# Precipitation phenomena observed by microwave radar and optical Lidar

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## 1. Introduction

Precipitation phenomena play an important part in fields related to radiowave attenuation and propagation. It is not only important in considerations relating to the physics of precipitation, but also for various engineering applications such as remote-sensing and telecommunications and lately in the field of global climate monitoring. In the study of precipitations, one of the main instrument used is the radar. It was first shown by Marshall and Palmer that the radar reflectivity factor is related to precipitation intensity, and that the rain drop size distribution (dsd) is generally exponential [1]. Later, these have been the subject of many studies by various authors, among them [2], [3]. However, empirical determination of the Z-R coefficients tend to differ rather largely [4], [5].
In this paper we present preliminary results from a starting long-time survey of precipitations in the city of Kanazawa, located by the sea of Japan. It has been pointed by [5], [6] and [7] that the sample quantity and temporal resolution are critical in succesful determination of the Z-R parameters.

## 2. Methods

The measurement equipment includes: a small bistatic weather radar, an electric balance, a high sensitivity drop counter and a profiling Lidar. The POSS (Precipitation Occurrence and Sensor System) radar is a small solid state 10.525 GHz, 43mW Doppler radar set developed by the Canadian Atmospheric Environment Service. The transmitter and receiver are tilted 30 degrees from the vertical and separated by only 31 cm, which effectively translates into immediate backscatter from the sensing volume. The POSS is not calibrated for reflectivity but has a linear output relative to received power $P_r$, the reflectivity is only a constant $C$ multiplier away as seen from the simplified radar equation

$$P_r = C$$

The electric balance and drop counter are situated approx. 30 m away in an enclosed area. Experience has shown that they can reliably measure precipitations above 0.3 mm/h. The profiling Lidar, Vaisala model CT25K, is a pulsed diode laser with wavelength 905 $nm$ and 8.9 mW average power. It is tilted 9 degrees from vertical and facing northwest, the main wind direction. Backscatter profile is obtained at a resolution of 30 m up to a height of 7000m. All instrument data is recorded by computers with unified time reference.

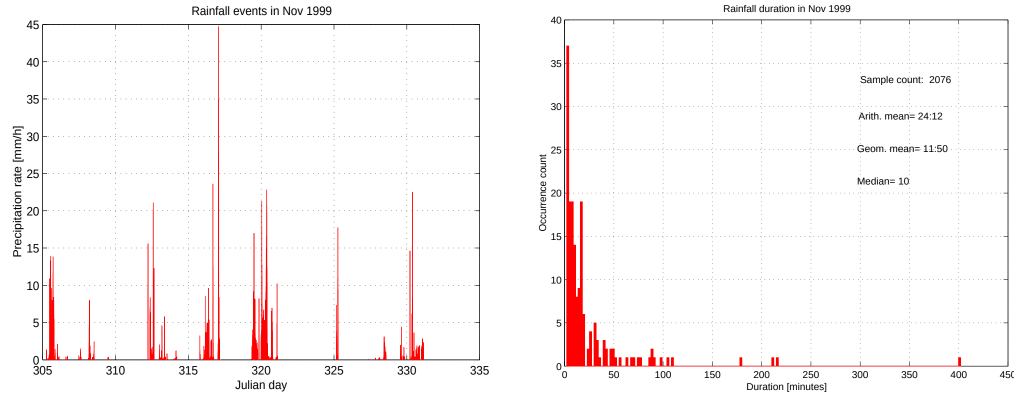


Figure 1: Rainfall events in November,time series and histogram.

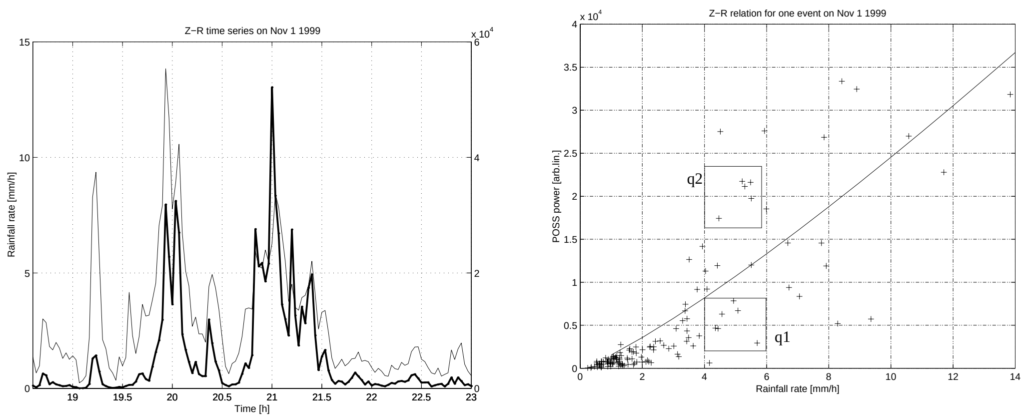


Figure 2: Time series and Z-R regression for one event on Nov.1 1999.

