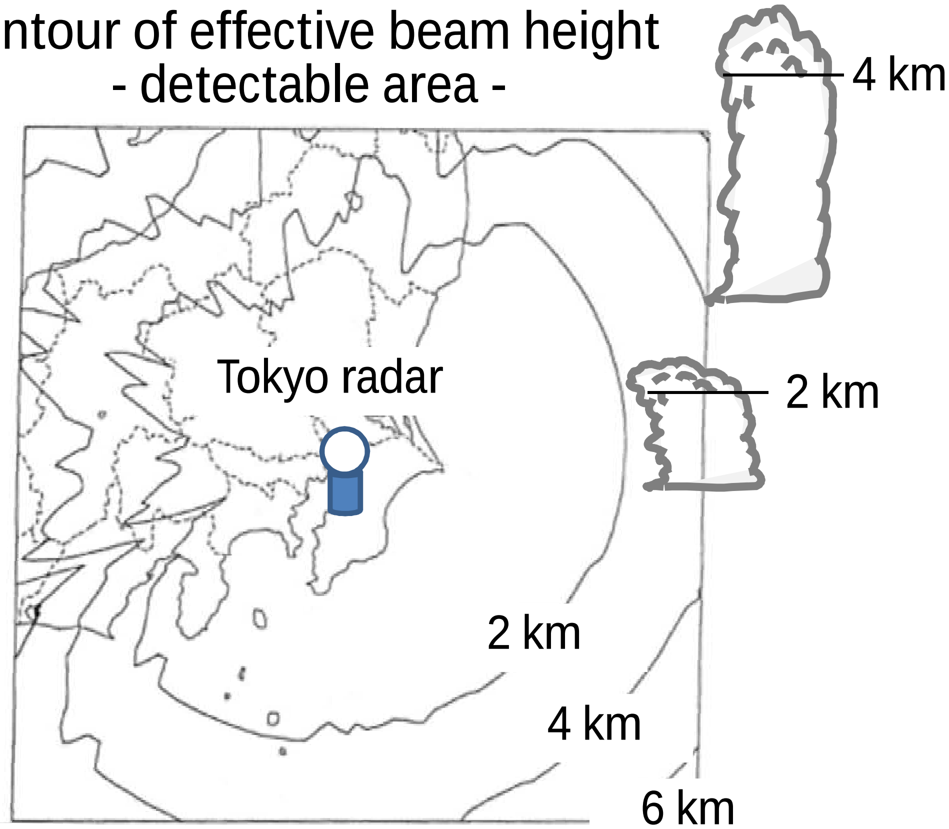
$$H = H_0 + 1000\, r\sin\theta + 0.0589\, r^2\cos^2\theta$$

Effective beam height

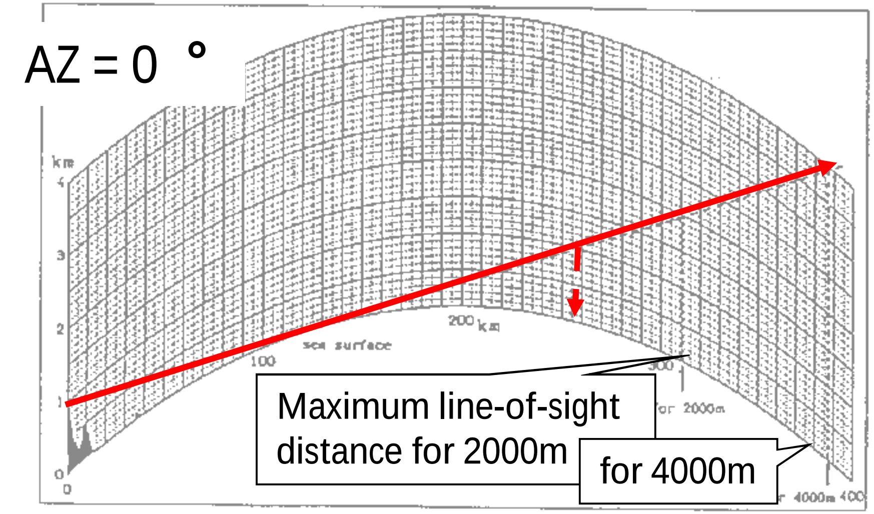
Topographical maps and the effective earth radius give us the "Contour of effective beam height " around a radar.   outside the area a effective beam height (e.g. 2 km) contour, precipitation clouds taller than the beam height are detected by the radar.

