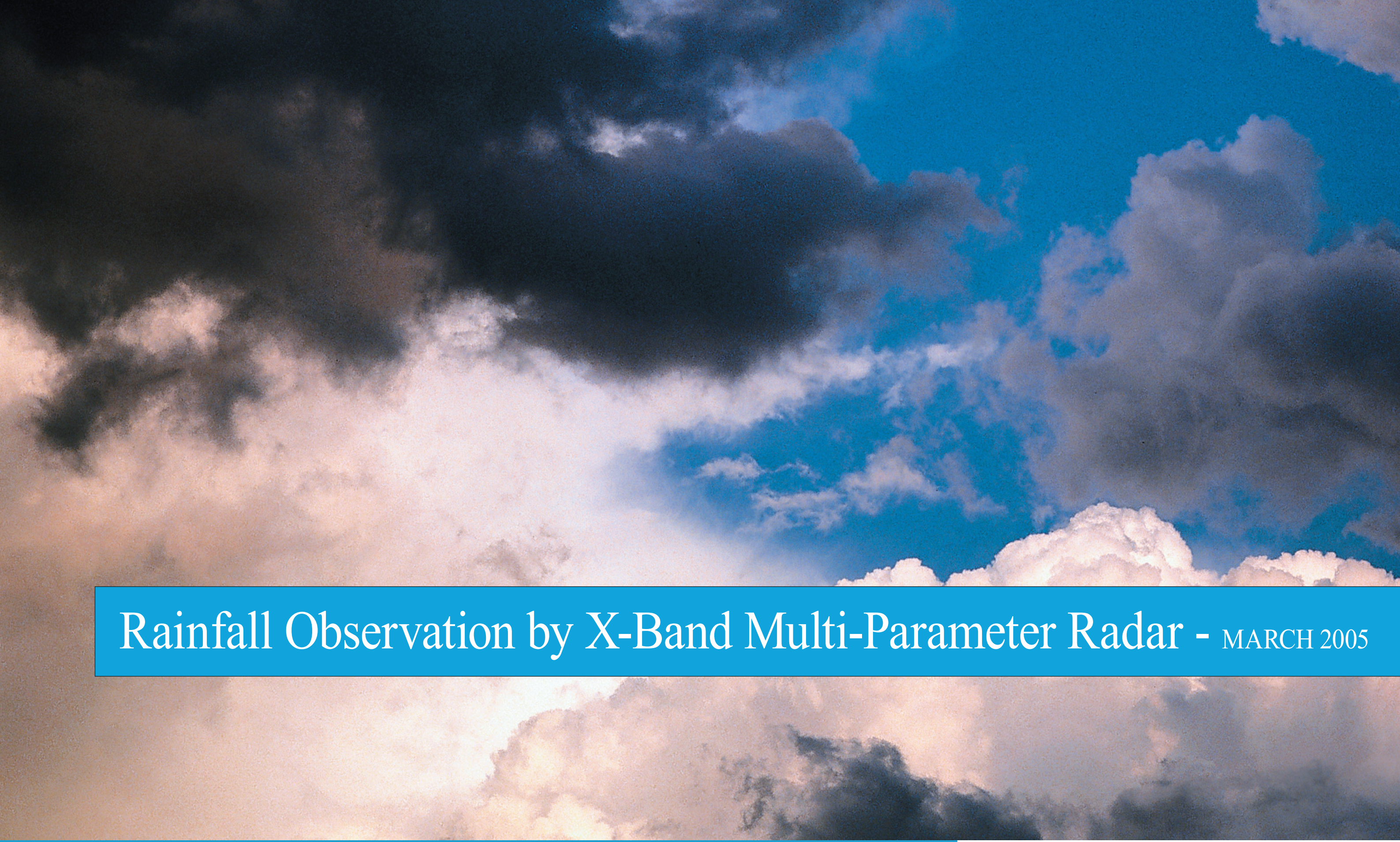


Rainfall Observation by X-Band Multi-Parameter Radar - MARCH 2005

NIED
National Research Institute for Earth Science and Disaster Prevention

Introduction

Since 2000, the National Research Institute for Earth Science and Disaster Prevention (NIED) has been conducting a study on the prediction of landslide disasters caused by torrential rain. In 2003, the X-band multi-parameter radar (MP-X) was installed in Ebina, Kanagawa prefecture, and continuous observation of rainfall began. The data obtained from such observations is used not only to predict landslide disasters, but also to reduce natural disasters. Through its observations, NIED aims to achieve the following:

1. The establishment of a high-precision, high-resolution precipitation estimation methodology
2. The creation of precipitation data for shallow landslide risk prediction and flood prediction
3. The development of short-term rainfall forecasting using three-dimensional precipitation information
4. An understanding of the microphysical process of precipitation
5. The real-time public disclosure of rainfall information using the Internet

Using the content below, this brochure provides a summary of our rainfall observations and describes the initial results obtained:

- What is multi-parameter radar?
- Types of radar
- Principle of rainfall estimation using multi-parameter radar
- Multi-parameter radar observation parameters
- Outline of radar observations
- Specially prepared raingauge networks
- A new methodology: the R-K_{DP} relationship
- R-K_{DP} method unaffected by rain attenuation
- 500-meter mesh rainfall information
- Verification using ground-based raingauges
- Appendix – History of NIED weather radar research

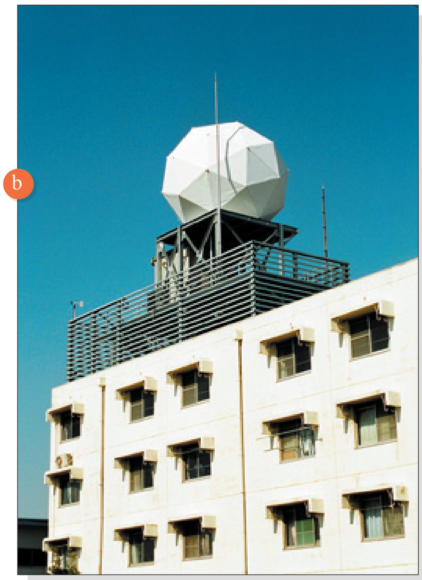
What is multi-parameter radar?

In order to study the cloud and precipitation process, the multi-parameter radar system (MP radar system) was completed in 2000, following a technology survey and basic and detailed design processes which were conducted in 1996 - 1997. The MP radar system comprises a dual wavelength high sensitivity radar (MP-Ka/W radar) for cloud observation, and a 3 cm wavelength polarization radar (MP-X radar) for rainfall observation. Although the MP-X radar was originally mounted on a 4-ton truck to facilitate mobile observations, in 2003 it was fixed atop a 4-story building located in Ebina in Kanagawa prefecture so as to conduct continuous observations of rainfall. This has enabled the constant monitoring of the generation of heavy rainfall in the Tokyo metropolitan area. This brochure describes only the MP-X radar.

a

1a The multi-parameter radar system at NIED in 2000 (Tsukuba). Left: MP-Ka/W, right: MP-X.

