Attenuation and Radar Reflectivity in Melting Layer measured with Ground-based Ka-band Radars

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Abstract: Estimation method of specific attenuation and equivalent radar reflectivity in a melting layer using a dual Ka-band radar system is studied. The system consists of two identically designed Ka-radars. When a precipitation system comes between two radars, the radars observe the system with opposite directions. The radar applies FM-CW type and designed for the measurement of the scattering characteristics of precipitation particles. The precipitation echoes suffer from rain attenuation. The reduction due to rain attenuation symmetrically appears in both radar echoes. By differentiating averaged measured radar reflectivity with range, the specific attenuation can be estimated. After obtaining the specific attenuation, equivalent radar reflectivity is estimated. In the melting layer, specific attenuation and the equivalent radar reflectivity vary largely along the radio path, and the estimated specific attenuation is very sensitive to the setup configuration of the experiment. The accuracy of the estimated specific attenuation is found to depend on the curvature of the equivalent radar reflectivity with respect to range and the distance for the differentiation. The measurement system and actual procedure of data analysis are also described.

Observation

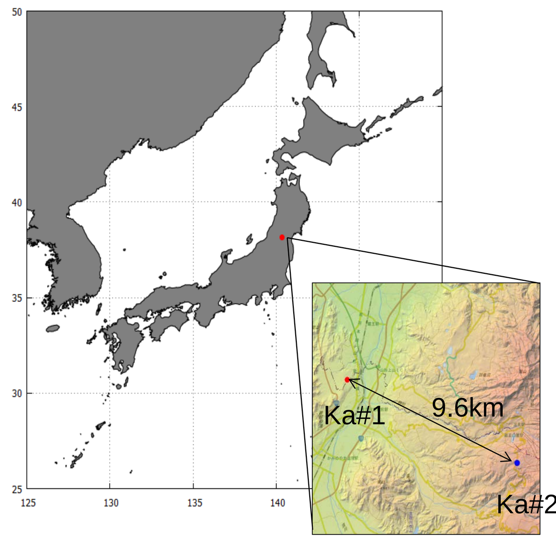
The intensive observation period in Mt.Zao was held twice for 40days.

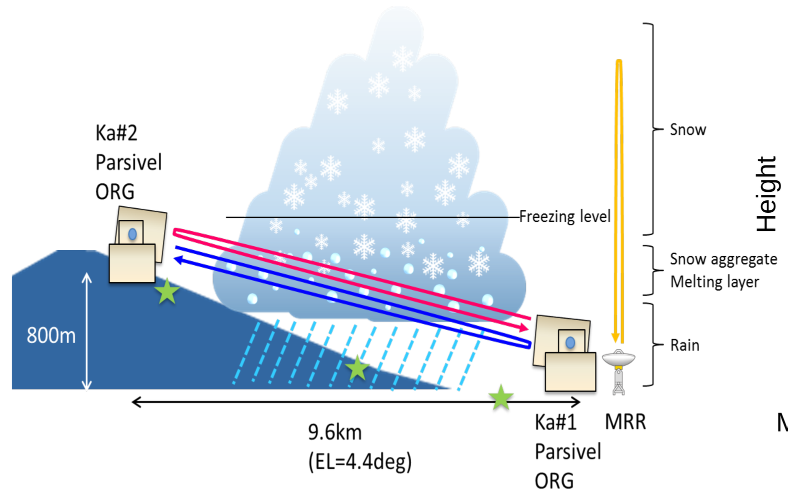
13 Dec. 2014 to 12 Nov. 2014 (29days)

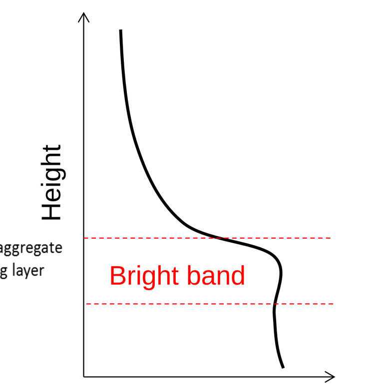
28 Feb. 2015 to 11 Mar. 2015.(11days)

When the melting layer comes down/up as the temperature decreasing/rising, the beams of radars go through the melting layer thus the k and Ze in the melting layer can be measured.