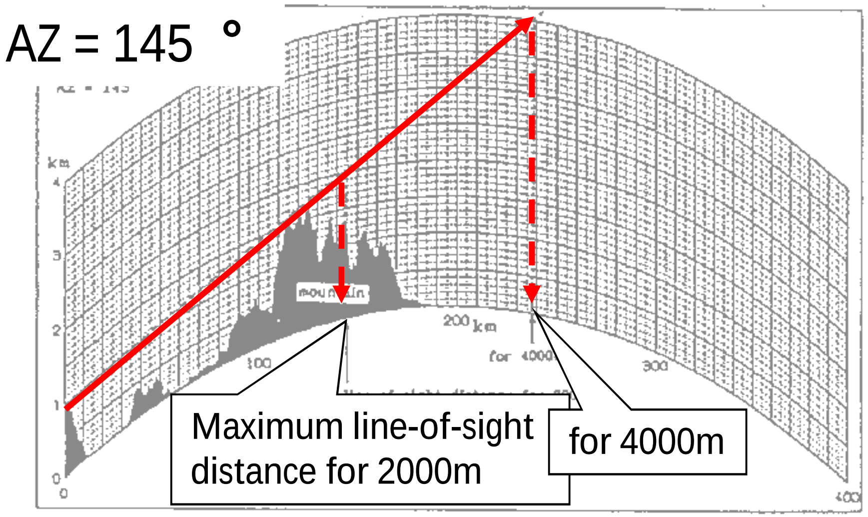
Contour of effective beam height
- detectable area -

Google Map



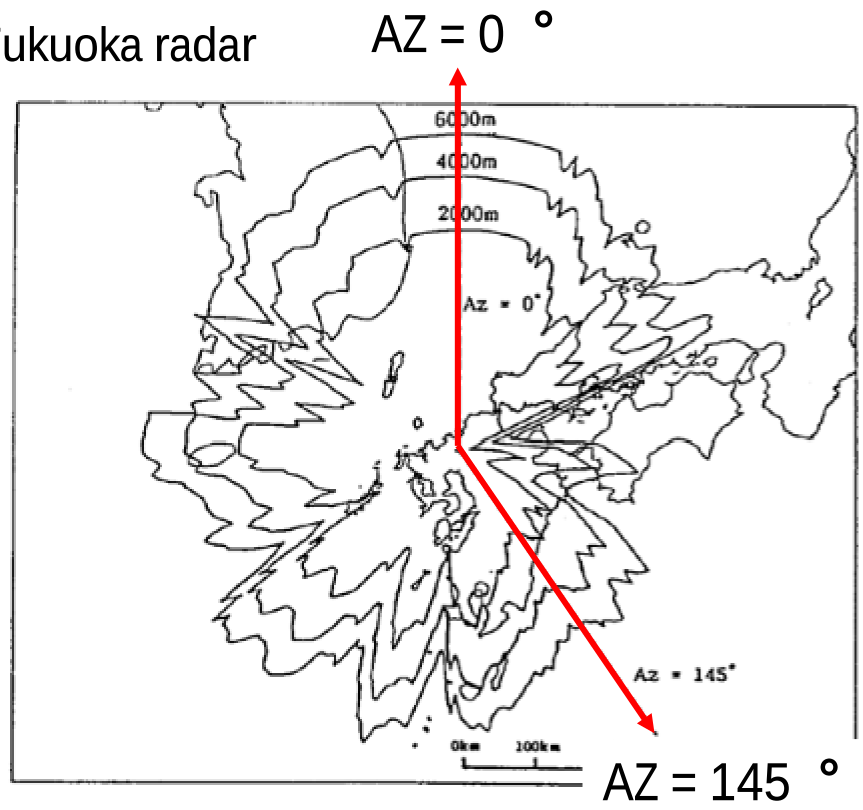
Classical chart to get effective beam height