b

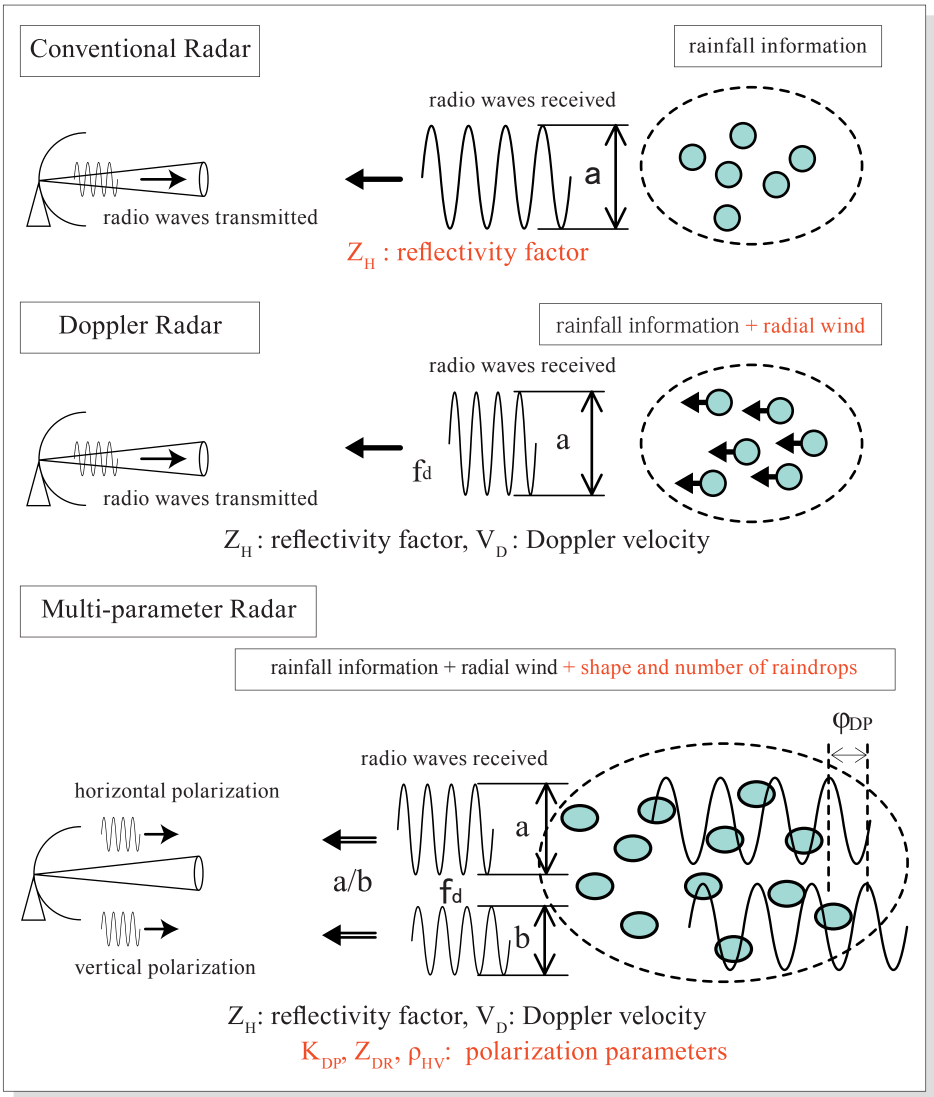


1b The MP-X after relocation in 2003 (Ebina, Kanagawa prefecture).

Table 1 – NIED MP-X Radar Specifications	
Frequency	9.375 GHz
Antenna type	2.1m diameter parabolic antenna
Scanning range (speed): AZ	360°(≤ 36 deg/s)
EL	-2 ~ +92° (≤ 18 deg/s)
Antenna gain	41.6 dB
Beam-width	1.3 deg
Transmission tube	Magnetron
Peak power	50 kW
Pulse width	0.5 μs
Pulse repetition frequency	≤ 1,800 Hz
Polarization	H, V
Doppler processing	PPP, FFT
Noise figure	2.3 dB
Observation range	80 km
Observation parameters	Z_H, V_D, W, Z_{DR}, ρ_{hv}, Φ_{DP}, K_{DP}

Types of Radar

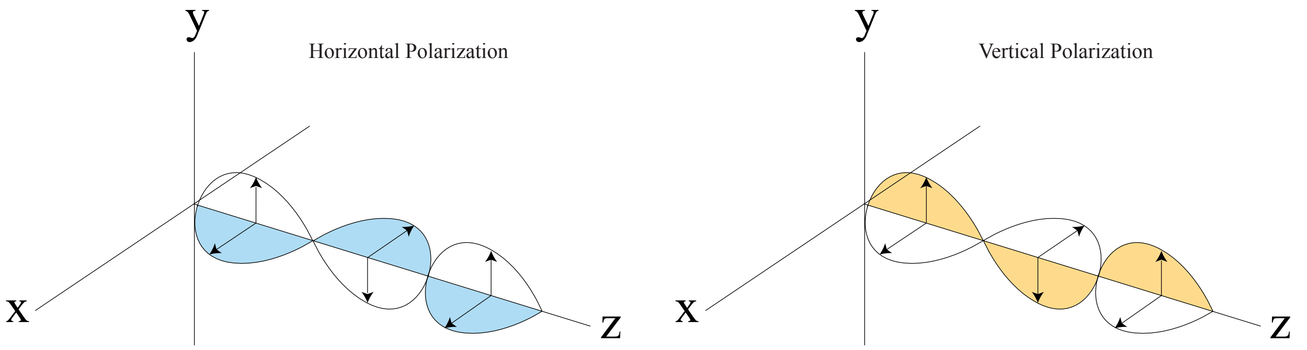
Radar is an acronym for 'radio detection and ranging'. Radars, equipment used to detect and measure the distance to a target via radio waves, can be classified by the type of radio waves used and the information that can be obtained. Conventional radars, such as those used by the Japan Meteorological Agency, measure only the amplitude information of the radio waves which have back-scattered from raindrops and returned to the radar (reflectivity factor), and with which rain rates can be estimated. Doppler radars, in operation as airport radars, measure frequency information (Doppler frequency) in addition to the amplitude information, from which the radial velocity (Doppler velocity) of raindrops to the radar can be measured. Multi-parameter radars enable the transmission of two types of radio waves; vertical and horizontal polarization, while conventional and Doppler radars can transmit only a single type. Various parameters can be obtained from the signals that are reflected from raindrops. The use of multi-parameter radar enables accurate rainfall estimates, as polarization parameters are closely related to raindrop shape and their drop-size distribution. Further, distinctions can be made such as that between rain and snow.



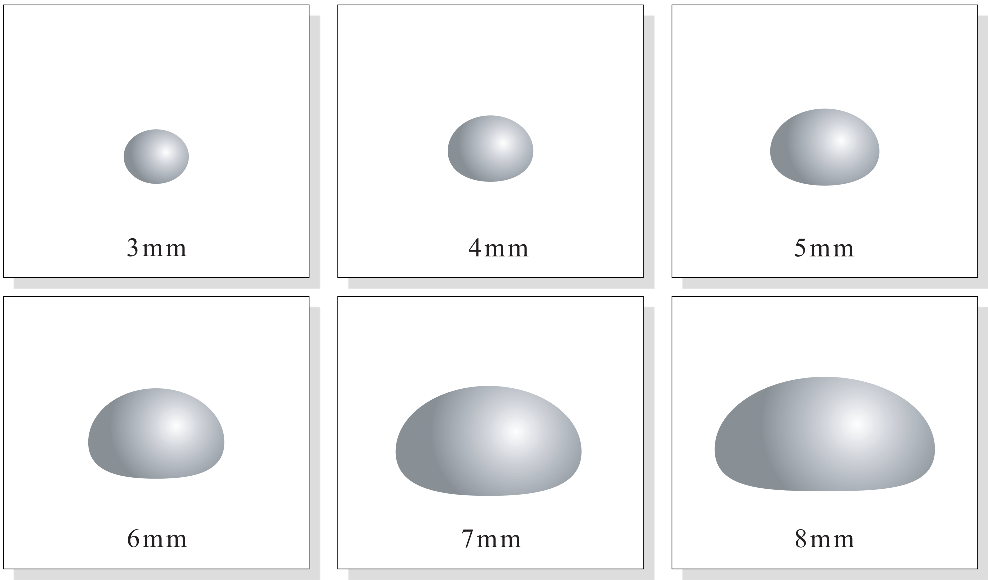
2 Radar types and the information that can be obtained.

