THE SPECTRUM THRESHOLD FILTER METHOD FOR CHAFF AND RAIN

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Abstract

Polarization doppler radar observations of chaff and rain were conducted. At least in the vertical pointing case, the spectrum of chaff is much narrower than that of rain. In data analysis a new method of filtering chaff data from noise is used. This filter method, named the spectrum threshold filter method, was also applied for rain data for comparison. Instead of using the average power as in the conventional method this filter method utilizes the doppler spectral peak power. Consequently this filter method is able to detect a presence of even a single strong doppler velocity signals. Hence the performance of this filter is better with metallic strips, such as chaff, than raindrops. The variation of the filter's threshold will change significantly the filtered rainfall area but not the chaff one. The filter technique is also useful to detect a narrow but strong spectral data.

Intisari

Pengamatan hujan dan chaff dengan memakai radar dengan polarisasi doppler telah dilakukan. Paling tidak pada posisi tegak lurus, spektrum dari chaff lebih sempit daripada pada butir hujan. Dalam melakukan analisa data kita telah mengembangkan sebuah metoda filtering untuk memilah data chaff dari noise sekitarnya. Metoda filter ini, yang disebut metoda filter spectrum threshold, juga diterapkan pada data hujan sebagai perbandingan. Daripada memakai kekuatan rata-rata dengan metoda umumnya, metoda filter ini memakai puncak spektrum. Sehingga metoda filter ini dapat mendeteksi keberadaan dari hanya sebuah puncak kecepatan doppler dalam sinyal. Pada akhirnya kinerja metoda filter ini lebih baik untuk aplikasi pada pita-pita logam seperti chaff daripada butiran hujan. Variasi dari batas ambang (threshold) dari filter ini akan mengubah area hujan yang terfilter secara drastis tetapi tidak pada data chaff. Teknik filter ini juga berguna untuk mendeteksi spektrum doppler yang sempit tetapi kuat.

Keyword: chaff, rain, polarization doppler radar, filter method

1. INTRODUCTION

Perhaps the earliest work on radar detection for chaff like materials was done by Van Vleck et al. (1947). Chaff research ever since has became so popular especially in military for shielding purposes Kownacki (1967), Nagl et al. (1991). Several researchers have studied chaff properties on radar tracking. Kownacki (1967), Nagl et al. (1991), Guo and Uberall (1992) and Winchester (1992) did researches on chaff's scattering properties related to the radar cross section. Later research Widdel (1990) discussed about chaff's flight behavior in stagnant air. Later on chaff research has attracted radar meteorologists for atmospheric researches. Widdle (1990) used chaff to study the atmospheric motion in the middle atmosphere. Moninger and Kropfli (1982) presented a way to use chaff as a tracer of air movement in and out of a cloud. Reinking and Martner (1996) extended Moninger's research and studied chaff behavior and distribution in convective clouds.

Since few decades ago researchers had used doppler radars and polarization radars to observe rain, but chaff application for the weather observation is relatively a new and an interesting subject. We conducted an experiment with an airborne multi-parameter precipitation radar called CAMPR (Kumagai et al., 1996). CAMPR was developed by the Communications Research Laboratory (CRL), Japan. CAMPR uses a frequency of 13.8 GHz, which is nearly the same frequency as the precipitation radar installed in the TRMM satellite Simpson et al. (1998). One of the main purposes of CAMPR is to calibrate the TRMM Precipitation Radar (TRMM-PR) data. CAMPR has dual polarization and dual doppler capabilities.

In this paper we show results of chaff and rain observations using the polarization doppler radar. A filter method, which is called the spectrum threshold filter method, was introduced during chaff and rain data processing. In this study we examine rain and chaff polarization characteristics.

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2. DATA

The data was taken from the chaff and rain experiments conducted from November 29 until December 1, 1995 over the Japan Sea. The purpose of these experiments was to study the co-polar and the cross-polar radar reflectivity of chaff and rain. On November 29, we performed chaff measurements, while on the other days we performed rain measurements. During the chaff measurement, we varied elevation angle of the CAMPR antenna from nadir to near horizon. At this time we used two aircrafts: one scattered chaff, and the other carried CAMPR.