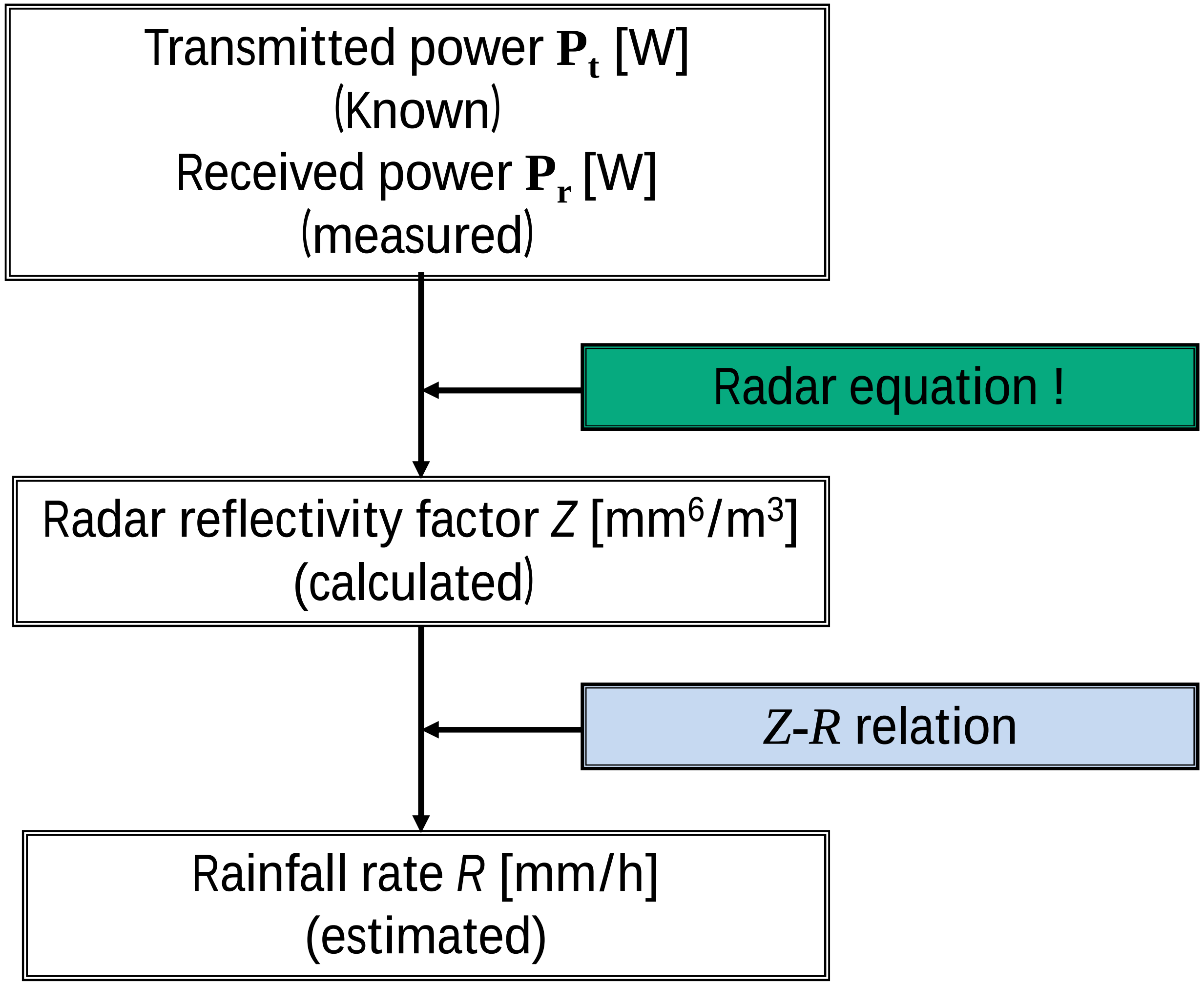


Now we are easily able to make it using a PC !

Fukuoka radar



Today's goal


Transmitted power P_t [W]
(Known)
Received power P_r [W]
(measured)
Radar equation !
Radar reflectivity factor Z [mm^6/m^3]
(calculated)
Z-R relation
Rainfall rate R [mm/h]
(estimated)