Principles of Multi-parameter Radar Estimation

Multi-parameter radar uses two polarization waves, while conventional meteorological radars use a single-polarization wave (Fig. 3a). The principle of rainfall estimation using multi-parameter radar is based on the fact that raindrop shapes change from round to flat with increases in rainfall intensity.



3a Structure of horizontally and vertically polarized waves



3b Changes in raindrop shape

Radar parameters used to estimate rainfall intensity:

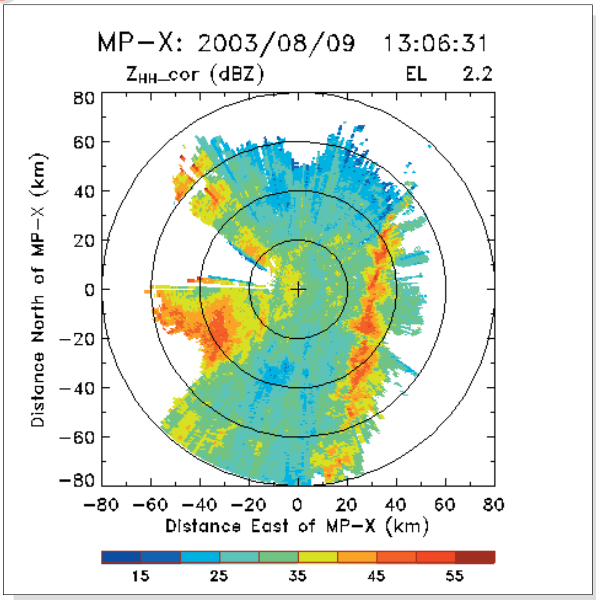
- Reflectivity factor Z_H: The strength of the radio waves reflected back to the radar after it hits raindrops. Z_H is a parameter that is used in conventional metrological radar observations. The rainfall intensity is computed using a predetermined R- Z_H relationship.

- Differential reflectivity Z_{DR}: Defined as the ratio of the reflectivity factor for horizontal polarization Z_H to that for vertical polarization Z_V. Z_{DR} is one of the important polarization parameters that MP radar can measure, and from which parameter information on rain drop size distribution can be obtained.

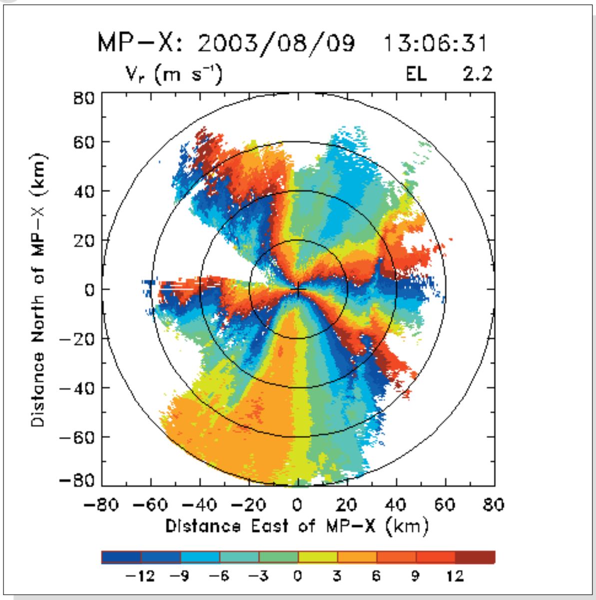
- Specific differential phase K_{DP}: Defined as the difference in phase velocity per unit distance of horizontally- and vertically-polarized waves. K_{DP} is one of the polarization parameters that MP radar can measure, and from which accurate rainfall intensity can be determined.

Multi-parameter Radar Observation Parameters

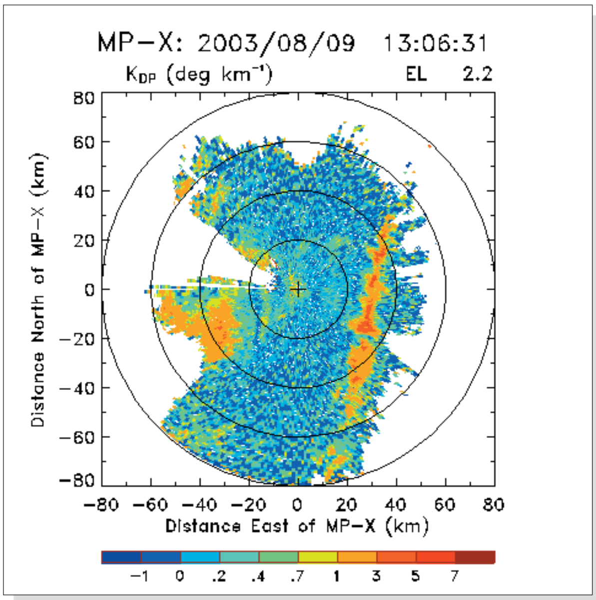
a Reflectivity factor Z_H.



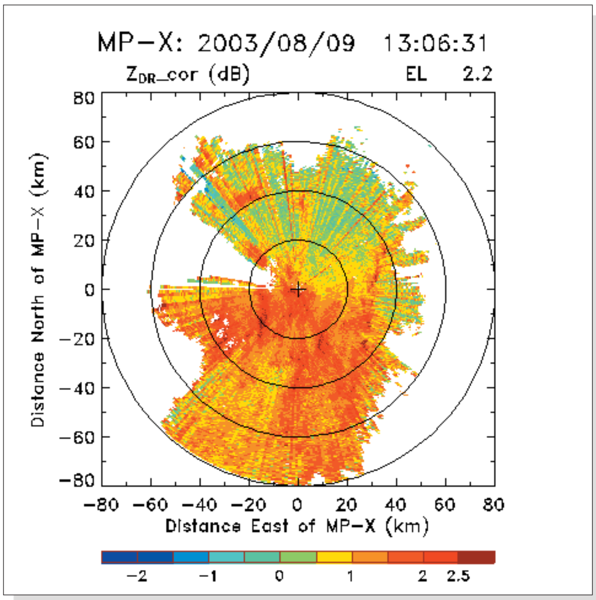
b Doppler velocity V_D.



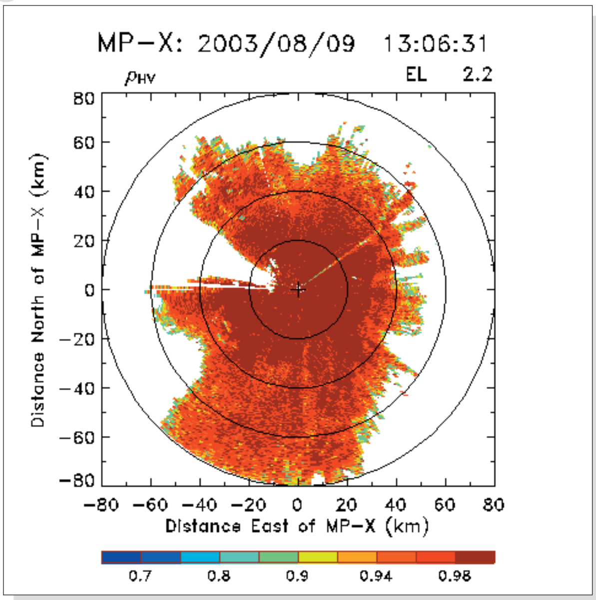
c Specific differential phase K_{DP}.



d Differential reflectivity factor Z_{DR}.



e Correlation coefficient between two polarizations ρ_{HV}.