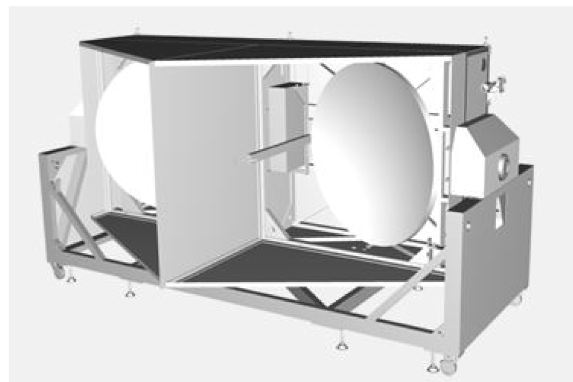
The geolocation of the observation sites.







Measured radar reflectivity [dBZ]



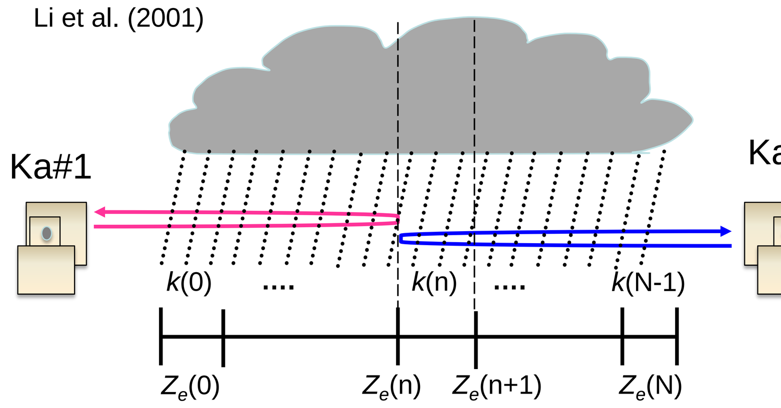
★:Three **G-PIMMS**, abbreviation for "Ground-based Particle Image and Mass Measurement System", which was newly developed for this experiment by Dr.Suzuki , Yamaguchi University

Inside view of the radar. Two offset parabolic antennas for transmission and reception are installed.

Specification	
Frequency	*35.25 GHz (Ka-band)*
Modulation Principle	*FMCW* *(Frequency-modulated continuous wave)*
Minimum Detect Zm	*-20 dBZ at 10 km*
Range Resolution	*< 50m (min.12.5m)*
Doppler Velocity	*> ±10 m/s*
Observable range	*From 500 m to 30 km*
Antenna beam width	*0.6 deg*
Antenna Sidelobe	*25 dBZ >*

Dual-Radar Method

Li et al. (2001)



$$\begin{bmatrix} Z_{SN1}(n) = Z_e(n) - 2\sum_{i=0}^{n-1} k(i)\delta h \\ Z_{SN2}(n) = Z_e(n) - 2\sum_{i=n}^{N-1} k(i)\delta h \end{bmatrix}$$

$$\left[\begin{array}{l} Z_e(n) = [Z_{SN1}(n) + Z_{SN2}(n) + 2\sum_{i=0}^{N-1} k(i)\delta h]/2 \\ k(n) = [Z_{SN2}(n+1) - Z_{SN2}(n) + Z_{SN1}(n) - Z_{SN1}(n+1)]/4\delta h - C \\ ttlAtt = 2\sum_{i=0}^{N-1} k(i)\delta h = Z_{SN1}(0) - Z_{SN2}(0) = Z_{SN2}(N) - Z_{SN1}(N) \end{array}\right.$$