During the rain measurement, we set the elevation angle near nadir. At this time we also used two aircrafts, one carried CAMPR and the other carried a particle probe instrument. The weather condition during the chaff experiment was relatively calm, while light rain appeared in the rain experiment days.

The chaff used in this experiment is thin conducting metal stripes whose width and thickness are very small compare to the radar wavelength, i.e. $L/d >> 1$ and $kd << 1$, where L is the length of the chaff, d is the width, and k is the wavenumber of the radar radio wave. The chaff used in this experiment has dimensions: L = 32 mm and d = 0.25 mm. Chaff was released from the first aircraft intermittently, while the second aircraft tracked chaff locations by scanning the CAMPR antenna. CAMPR has a simultaneous measurement capability for two orthogonal polarizations by using two receivers.

The CAMPR data consist of the I and Q (in-phase and quadrature) signals of specified numbers of contiguous hits. The chaff data have 40 range bins and rain data have 100 range bins. One subset of data composes of I and Q pairs in vertical and horizontal polarizations with total of 256, 512 or 1024 pulse pairs. Hence in one series of 256 pairs data there are 128 pairs of cross-polar (different polarization in transmitter and receiver) and 128 pairs of co-polar (equal polarization on both transmitter and receiver) data.

3. METHOD

During data processing we developed a filter method to discriminate echo of rain, chaff and noise. This filter method is applied throughout this paper. According to Doviak and Zrnick (1993), in a typical weather radar, the mean power $\overline{P}(\tau)$ over N_s number of hits is given by

$$\overline{P}(\tau) = \frac{1}{N_s}\sum_{i}^{N_s}\left|I_i^2 + Q_i^2\right|$$

The mean power intensity $\overline{P}$ is related to the radar reflectivity factor (Z) and distance r according to a formula:

$$\overline{P}(r) = c\,\frac{Z}{r^2}$$

where c is a constant determined from the radar system parameters, and r is the distance from the radar to a hydrometeor. Since we use only relative values we hereafter neglect c.

There are four definitions of reflectivity according to their polarizations used in this work. If a signal is transmitted horizontally polarized and received vertically polarized, it is symbolized with Z_{hv}. In a similar fashion other reflectivity parameters used here are Z_{hh}, Z_{vv} and Z_{vh}. From these, two more radar observable parameters, which are used in this paper, are the *ZDR* (Differential Reflectivity) and the *LDR* (Linear Depolarization Ratio) which are defined as

$$ZDR = 10\log\left(\frac{Z_{hh}}{Z_{vv}}\right)$$

$$LDR = 10\log\left(\frac{Z_{vh}}{Z_{hh}}\right) \cong 10\log\left(\frac{Z_{hv}}{Z_{vv}}\right)$$

In this work the first (left) *LDR* definition is used.

One difficulty in chaff data processing is differentiating the echo from the background noise. In a theoretical work, Moninger and Kropfli (1987) have investigated the difference between the reflectivity of chaff and other cloud hydrometeors. They summarized that radar's ability to distinguish chaff from cloud hydrometeors increases by a factor of λ^6. Further discussion of the scattering

Table 1. CAMPR Specification (Kumagai et al., 1996)

Frequency	13.8 GHz
Antenna type	Slotted waveguide antenna array for H & V polarizations
Antenna radome size Antenna size	3200 mm x 420 mm ϕ 820 x 360 mm (each)
Antenna gain	33.1 dBi (V) and 33.5 dBi (H)
Antenna beam width	2.1^0 x 4.4^0 (V) and 2.0^0 x 4.4^0 (H)
Antenna sidelobe level	-26.4 dB (V) and –25.4 dB (H)
Cross-polarization discrimination of antenna	46.0 dB (V) and 44.8 dB (H)
Transmitter power (peak)	2 kW
Pulse width	0.5, 1, 2 μs
PRF	2 kHz, 4 kHz, 8 kHz
Receiver noise figure	7 dB
Transmitter polarization	H/V switch pulse-by-pulse
Receiver polarization	H and V simultaneously
Antenna scanning	$+75^0$ to -60^0 (nadir=0^0)

Table 2 Chaff and rain dimensions (Battan, 1973)

	Rain	Chaff
A	1	128
B	1	1
C	0.8	9.001
L_1	0.30278	3.19128x10^{-6}
L_2	0.39444	0.0098995
L_3	0.30278	0.9900098

property of chaff due to radar is given by Kownacki (1967), Nagl et al. (1991), Guo and Uberall (1992) and Winchester (1992). A similar study for hydrometeors was performed by Moninger and Kropfli (1982).