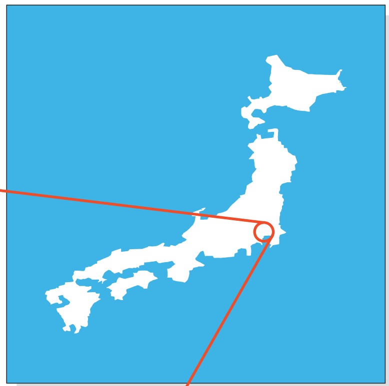


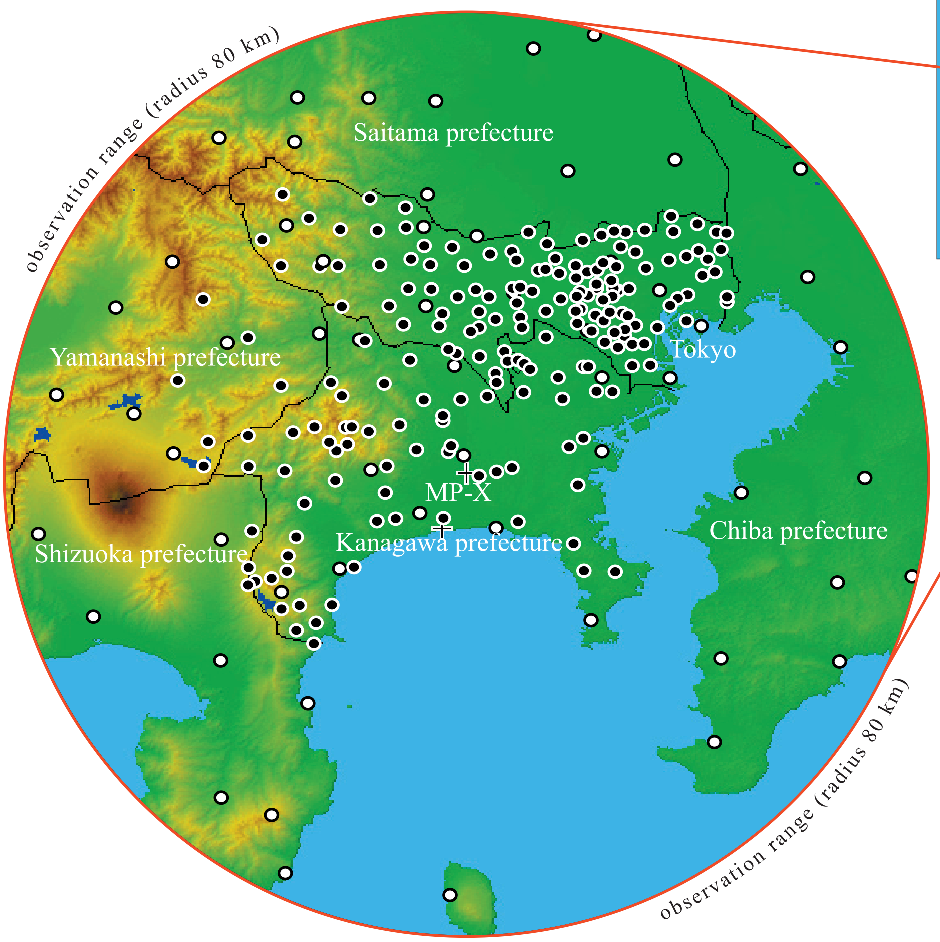
4 Examples of rainfall caused by typhoon T0310, which was observed on August 9, 2003. A variety of rain cloud information was obtained through observations with multi-parameter radar.

Outline of Radar Observations

In June 2003, the MP-X was moved to Ebina, Kawasaki in order to conduct continuous observations of rainfall. Its observation range of radius 80 km covers mountainous areas such as Mt. Fuji, Hakone and Tanzawa, and flat areas where big cities such as Tokyo and Yokohama are located. The MP-X enables simultaneous examination of rainfall distributions at two geologically different positions. There are two existing raingauge networks in the radar observation area, which networks are used for verification of rainfall estimate algorithms. One, the Japan Meteorological Agency AMeDAS raingauge network, provides 10-minute rainfall data with spacing of about 17 km. The other rainguage network is that operated by municipalities such as Tokyo and Kanagawa prefecture, from which is obtained 10-minute rainfall data with spacing of about 5 km.

5 NIED MP-X installed in Ebina, Kanagawa prefecture (June 2003).

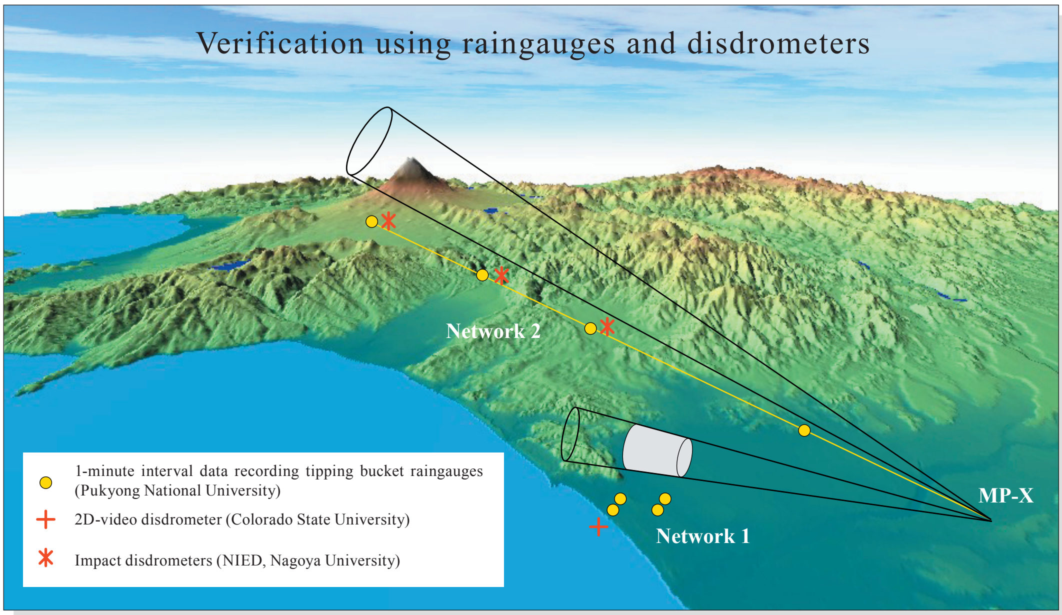




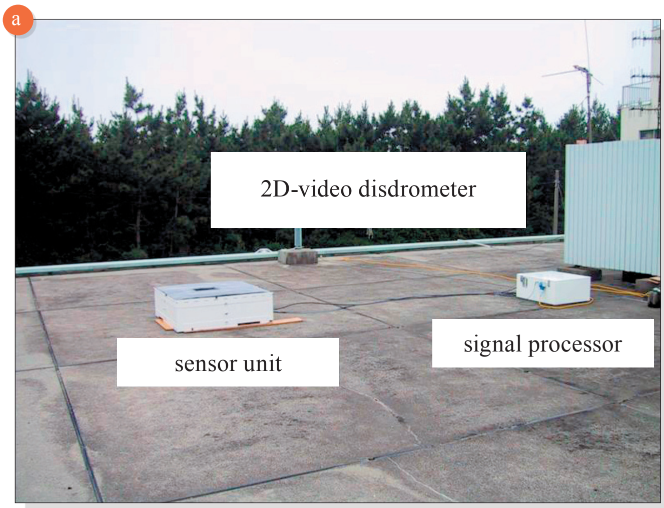
6 MP-X location and observation range. ● shows ground-based raingauge network in Tokyo and Kanagawa prefecture. ○ shows the Japan Meteorological Agency's rainfall observation points.