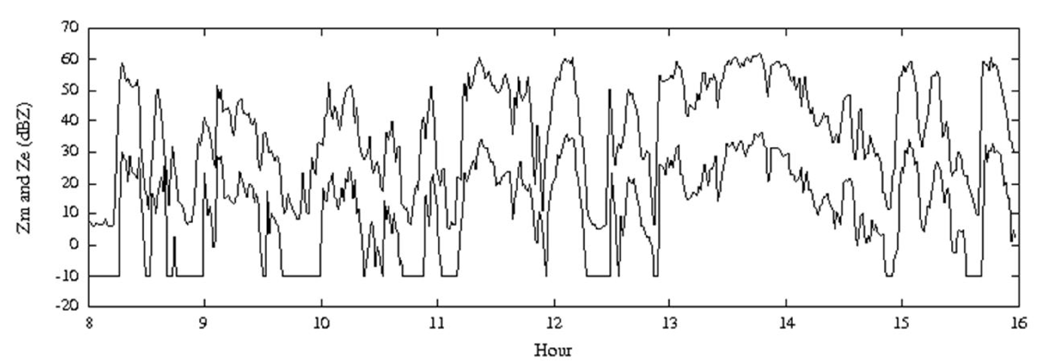
This method provides the both total path attenuation and the attenuation efficient at each range. And equivalent radar reflectivity can be retrieved directly by combining two measured reflectivity profiles without any a priori knowledge of the attenuation characteristics along the path. Hence it is suitable to measure melting layer, which has large variety of attenuation in small range.

Calibration and Correction of Zm

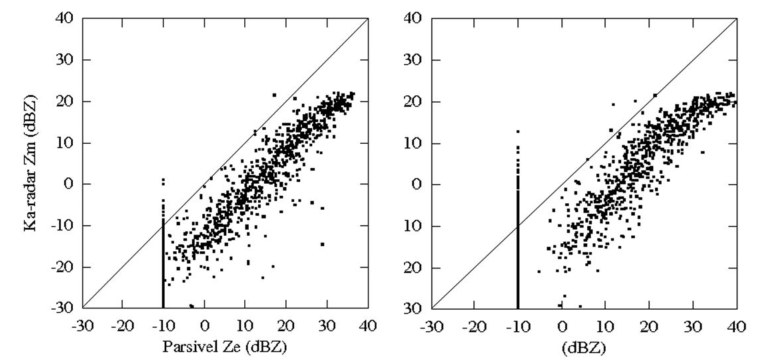
Even though the system parameters are well specified, calibration is required. Actually, our Ka-radar was found unstable, particularly, in cold season. Zm was adjusted by radar disdrometer, which is a commercial one colled Parsivel, and dual total path attenuation.

Using the dropsize distribution from Parsivel which is located only a few tens meter away from the radar, equivalent radar reflectivity at Ka-band is calculated and compared with Ka-radar measurement. Only rain cases are used, because radar reflectivity of rain is much more stable than snow.

1. *Estimation of bias of Ka #1 : calculating Ze, including Mie scattering effect, from measured DSD by Parsivel and making comparison with Zm(#1) then the bias of SN1 is obtained.*
2. *The total attenuation along the beam should be the same between Ka#1 and Ka#2. Ka#1 has been adjusted by Parsivel so the discrepancy of SN1 vs SN2 should owe to the bias of SN2.*
3. *Validating the obtained k-Ze datasets of Ka-radar by k-Ze relationship of Parsivel.*