1. Weather Radar Operation

1.1 History and Current Situation of Weather Radar

1.2 Basics of Weather Radar

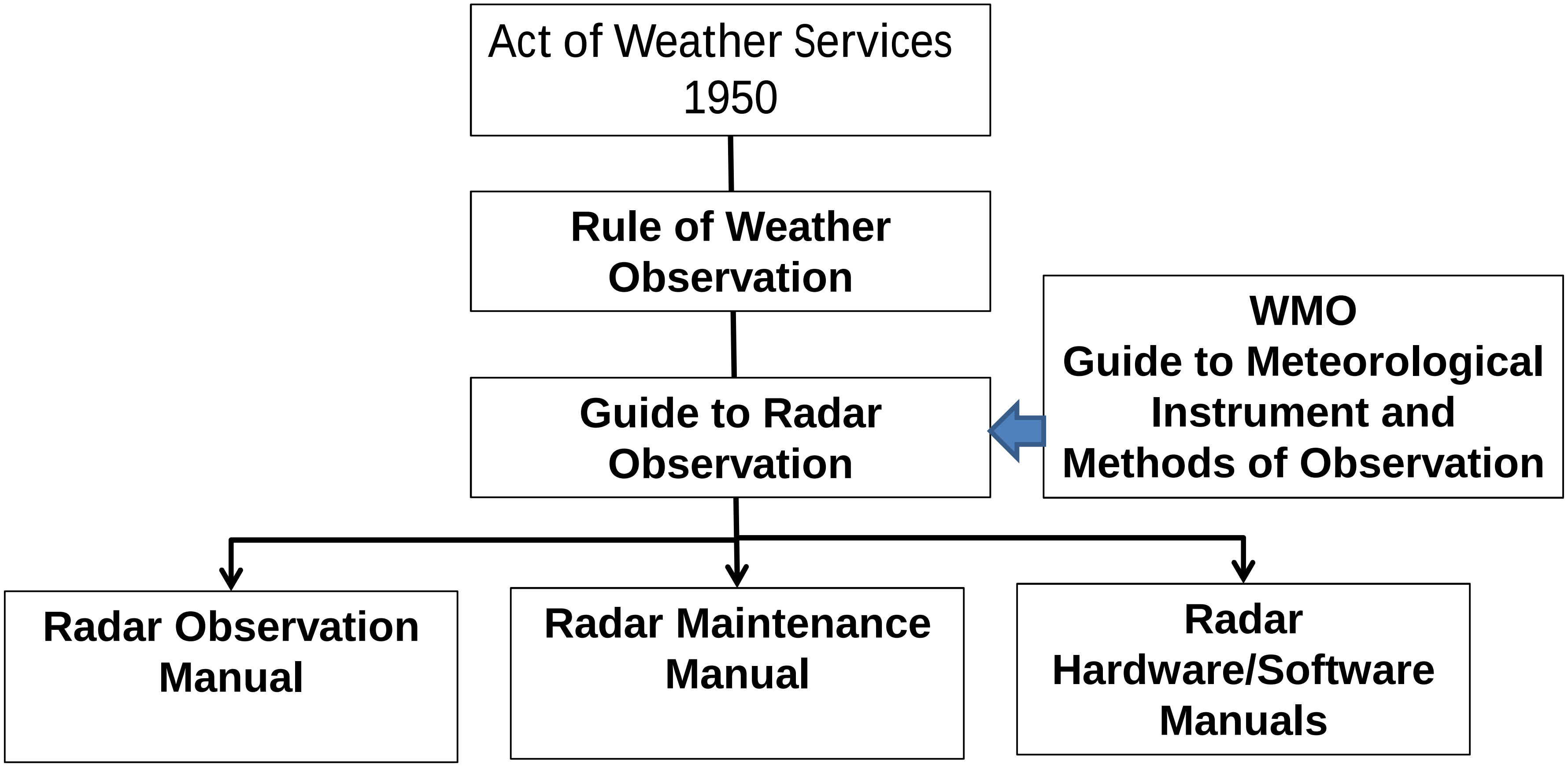
1.3 Operation of Weather Radars

1.3 Weather Radar Operation

- Rules for weather radar observations
- Radar observation: radar system monitoring, human quality control, briefing (interpretation) of the current situation of radar echo (precipitation) to forecasters
- Radar maintenance: periodic check, periodic maintenance, spare parts control
- Radar data: first radar data, secondary radar data
- Capacity development: training of radar meteorologists and radar engineers
- Radar network design: planning of renewal/upgrading of radars
- Radar data exchange and composite among National Meteorological and Hydrological Services: OPERA in EUMETNET

Rules for weather radar observations

The Law system to make weather radar operation
in Japan Meteorological Agency



Radar observation

Radar system monitoring, human quality control, briefing of the current situation of radar echo to forecasters

Time table of radar observers in charge (daytime duty)
08:30【Participation in the forecast discussion】
· Collecting information on the current situation and forecast of weather.
· Briefing to forecasters on current precipitation situation.
【handover from the previous observers】
· Reporting current operation status of radars (driving situation, echo condition, quality control).
· Reporting planned operation schedule of radars (schedule of system shutdown due to periodic check, maintenance and fault).
【Description of reports】
· Filling up the operation logbook.