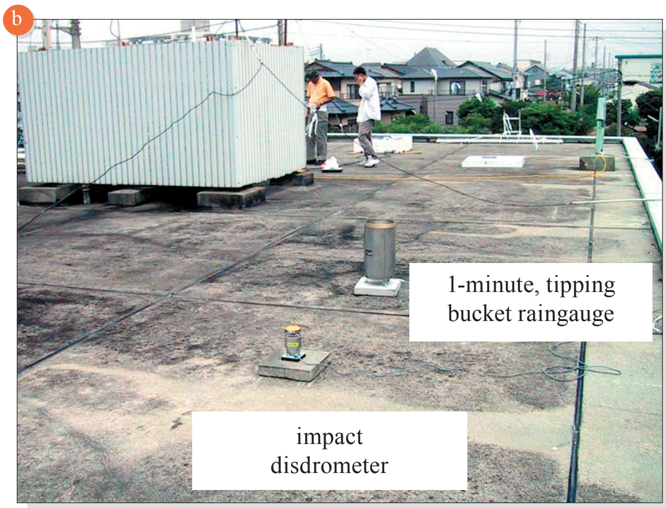
Specially Prepared Raingauge Networks

In addition to the existing raingauge networks, for the 2003 observations special instruments were installed jointly by universities at home and abroad. Pukyong National University in Korea provided two networks. One of them, Network 1 (Fig. 7), comprises four tipping bucket raingauges placed about 10 km away from the radar with a spacing of about 300 meters. The rainfall intensity in space, which the radar measures, can thereby be obtained. The other, Network 2, comprises four raingauges placed in a mountainous area, on a straight line from the radar. Network 2 was put in place so as to confirm the accuracy of rainfall estimates for mountainous areas. Such raingauges have a resolution of 0.1mm, and a sampling interval of one minute. In addition to these networks, three impact type disdrometers were deployed, with which devices raindrop size distributions can be measured. Furthermore, a 2D-video disdrometer, which enables the measurement of raindrop size, was deployed by Colorado State University.



7 Network comprised of specially prepared raingauges and disdrometers (2003).

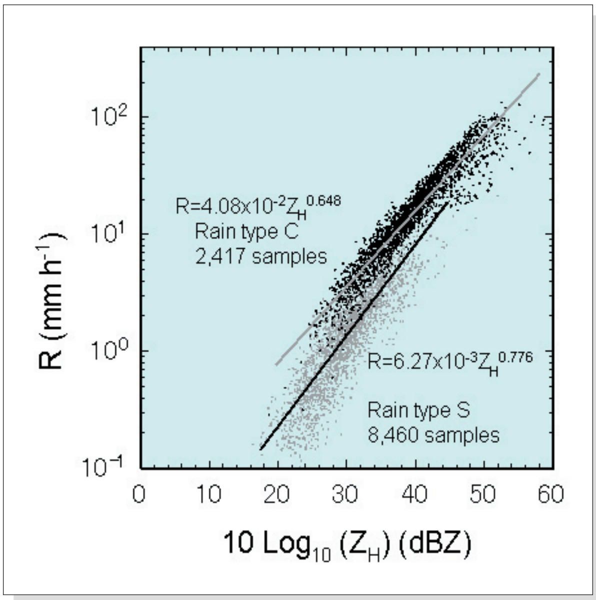




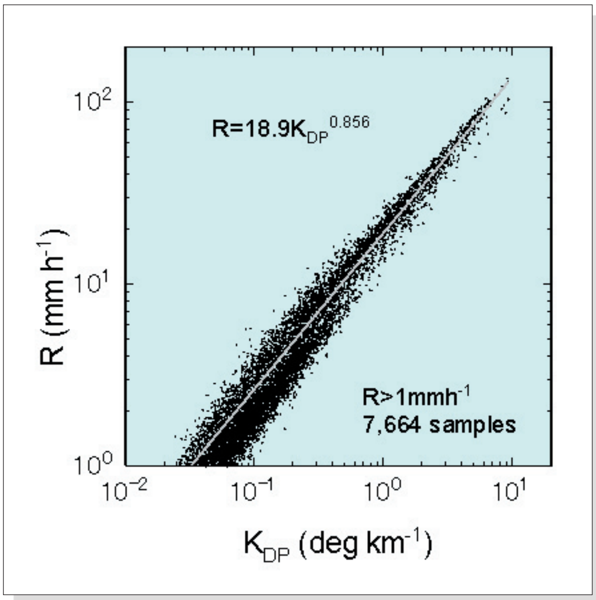
8 (a) 2D-video disdrometer placed on the rooftop of the NIED Hiratsuka Testing Yard (Hiratsuka, Kanagawa).
(b) One-minute interval data recording tipping bucket raingauge and impact disdrometer placed at the same location.

New Methodology: The R-K_{DP} Relationship

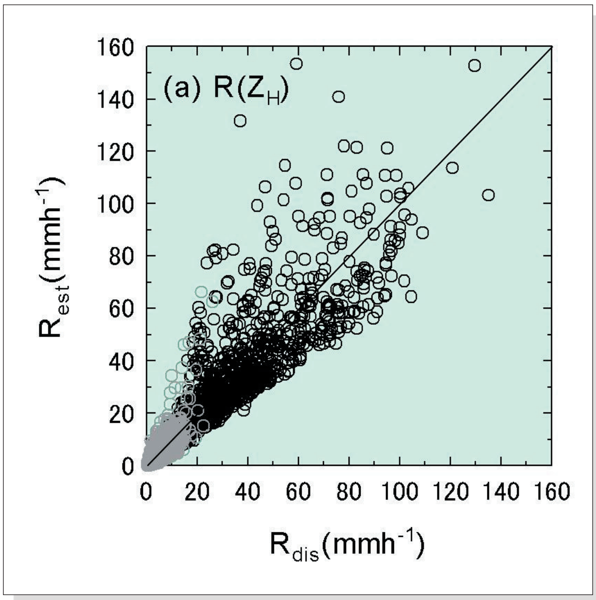
The method generally used to perform rainfall intensity estimates with conventional weather radars is that of estimating rainfall intensity from reflectivity factor Z_H (the so-called R-Z_H method). Since this method is sensitive to fluctuations in raindrop size distribution, it is known that there are substantial errors in rainfall intensity estimates. On the other hand, one feature of the R-K_{DP} method, which uses specific differential phase, is that it is not so sensitive to fluctuations in raindrop size distribution. Simulations show that the R-K_{DP} method has an estimation error of below 30 percent, while the Z-R method has an estimation error of 100 percent or more.



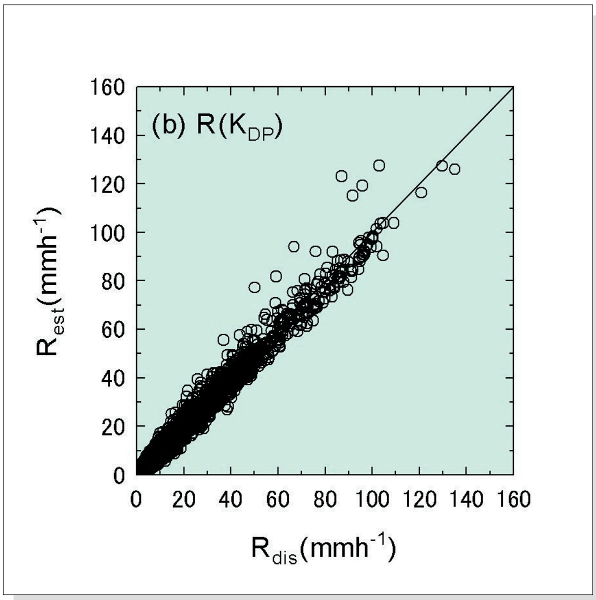
9a The R-Z_H relationship obtained by measured raindrop size distribution through simulation.



9b The R-K_{DP} relationship obtained by measured raindrop size distribution through simulation.