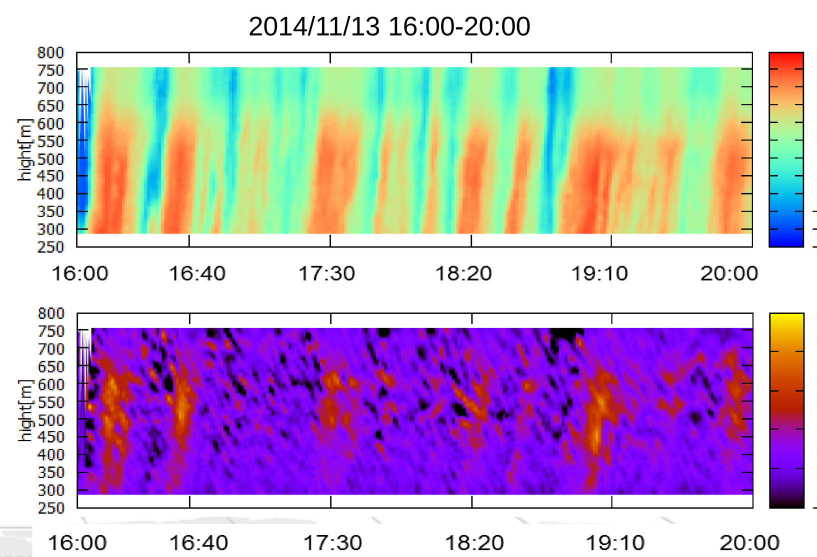


Comparison of radar reflectivity from DKR and Parsivel data on 26 Nov. 2013. Upper curve is from DKR and lower is from Parsivel. Curve from DKR is biased with 40 dB to avoid overlapping of the two curves. (Prof. Nakamura)

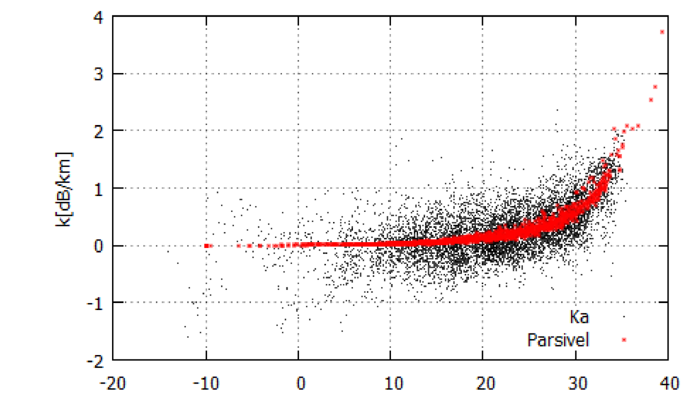


Scattergram of the radar reflectivity derived from DKR and Parsivel data. Left is with Mie scattering calculation in Parsivel data, and right is with Rayleigh scattering calculation. The data at -10 dBZ in Parsivel represent non-available data. (Prof. Nakamura)

It should be noted that the radar calibration is required for equivalent radar reflectivity measurement, but not for specific attenuation measurement, since only relative variation in range is used in the specific attenuation measurement.



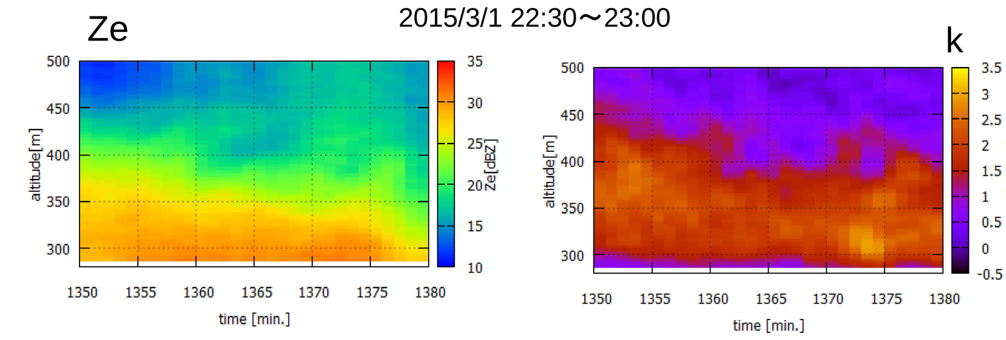
Top: Ze from Dual-Ka radar Bottom: k from Dual-Ka radar



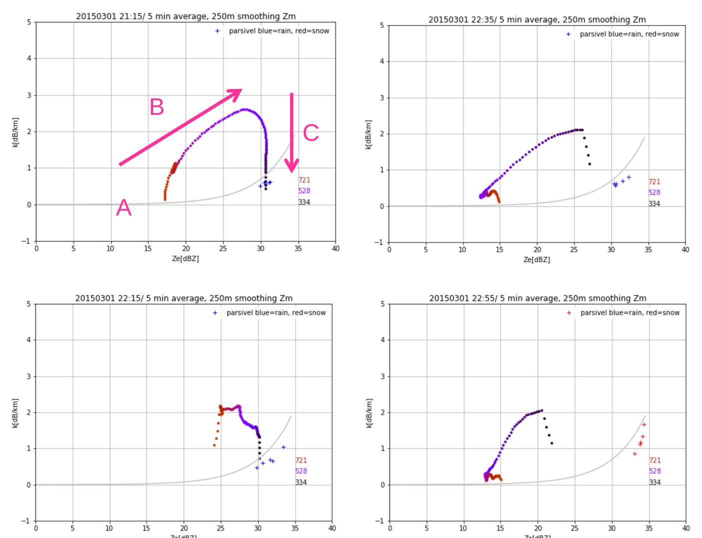
k and corrected Ze of dual-Ka method shows the good agreement with theoretical k-Ze relationship from DSD of Parsivel in case of rain.