## 3. Data and analysis

Figure 1 shows a time series of precipitation events in November 1999. All data were averaged at 2 minute intervals and defining one event as the continuous time that precipitation exceeds 0.5 mm/h, a total of 173 events were recorded totaling 2076*2 minutes or 69 hours and 12 minutes. It can be observed that most events are of very short duration, and the median is 10 minutes and geometrical mean 11 minutes 50 seconds. Four events lasted for more than 2 hours. Using the $Z-R$ relation between radar reflectivity and rainfall rate

$$Z = BR^{\beta} \qquad [mm^6/m^3] \tag{1}$$

and solving the coefficients ($B = 1555$, $\beta = 1.2$), the regression line for one long event on November 1st is shown in the right of Figure 2. Comparing it with the time series plot of rate and received radar power, it can be seen that using this equation rainfall can be largely under- or overestimated. This despite the fact that coefficient of determination $R^2$ for this event was as high as 0.77. Examining the Doppler shift of samples inside the quadrants marked $q1$ and $q2$ in the right of Figure 2, we find the distributions shown in Figure 3.
If there was no wind it can be assumed that the Doppler velocity corresponds to the terminal velocity $v$ of raindrops, which is exponentially related to their diameter $D$[mm] by

$$v(D) = 9.6(1 - e^{-0.5674D}) \qquad [m/s] \tag{2}$$

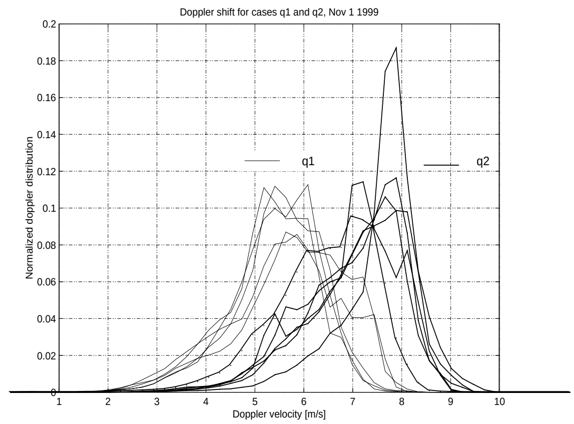


Figure 3: Doppler shifts of samples inside q1 and q2.

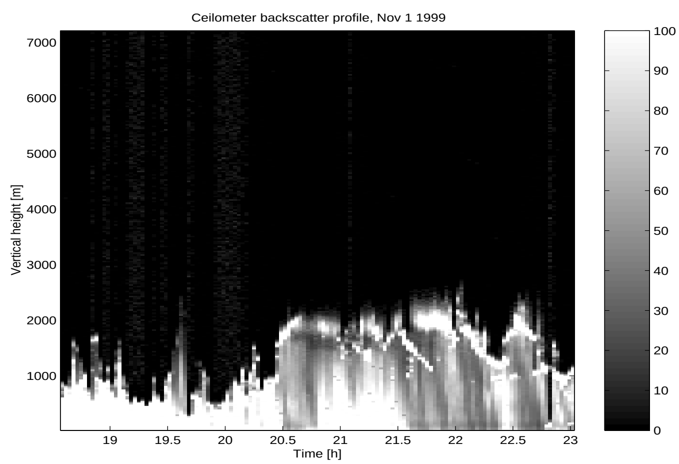


Figure 4: Optical backscattering profile.

Thus, it can be concluded that the narrow distributions present in $q2$ corresponding to fast and uniformly big raindrops have higher reflectivity than the slower, more distributed in size contained in $q1$.

Observing the same rainfall event using the optical Lidar, we obtain the height profile showed in Figure 4. The actual backscattering values have been scaled to the 0-100 colormap for clarity, larger values showed in brighter color. Again the samples represent 2 minute averages. By comparing this profile to the rainfall rate series in the left of Figure 2, we can observe that during heavy rain the scattered signal comes from very low altitudes, i.e. optical extinction is significant. Since the visibility, backscatter coefficient and extinction are all related, it should be possible to use this information to complement the radar for determination of rainfall rate, in a similar way to that of using multiple frequency and/or polarization radars. It is interesting to note that the total height-integrated backscatter during this event has a negative correlation coefficient of -0.25 with radar reflected power.

## 4. Discussion

From our observations it can be concluded that although the $Z-R$ relation is fairly good in the average case, it is off when the drop size distribution changes during short time intervals. It was observed from the duration histogram that most rainfalls last a relatively short time and that phenomena in the lower atmosphere change rapidly as seen by the Lidar. We therefore suggest that two techniques could be employed to better estimate precipitation.

- asses the possibility of using an optical instrument to complement the radar both through temporal and backscatter analysis
- evaluate the radar estimate through a time window and adjust the precipitation rate in retrospect

*Acknowledgement.* This work was partly supported by the Japanese Ministry of Education, Science, Sports and Culture Grant-in-Aid for Scientific Research (09555124)

## References

[1] Marshall J.S. and Palmer W.McK. The distribution of raindrops with size. *J.Meteor*, 5, 1948.

[2] Atlas D.R., Srivastava R.C., and Sekhon R.S. Doppler radar characteristics of precipitation at vertical incidence. *Rev. Geophys. and Space Phys.*, 4, 1973.

[3] Willis P.T. and Tattelman P. Drop-size distributions associated with intense rainfall. *J.Appl.Meteor.*, 1989.

[4] Fujiwara Miyuki. Raindrop size distribution from individual storms. *J.Atmos.Sci.*, 22, 1965.

[5] Doelling I.G., Joss J., and Riedl J. Systematic variations of raindrop size distributions measured in northern Germany during 7 years.

[6] Krajewski W.F. and Smith J.A. On the estimation of climatological z-r relationships. *J.Appl.Meteor.*, 1991.

[7] Matrosov S.Y. Radar reflectivity in snowfall. *IEEE Trans.GeoSci.Remote.Sens.*, 30, 1992.