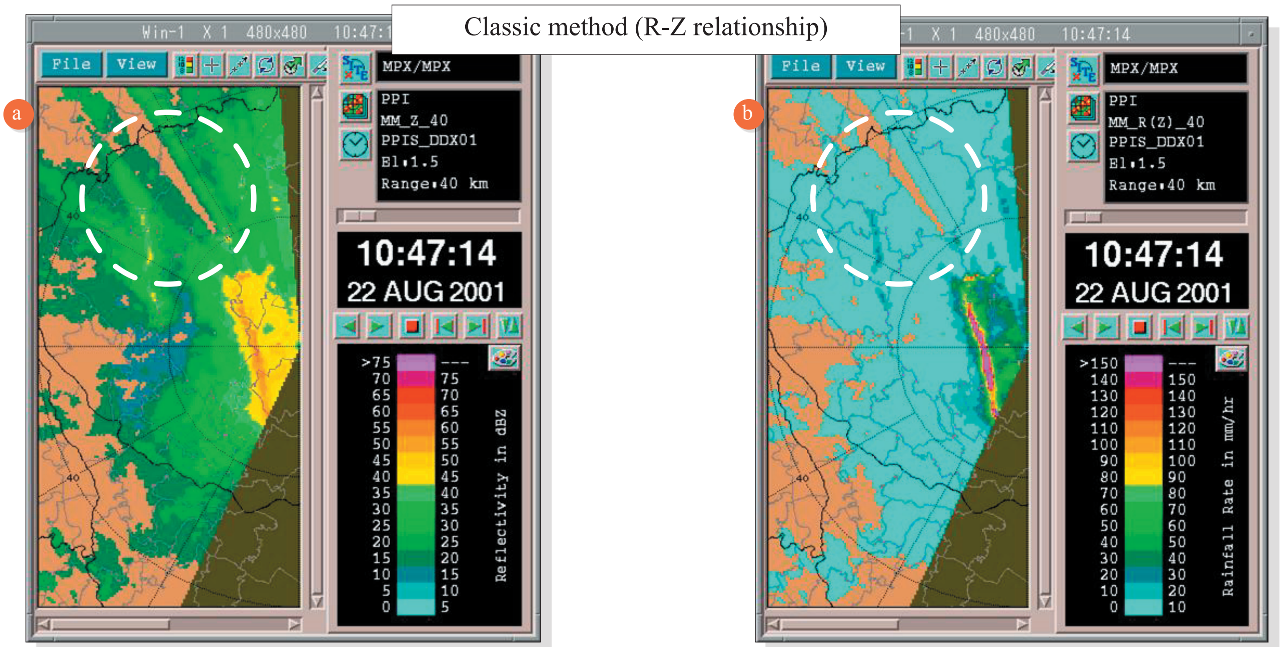
10a Comparison between actual rainfall intensity (transverse axis) and rainfall intensity obtained using the R-Z_H relation (longitudinal axis). The dispersion of points shows that this method is sensitive to fluctuation in raindrop size distribution.



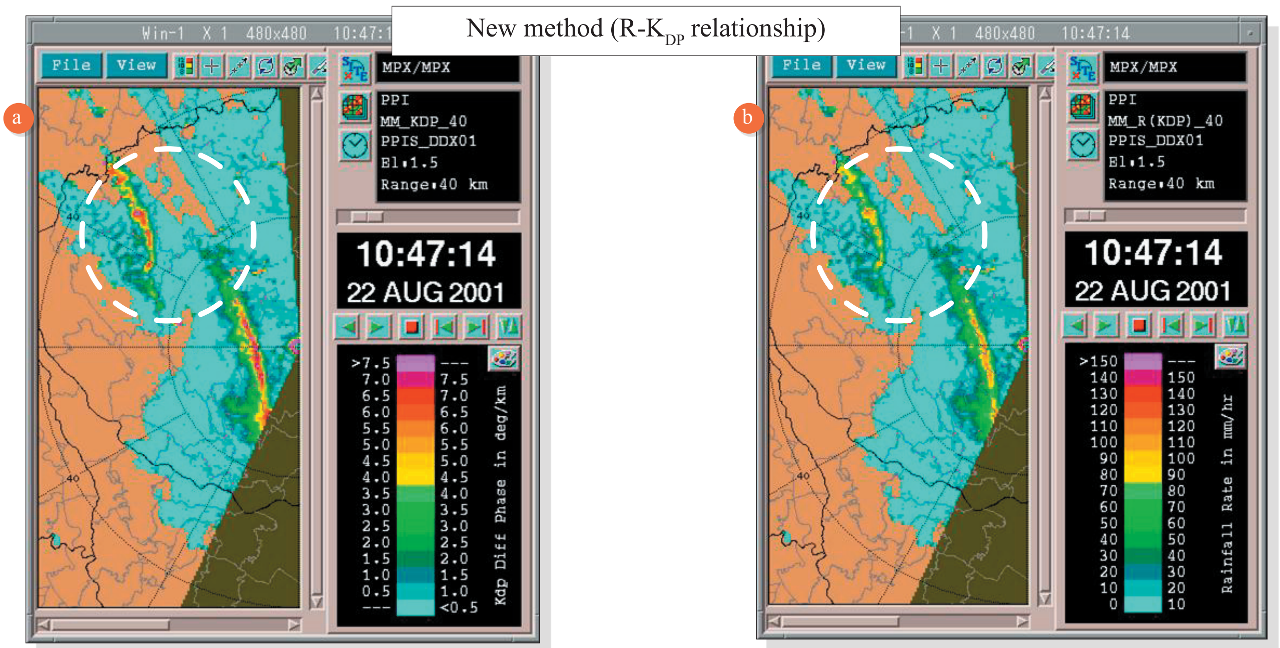
10b Comparison between actual rainfall intensity and rainfall intensity obtained using the R-K_{DP} relation. The dispersion is smaller than that obtained when the traditional method was used.

R-K_{DP} Method Unaffected by Rain Attenuation

After World War II, when the use of radars for rainfall observation was in its infancy, high expectations were placed on compact, low-cost X-band radars for their use in hydrology. However, after it became known that X-band radars were greatly affected by rain attenuation due to their short wavelength, and that they were unsuitable for quantitative measurement, such expectations drastically faded. Multi-parameter radars are unaffected by rain attenuation, as they use K_{DP} information instead of a reflectivity factor. The R-K_{DP} method has thus enabled quantitative rainfall estimates, which were conventionally difficult to obtain.



11 (a) Radar reflectivity factor of rain induced by Typhoon T0111. (b) Distribution of rainfall intensity estimated from radar reflectivity factor. Heavy rainfall within the area shown in the dotted-line circle is not being detected due to attenuation caused by the strong rain band near the radar.

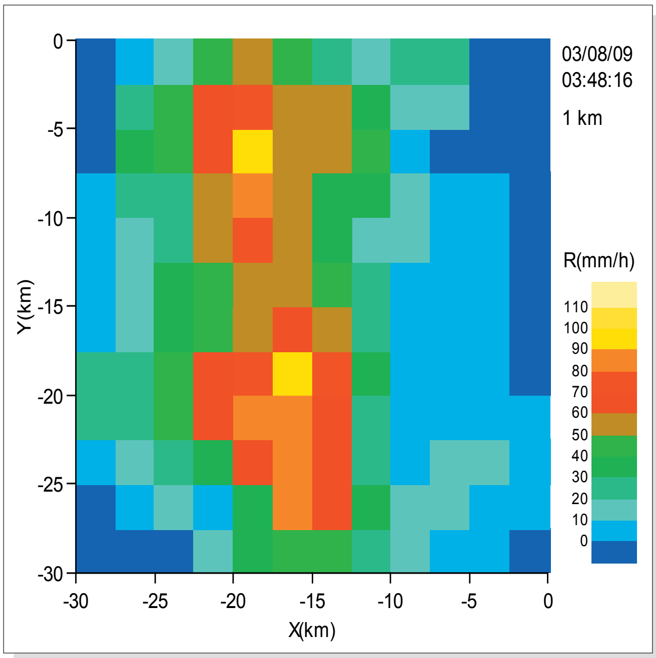


12 (a) Specific differential phase K_{DP} of rain induced by Typhoon T0111. (b) Distribution of rainfall intensity estimated from the K_{DP}. The heavy rainfall area, which was not detected in Fig. 11, is being detected.