Experimental Results

The case of dual-radar observation through melting layer is in total about 54 hours. The method is still developing, however, the preliminary results indicate the characteristic behaviors of k-Ze relationship depends on the position of the melting layer, that is, the state of the melting particles.



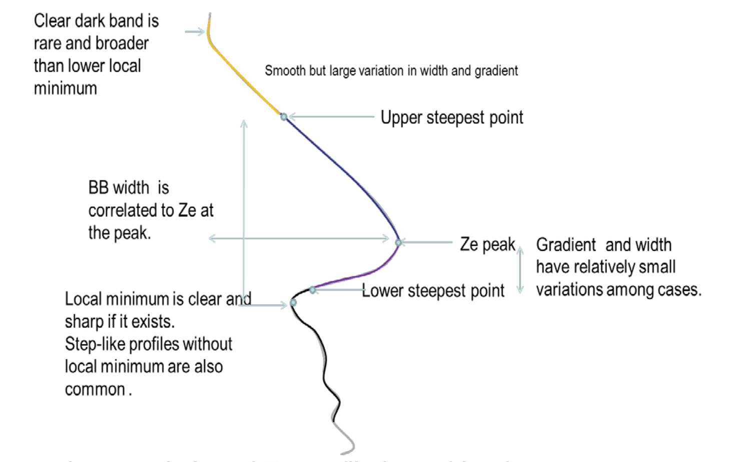
As the height of melting layer decreases from 400m high to below 300m high during 30 minutes.
Those two figures show the peak of k appear higher than peak of Ze.



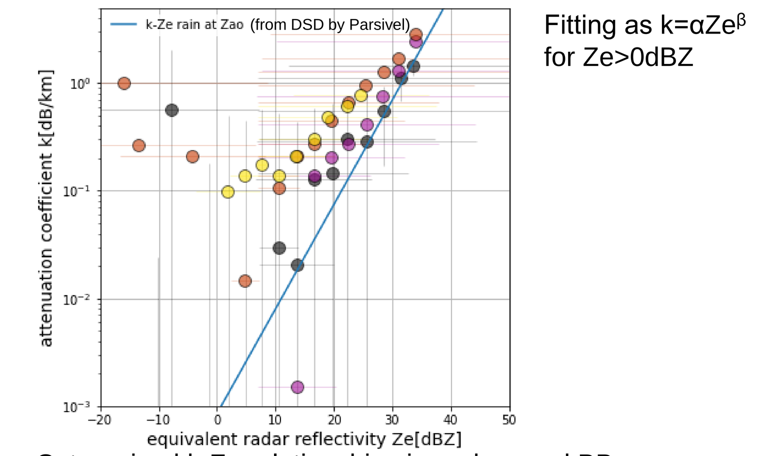
the variation of k-Ze. Both k and Ze in minor area(A) is above the melting layer where the particle is solid. As the ratio of number of melting particle and melting ratio in a particle itself increases, the k and Ze are also increasing(B). After going over a peak of k, Ze is almost constant but the k rapidly decline (C) and it will conform to the k-Ze relationship of rain of DSD at the ground at the end(D).

Discussion

Regions in the melting layer is categorized by Ze profile and k and Ze in same region in each cases are fitted as k=αZe^{β} .