First, we tried to discriminate the chaff echo from the noise. As the name suggests, a special filter method that is used here distinguishes the echo from the background noise by considering their spectrum peaks above a certain threshold value. Conventionally, a high Z value is considered as an echo while a low Z as a noise. This conventional filter technique can distinguish the rain area from the non rain area very easily. However, in chaff case this technique does not work properly because quite frequently the signal to noise ratio (SNR) is very low.

One proposed method is the use of the peak spectral power instead of the total power. The spectral density is calculated using the discrete Fourier transform algorithm, which can be defined according to Sirmans and Bumgarner (1975) as:

$$S_t = \left| \frac{1}{N} \sum_{k=0}^{N_s} Z_k \exp\left(-j2\pi l \frac{k}{N} \right) \right|^2$$

where $Z_k = I_k + jQ_k$. Then, the spectrum threshold filter method is summarized as:

$$\overline{P}'(\tau) = \begin{cases} 0 & ,if\ S_l < A_{th}\ \ for\ any\ l \\ \overline{P}(\tau) & ,otherwise \end{cases}$$

where l is the index of the frequency bin and A_{th} is the filter threshold intensity. Before applying this filter, an additional filter to remove DC biases, which appear at the zero frequency was applied.

With the spectrum threshold filter method, chaff and rain data are filtered out from their background noises. Only data, whose doppler spectra have peak power values above the filter threshold value A_{th}, are considered as echoes. The filter sensitivity can be adjusted by changing the A_{th} value.

A Similar filter technique was used previously by Sirmans (1975), who used this kind of filter as one of mean doppler estimators, but here we applied the method as a noise filter. His filter method depends on the signal spectral density and the SNR while filter method in this study depends on the spectra peak value and SNR.

4. RESULTS

This filtering method works excellently for chaff data because of their strong and narrow spectra. Figures 1 shows their normalized spectral power density. Figure 1a shows an example of the chaff spectra. The central peak around zero frequency f_0 is due to DC bias. From Fig. 1a, chaff is located at around a height of 5.64 km. Strong peak and narrow spectra are quite significant. In comparison to chaff, Fig. 1b shows rain spectra which is widely distributed and has weaker peak value. The chaff spectra contain spectral peaks up to more than 100 units while rain only up to 24 units. The chaff spectra have peak distributions in the negative doppler frequency which indicates a downward movement, while rain spectra show both upward and downward movements. Apparently, the chaff spectra have narrow spectral widths and stronger peaks, which give less biases in first spectral moment calculation. In the case of the chaff spectral widths and peaks vary with air turbulences. Thus, if chaff is scattered in rainy condition, in which more turbulences is expected, wider spectral shapes are anticipated.

The normalized spectral power density at several range bins of Fig. 1 is given in Fig. 2. In Fig. 1 only chaff central peak is obvious. In Fig. 2, these peaks have values around 10 dB. Figures 1 and 2 use the same range bin resolution (37.5 m). Figure 2a shows the spectra of gate 11 to gate 16 from a height of 5.709 km to 5.522 km and Fig. 2b shows spectra from a height of 2.750 km to 2.563 km. The intensity shown in Fig. 1a is in a linear scale while that in Fig. 2 is in logarithmic scales. From Fig. 1b, the rain peak values are distributed widely and unstructured, but after the 1-2-1 convolution in the logarithmic scale, Gaussian shapes appear as shown in Fig. 2b. From Fig. 2a, chaff appears from gate 12 to 15 and is indicated by strong peak values. This range corresponds to 150 m in height.