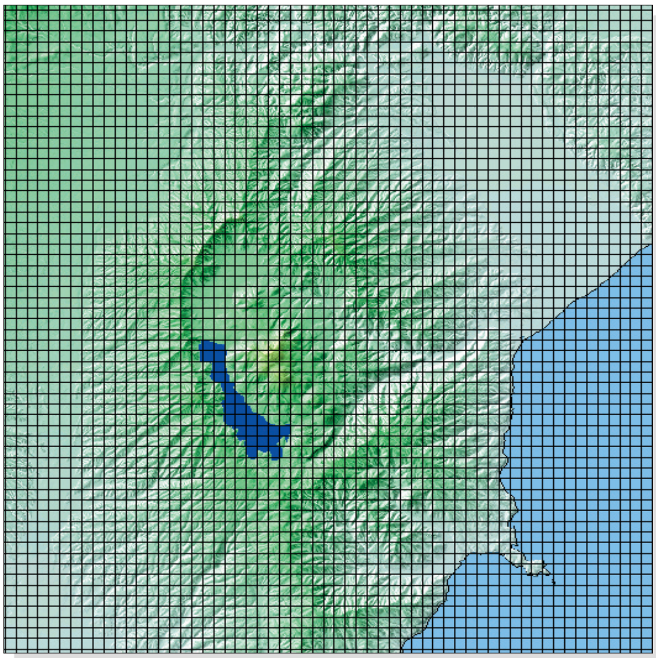
500-meter Mesh Rainfall Information

The spatial resolution of the radar-AMeDAS precipitation charts, which is operationally provided by the Japan Meteorological Agency as fields of hourly precipitation amounts, is 2.5 km. On the other hand, observations made with the MP-radar are at a resolution of 500 meters. Fig. 13 and Fig. 14 show the difference between these spatial resolutions. The 500m spatial resolution enables the provision of more detailed rainfall distribution compared with the 2.5 km spatial resolution. In order to predict disasters such as urban floods and shallow landslides, it is necessary for rainfall information to be as detailed as possible.

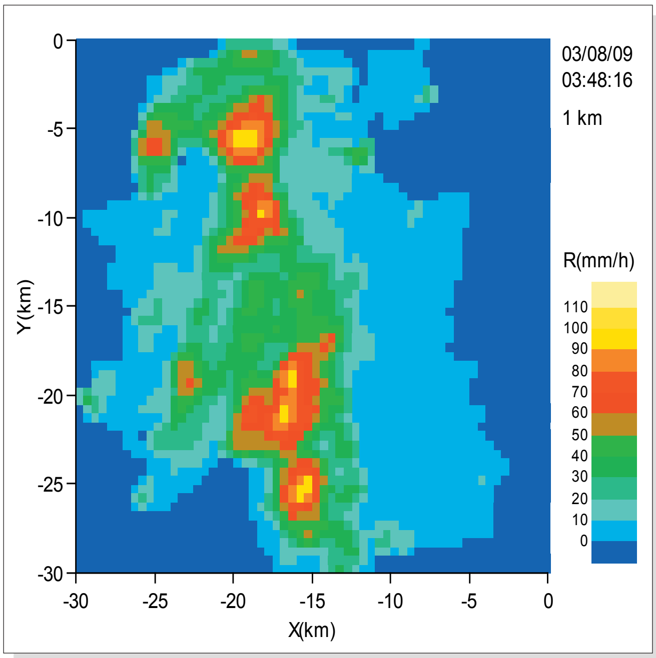
13a Hakone region topographical map, with a mesh size of 2.5 km.



13b Rainfall distribution at a 2.5-km mesh size.

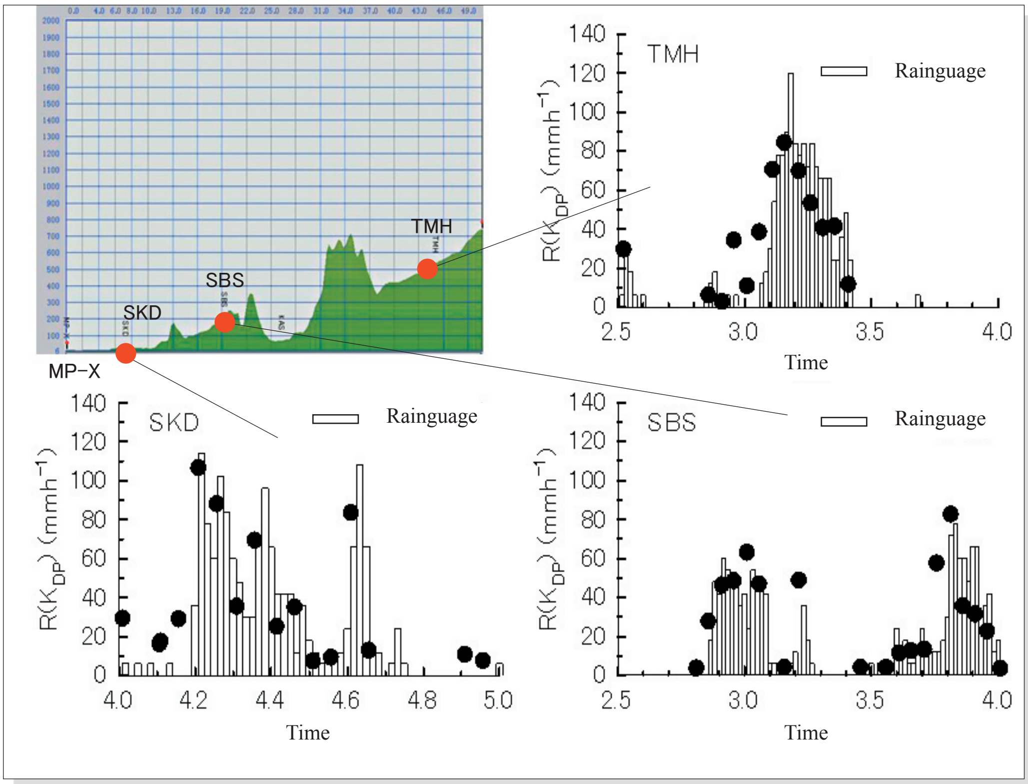


14a Hakone region topographical map, with a mesh size of 500m.

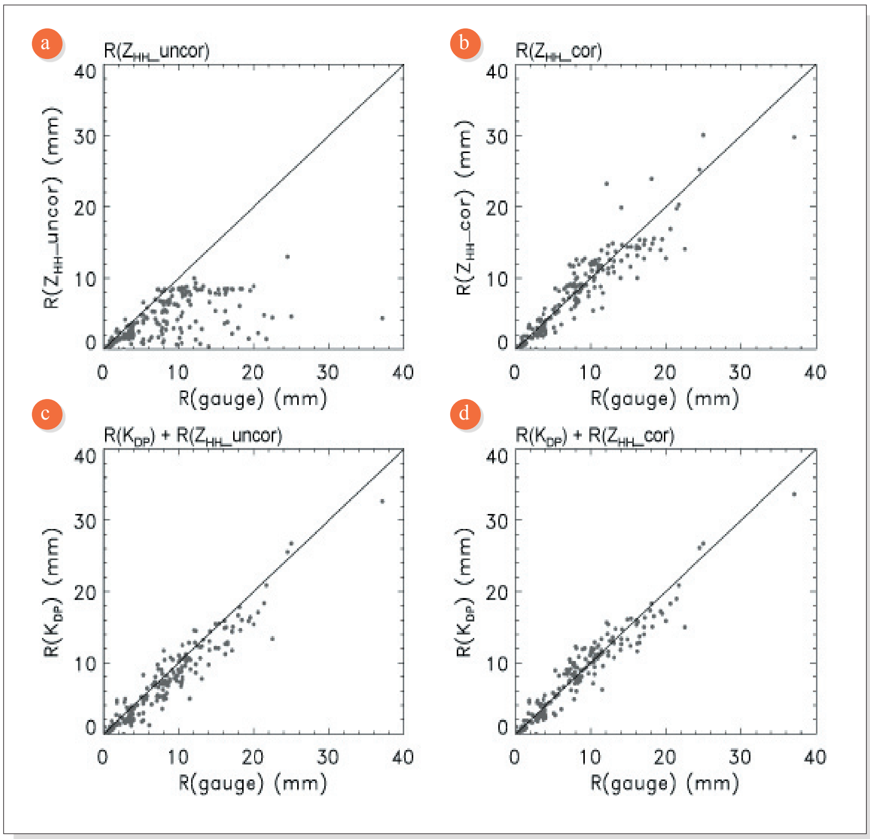


14b Rainfall distribution at a 500m mesh size.