Every hour from 09:00 to 16:00【Regular observations】
·Monitoring the system status (radars, telecommunication lines, center system
·Trouble shooting at the time the system fault
· Monitoring echo status, data input status and equipment operation status
· Data quality control (sending reports on non-precipitation echo, setting forced no-echo)
· Lightning countermeasure (operation of the engine-generator)
·Identify the center of typhoon and reporting
· Input to the wireless operation log

16:30 takeover to observers in nighttime duty

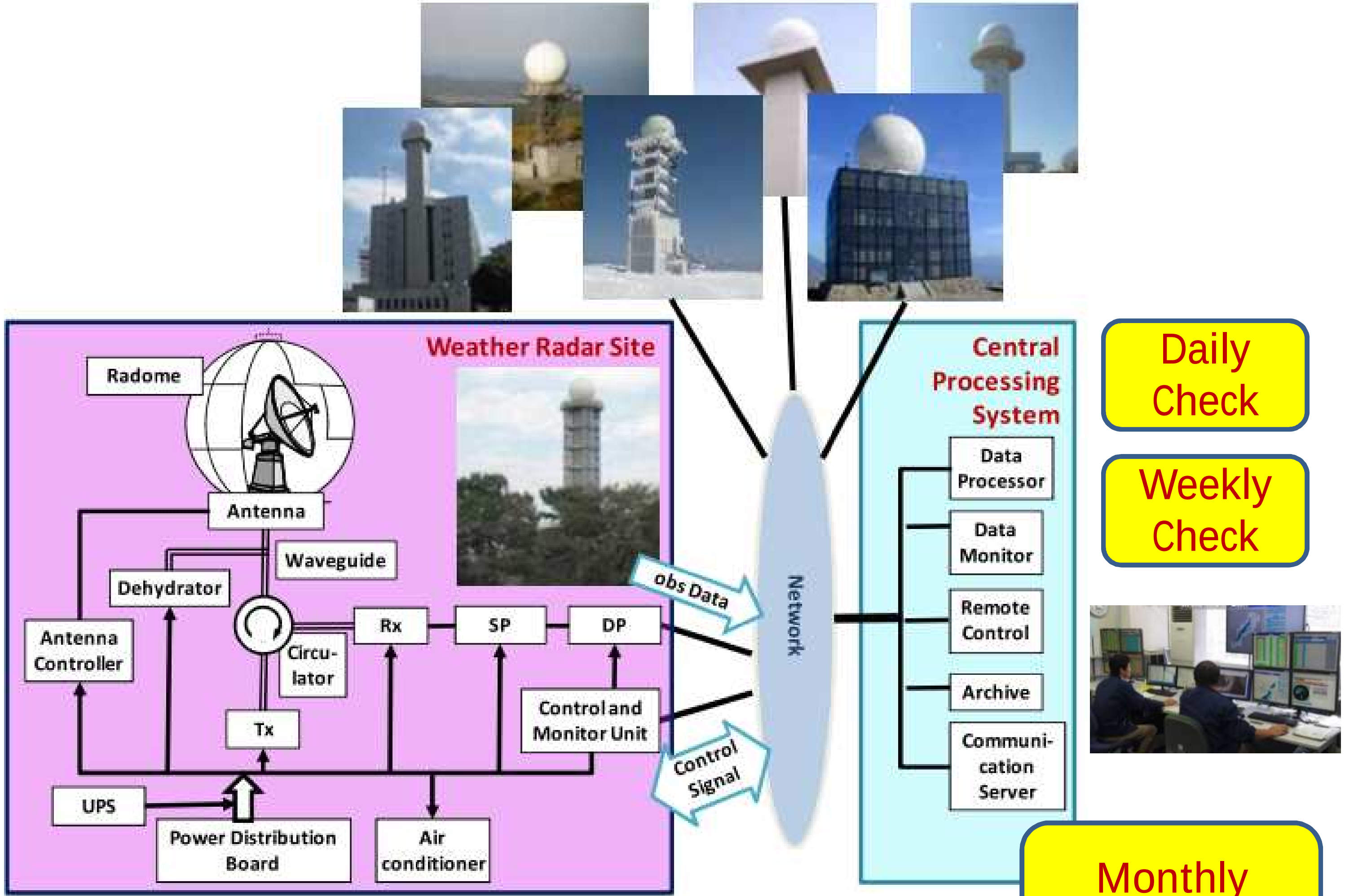
Radar maintenance: periodic check, periodic maintenance, spare parts control