Gate 14 shows the strongest chaff peak. All rain spectra from gate 11 to 15 have peak values below 0 dB. the rain spectra shown here also show the movement of the first spectral moment, or the the mean doppler velocity, to the right from gate 11 to 15 as expected from Fig. 1b, on the other hand the chaff first spectral moment does not change from gate 11 to 15. From gate 16 and below, chaff is not detected any more. Hence, gates 12 and 13 are the chaff trail in going downward. The rain spectra show aliasing in the right side, which indicates that the radar Pulse Repetition Frequency (PRF) in rain case does not cover the whole velocity spectrum. The mean doppler velocity calculation for rain case will be more biased than the chaff result. Notice that in our experiment, the PRF for the rain observation is 2 kHz while that for the chaff is 4 kHz. If rain experiments had used similar PRF, we would

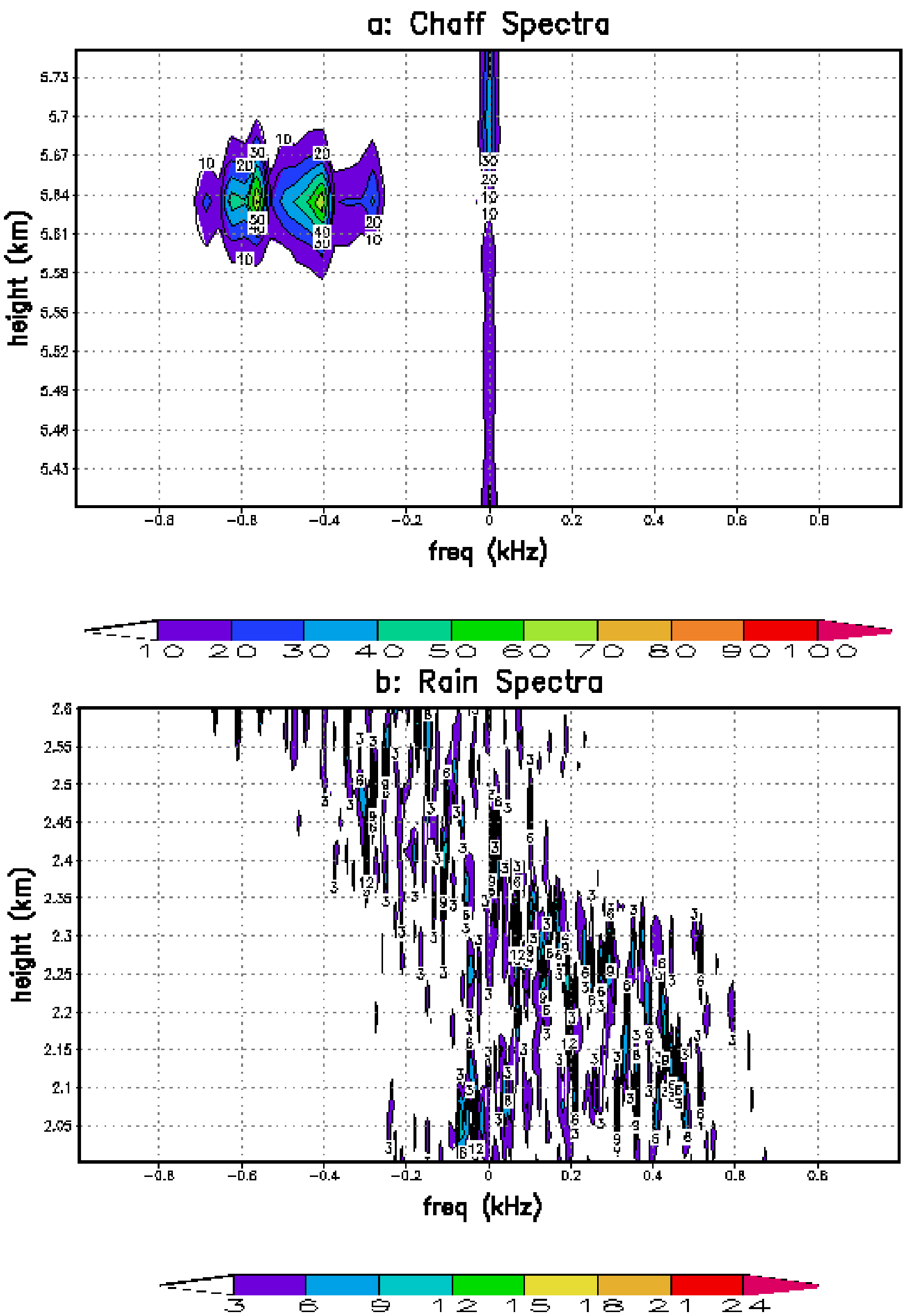

Figure 1 Spectral comparison of chaff (a: left) and rain (b: right), notice peak values and spectral distribution on each figure

expect a less biased doppler result. If we compare the spectra in Fig. 2 to Fig. 1, we can say that in any case the mean doppler velocity of chaff will be less biased than that of rain.