Shape characteristics of Ze profile in melting layer

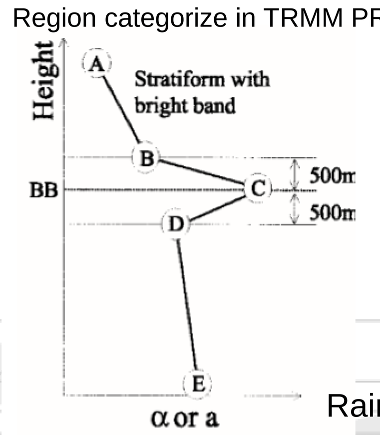


Fitting as k=αZe^{β} for Ze>0dBZ

Categorized k-Ze relationships in and around BB

Comparison of α and β between TRMM/PR Algorithm and Ground measurement

Region categorize in TRMM PR, (Iguchi, 2000)



	α	β
Snow at A	0.0000861	0.79230
Snow (A-B)	0.0775	0.388
Melting at B	0.0001084	0,79230
Upper BB (B-C)	0.0153	0.697
Peak at C	0.0004142	0.79230
0°C water at D	0.0002822	0.79230
Rain(D-E)	0.00393	0.772
Rain at E by Persivel	0.000849	0.971

Cf.: Okinawa-Nagaoka, rain cases: α=0.00439, β=0.707

There is large disparity on the value of α and β, even though the frequency difference between PR and Dual Ka-radar is considered. Now this disparity is discussed.

References

Iguchi, T., Kozu, T., Meneghini, R., Awaka, J., & Okamoto, K. I. (2000). Rain-profiling algorithm for the TRMM precipitation radar. Journal of Applied Meteorology, 39(12), 2038-2052.
Liu, G.,"Approximation of single scattering properties of ice and snow particles for high microwave frequencies," *J. Atmos. Sci.*, vol. 61,pp. 2441-2456, 2004.
Liu, G., "Database of microwave single-scattering properties for nonsphericalice particles," *Bull. Amer. Meteorol. Soc.*, vol. 89, pp. 1563-1570. 2008.
H. Ishimoto., K. Masuda, Y. Mano, N. Orikasa, and A. Uchiyama, "Irregularly shaped ice aggregates in optical modeling of convectivelygenerated ice clouds," *J. Quantitative Spectr. Rad. Trans.*, vol. 113,pp. 632-643, 2012.
M. Nishikawa, K. Nakamura, Y. Fujiyoshi, K. Nakagawa, H. Hanado,H. Minda, S. Nakai, T. Kumakura, and R. Oki, "Radar attenuationand reflectivity measurements of snow with dual Ka-band radar,"*IEEE Trans. Geosci. Remote Sens.*, vol. 54, no. 2, pp. 714-722,10.1109/TGRS.2015.2464099, 2015.
T. Yokoyama, and H. Tanaka, "Microphysical processes of meltingsnowflakes detected by two-wavelength radar Part II. Application oftwo-wavelength radar technique," *J. Meteorol. Soc. Japan*, vol. 63, no. 4,pp. 668-678, 1984.
R. Misumi, H. Motoyoshi, S. Yamaguchi, S. Nakai, M. Ishizaka, andY. Fujiyoshi, "Empirical relationships for estimating liquid water fractionof melting snowflakes," *J. Appl. Meteor. Climatol.*, vol. 53, no. 10,pp. 2232-2245, Oct. 2014.
L. Li, S. M. Sekelsky, S. C. Reising, C. T. Swift, S. L. Durden, and G. A. Sadowy, S. J. Dinardo, F. K. Li, A. Huffman, G. Stephens, D.M. Babb, and H. W. Rosenberger "Retrieval of atmospheric attenuation using combined ground-based and airborne 95-GHz cloud radar measurements," *J. Atmos. Oceanic Technol.*, vol. 18, no. 8, pp. 1345-1353,Aug. 2001.

Conclusion

This unique measurement using two same wavelength radars viewing a same precipitation volume from opposite viewing angles shows the radar reflectivity(Ze) and attenuation(k) with reduced uncertainty. The k-Ze relationships of rain, melting layer, and snow were successfully measured. The method of the dual radar sensitivity collection was developed.
This result will make it possible to study the connection between the microphysical characteristics of the hydrometeor and the measureble quantity by radar observation.