Verification Using Ground-based Raingauges



15 Verification of results of rainfall intensity estimation formula R(K$_{DP}$). Comparison with raingauges placed on a straight line in a westerly direction from the radar. They match extremely well.

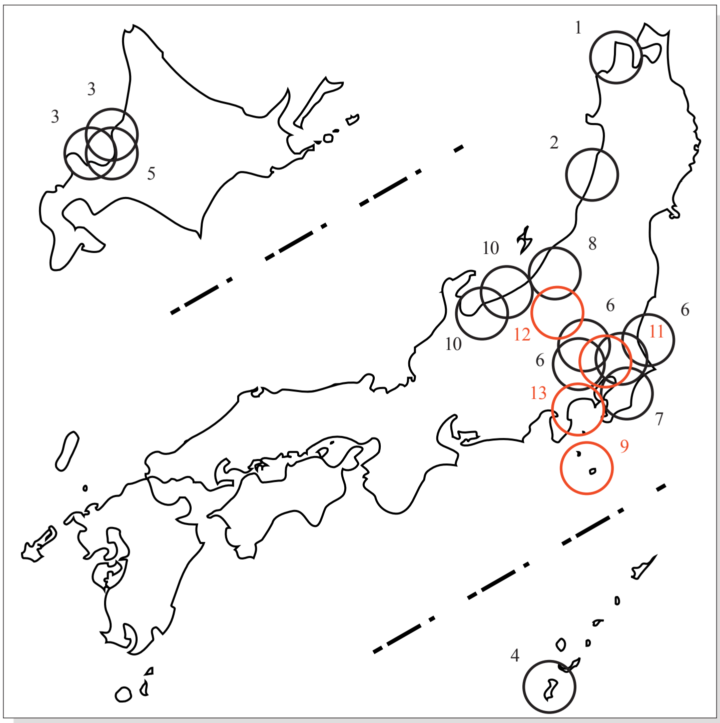


16 Verification for 1-hour accumulated rainfall obtained by four rainfall estimation methods.
(a) R(Z$_H$) method before rain attenuation correction.
(b) R(Z$_H$) method after rain attenuation correction.
(c) R(K$_{DP}$) and R(Z$_H$) method before rain attenuation correction.
(d) R(K$_{DP}$) and R(Z$_H$) method after rain attenuation correction.

Appendix – History of NIED Weather Radar Research

Many of the atmospheric phenomena that trigger disasters are mesoscale in nature, with spatial scales of from a few hundred meters to several hundred kilometers and with a life cycle of several tens of minutes to about two days. Torrential rains, heavy snowfall, lightening and tornadoes, which occur in Japan every year, and which cause damage to life and valuable assets, are typical examples of mesoscale phenomena. Mesoscale phenomena, which have a great diversity of forms and geographical characteristics, are on a small scale and sometimes occur unexpectedly. Weather radars are effective means to monitor such mesoscale phenomena. The use of radars with a Doppler function enables information on wind distribution to be obtained, in addition to the reflectivity information that is conventionally obtained. The use of multi-parameter radars with a Doppler polarization function enables non-Z-R relation-based rainfall estimates to be performed, and information on precipitation particle types to be obtained.

From a global point of view, it was 50 years or so ago that weather radars made their full-scale debut. The transfer of World War II era military radars to civilian use lead to the advent of weather radars. The first weather radar was introduced to NIED in 1969. Considering the fact that NIED was established in 1963, it can be said that with the introduction of weather radar, NIED has undertaken research since the early stages of its establishment. Looking at the history of NIED research using weather radar, it is divided broadly into three phases; non-Doppler radar, Doppler radar, and multi-parameter radar. A brief introduction to the main observations conducted by NIED is given here, with photographs.



1. Snow storm observation (Tsugaru Plain, 1989 ~ 1992)
2. Snow cloud observation (Sakata, 1989 ~ 1992)
3. Snowstorm observation (Ishikari Plain, 1994 ~ 1996)
4. Typhoon observation (Miyako Island, 1993)
5. Rainfall observation/DUETTO (Ishikari Plain, 1994)
6. Tsukuba Region Rainfall Observation (Kanto Plain, 1993 ~ 1996)
7. Narita International Airport radar verification experiment (Kanto Plain, 1995)
   JATMEX (Darwin, Australia, 1999 ~ 2000)
8. Snowfall observation (Nagaoka, 2000)
9. Miyake Island volcanic ash observation (Shikine Island, 2000)
10. Snow cloud observation (Niigata 2001)
11. DDX01/Dual Doppler (Kanto Plain, 2001)
12. SZW01/Artificial snowfall experiment (Niigata, 2001)
13. MMX03 Rainfall observation (Kanagawa, 2003 ~)

(black: XDOP and/or XPOL, red: MPX radar)

A1 Locations and themes of radar observation conducted from 1989.

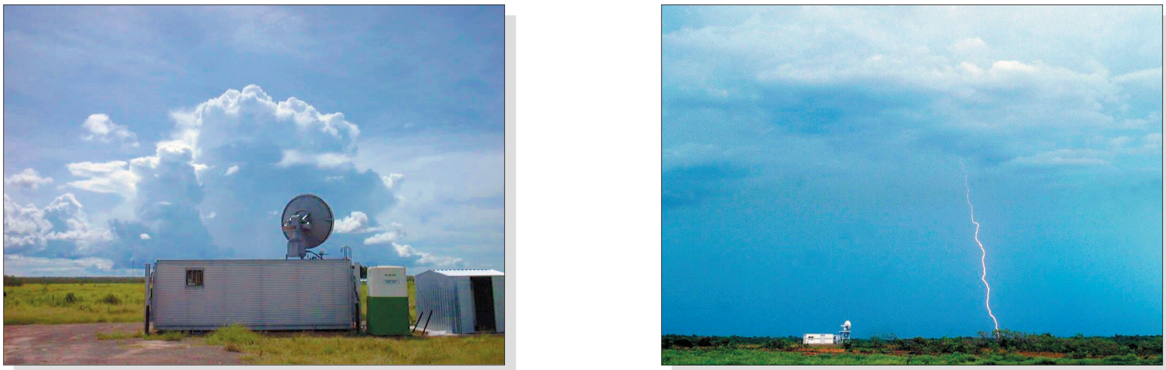
Appendix – Observation sites

A2 First radar (1969).

A3 Snowstorm research (X-DOP; 1988, Tsugaru Plain in Aomori prefecture).

A4 Snowstorm research - X-POI (1944, Otaru, Hokkaido).

A5 Observation of volcanic ash from Mt. Oyama, Miyake Island - MP-X (October - November 2000, Shikine Island, Tokyo).



A6 Tropical squall line observation (X-DOP [left] and X-POL [right]; 1988 - 1999, Darwin, Australia).

A7 Cloud and precipitation process and wind observation (August - October 2001, Kasumigaura Lakeside, Ibaraki prefecture).

A8 Artificial snowfall experiment - MP-X and MP-Ka/W (December 2001, Shiozawa, Niigata prefecture).

Tropical squall line observed in Darwin, Australia

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