Moninger and Kropfli (1982) pointed out that the chaff terminal velocity is 30 cm/s. With this falling velocity (30 cm/s) and the chaff location around 5.64 km (Fig. 1) chaff will remain in the air for at least 4 hours. Thus in the still air, or quite a similar air condition in this study, chaff is a good tracer of the air movement. Moreover an appreciable convective condition is sufficient to keep chaff aloft and increases its resident time.

The other important characteristic is the SNR of chaff and rain. The SNR values are affected proportionally by the reflectivity value (*Z*). Figure 3 shows chaff and rain SNR. Rain graphs only show data above surface (less than gate 80). From this figure the rain SNR is relatively higher than the chaff SNR, which indicates higher *Z* values. Note that, this is a light rain condition and a much higher SNR value would be expected for a normal or a

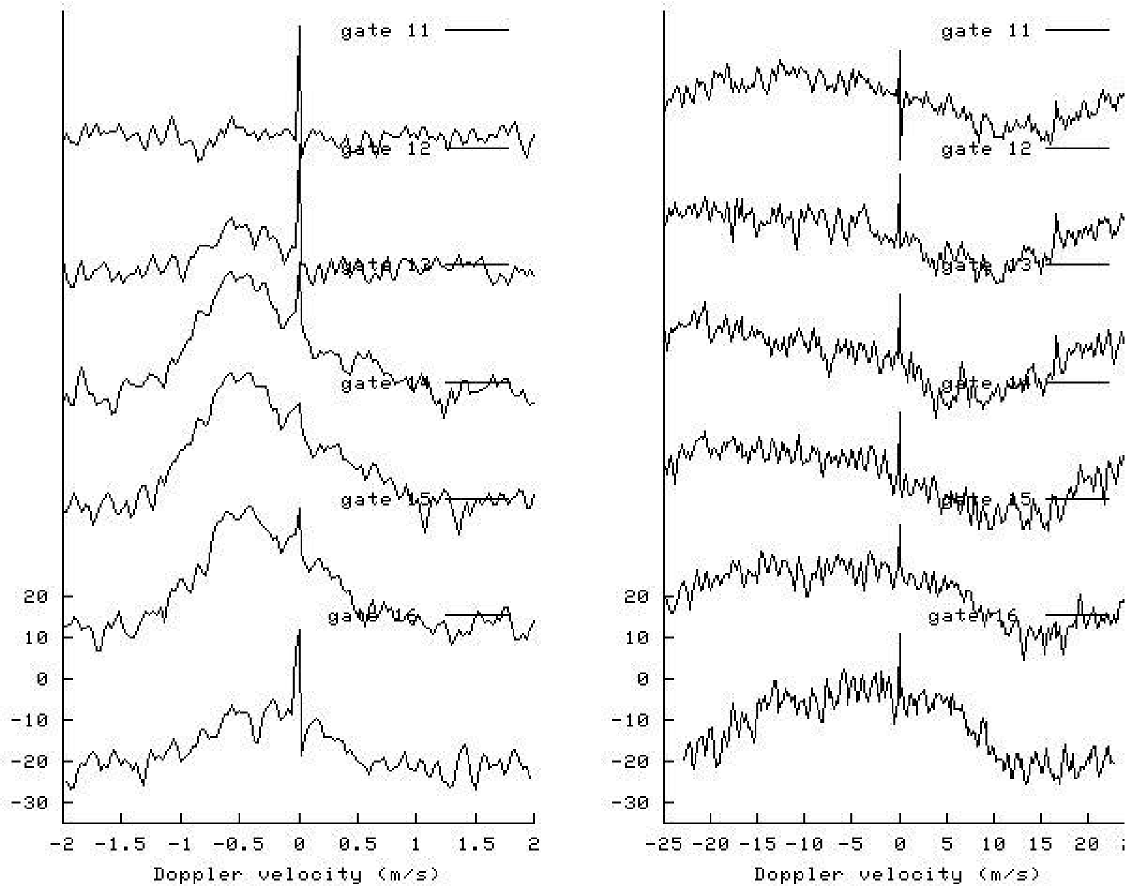

Figure 2. Cross section of (a) chaff (left) and (b) rain (right) spectra, after 1-2-1 convolution in log scale. Most of the rain spectra show Nyquist folding as clearly located in right most part of each graph. In general, rain spectra have wider distribution

hard rain. Chaff SNRs vary from around 5 dB up to 18 dB. Even for this small SNR value chaff echoes are detectable by the spectrum threshold filter method.