Daily Check

Weekly Check

Monthly Maintenance

6-Month Maintenance



Spare Parts control

Daily Check

Weekly Check

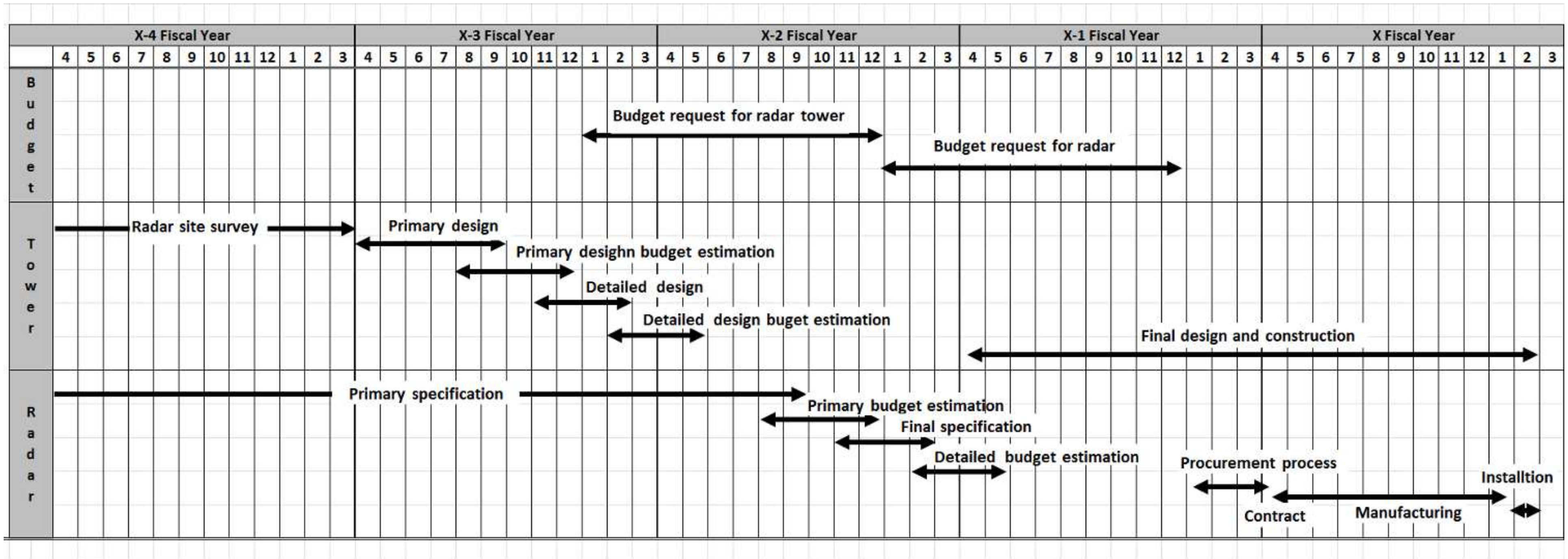
Monthly Maintenance

Radar data in case of JMA

	Data types	Unit	Time interval (minutes)
Primary data at each radar	r-θ−φ reflectivity	dBZ	10
	r-θ-φ Doppler velocity	m/s	10
Secondary data at each radar	x-y-z reflectivity	dBZ	10
	x-y-z Doppler velocity	m/s	10
	x-y reflectivity at the lowest level	dBZ	5 and 10
	x-y echo top height	km	10
	x-y-z reflectivity	dBZ	10
Nationwide composite radar map	x-y estimaited rainfall intensity at the lowest level	mm/hr	5 and 10
	x-y echo top height	km	10
	x-y vertically integrated liquid water content (VIL)	gr/cm^2	10
	Radar site whose data are used to make the composite	radar ID	5 and 10
	Mesocyclone (detection Image and text data)		at the detection
	JMA-MLIT composite estimated rainfall intensity	mm/hr	5 and 10

r-θ−φ: 3-dimentional polar coordinate (distance, tangential angle and elevation angle)
x-y-z: 3-dimentional pseudo orthogonal coordinate (longitude, latitude and 15 heights)
MLIT: Ministry of Land, Infrastructure and Transport

Radar network design: planning of renewal/upgrading of radars in case of JMA



Capacity development: training of radar meteorologists and radar engineers in JMA

- Introduction Training Course of new employees to JMA (1 hour for radar)
- Instruction Training in the Observation System Operation Office of JMA
- Remote Sensing Training Course for radar meteorologists at the radar sites (135 hours)
- Radar Maintenance Training courser for radar meteorologists at the radar sites (8 hours)

Thank you

Masahito ISHIHARA
mishihar0308@yahoo.co.jp