In this work we applied the spectrum threshold filter method to chaff and rain co- and cross-polar signatures. The result of the spectrum threshold filter method is given in Fig. 4a for chaff and in Fig. 4b for rain. These figures only show results of the filtering on Z_{hh} signatures as an example. Both figures show results from different A_{th} values for a comparison. In the chaff case, the filter works well with A_{th} = 0.35 or higher. The intermittent echoes around 5.6 km are chaff. In the rain case, the filter was not so effective. The filter can distinguish rain areas from noises. The picked up area is different from that by conventional method. In other words, the contours resulted from a change in the A_{th} value are not coincided with ones resulted from changing Z in conventional method. This is due to the nature of the filter technique itself, which picks up data according to its peak spectrum values instead of its total power. By using A_{th} from 0.35 up to 1.0 the filter still can pick up some areas, where the power intensity is lower than 10 dB. Conversely, some high intensity areas (> *25* dB) are missing with A_{th} = 1.0. One suggestion is that the technique developed here is

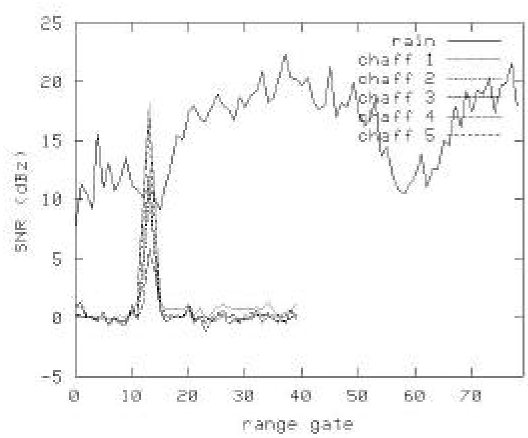

Figure 3. SNR of rain, chaff and simulated data, chaff only has 40 gates, while rain only shows the one above surface or up to gate 79. Rain data is taken at the extreme case (hard rain) and chaff data are taken from various experiments.

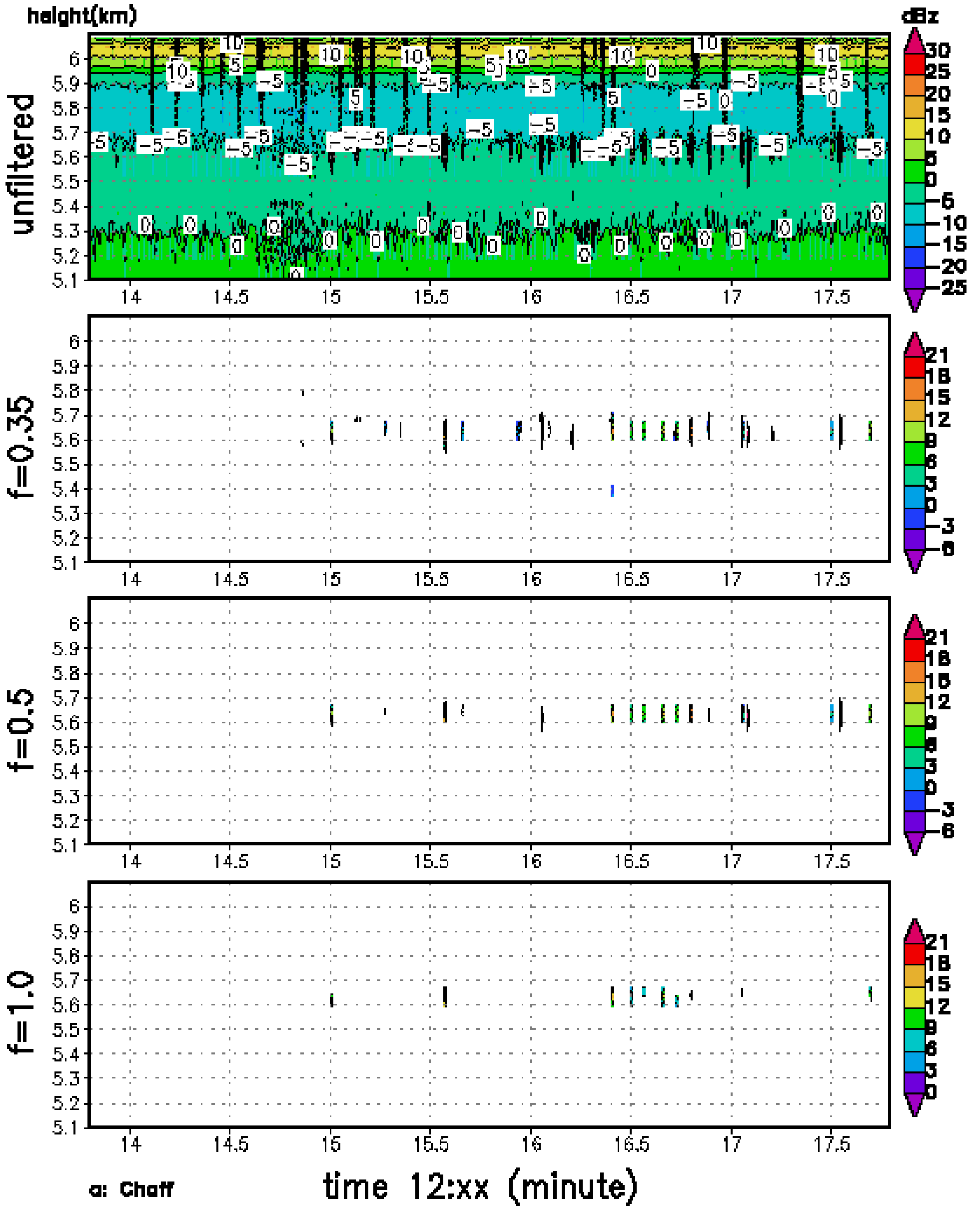

Figure 4. Filtered (a) chaff and (b) rain with different Ath showing filter performance. Chaff data are from November 29, 1995 and rain data from November 30, 1995. Data selected only from Zhh signatures. X-axes represents local time in minutes in indicated JST (Japan Standard Time)

able to detect the hydrometeor movement, although the SNR and reflectivity *Z* are low. This proves that this filter may be able to pick up true doppler velocity even from low reflectivity signals. A high spectrum peak indicates a strong single velocity in the spectra. Another advantage of this filter is that it can eliminate any malfunctioned data. Vertical lines in the unfiltered chaff signals as shown in Fig. 4a are due to the radar malfunction. After applying our spectrum threshold filter this radar malfunction data are completely removed.

Figure 5 shows scattergrams among Z_{hh}, *ZDR* and *LDR* before and after filtering. We have already known that our filter method worked well for chaff, thus we can assume that the filtered scatter graphs contain only chaff data. Chaff echoes are scattered evenly compared to bulky noise distribution. In the rain case (not shown here), the echoes and noise are not easily distinguished as in the chaff case. A comparison of chaff and rain scatter diagrams shows chaff's higher *LDR* values than their corresponding rain values.

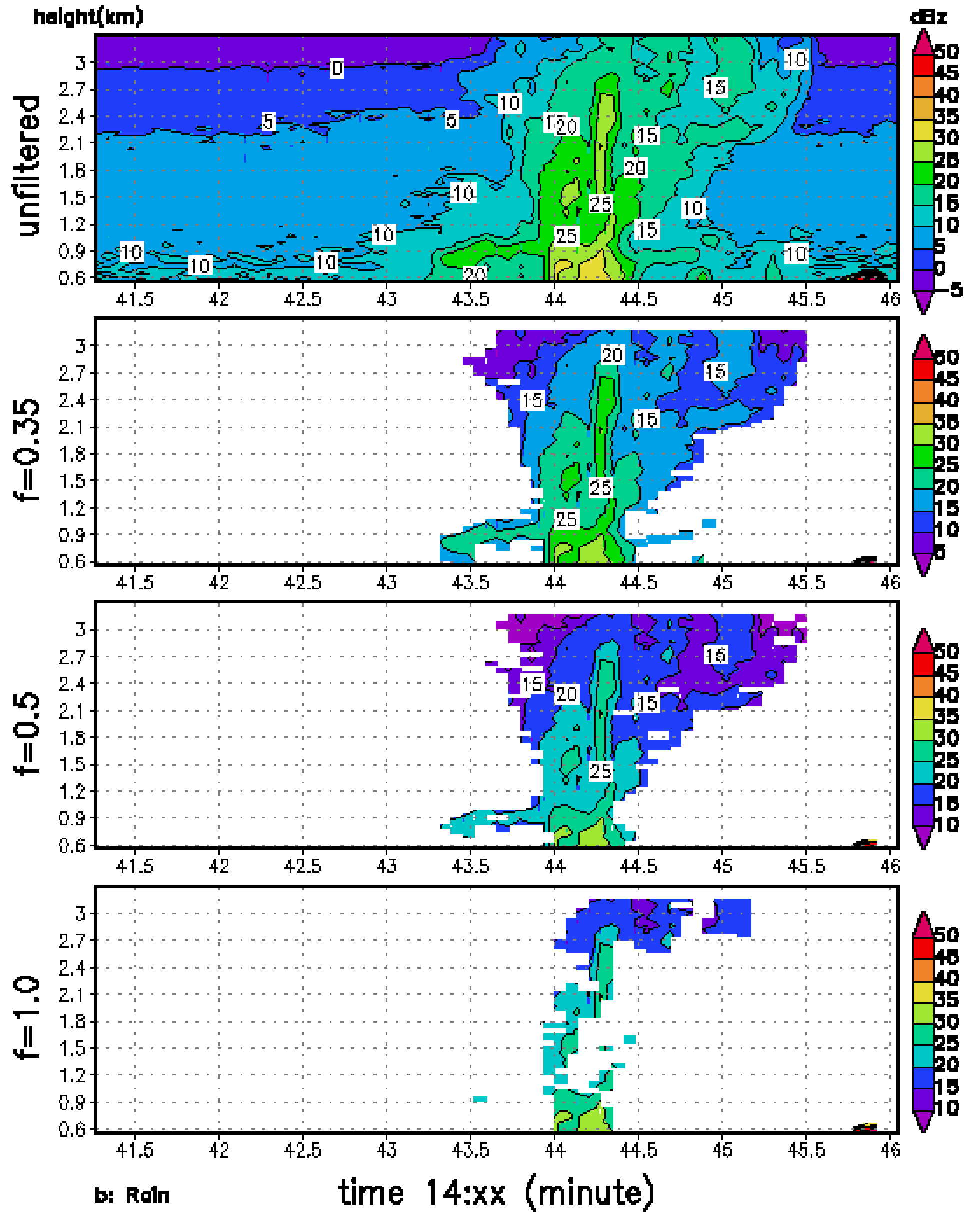

Figure 4b. continue.

5. DISCUSSION AND CONCLUSIONS

We performed polarization doppler radar observations using chaff and rain. In data analysis we developed a filter method called the spectrum threshold filter to discriminate echo from noise. The filter technique is a peak detecting method, which works better for chaff than for rain because chaff has a sharper doppler spectrum shape. Even for a weak cross-polar signal this technique works fine. In rain situation we may distinguish chaff from rain by using different threshold values. This filter picks up weak echo and eliminates noise.

The result show that the filter used here can eliminate radar malfunction problems as shown in the chaff experiment. Furthermore, the filter can disregard noise level at gates near radar (5 top gates), which is very common in radar operation. However, the rain echoes are better treated with the conventional method because of its certain dopller spectrum shapes. For a strong reflectivity and single doppler velocity material like chaff, the filter works better. The method can filter out echoes from noises in this kind of material even with a small threshold value.

This filter method is quite easy to implement and adjust. The authors hope that this method proves to be useful in general conditions. One disadvantage of this filter is the numerical processes, which is required to implement. It needs a high computing power and a fast algorithm. It is possible that the hardware implementation of this codes are possible in the future. One possible future implementation of the

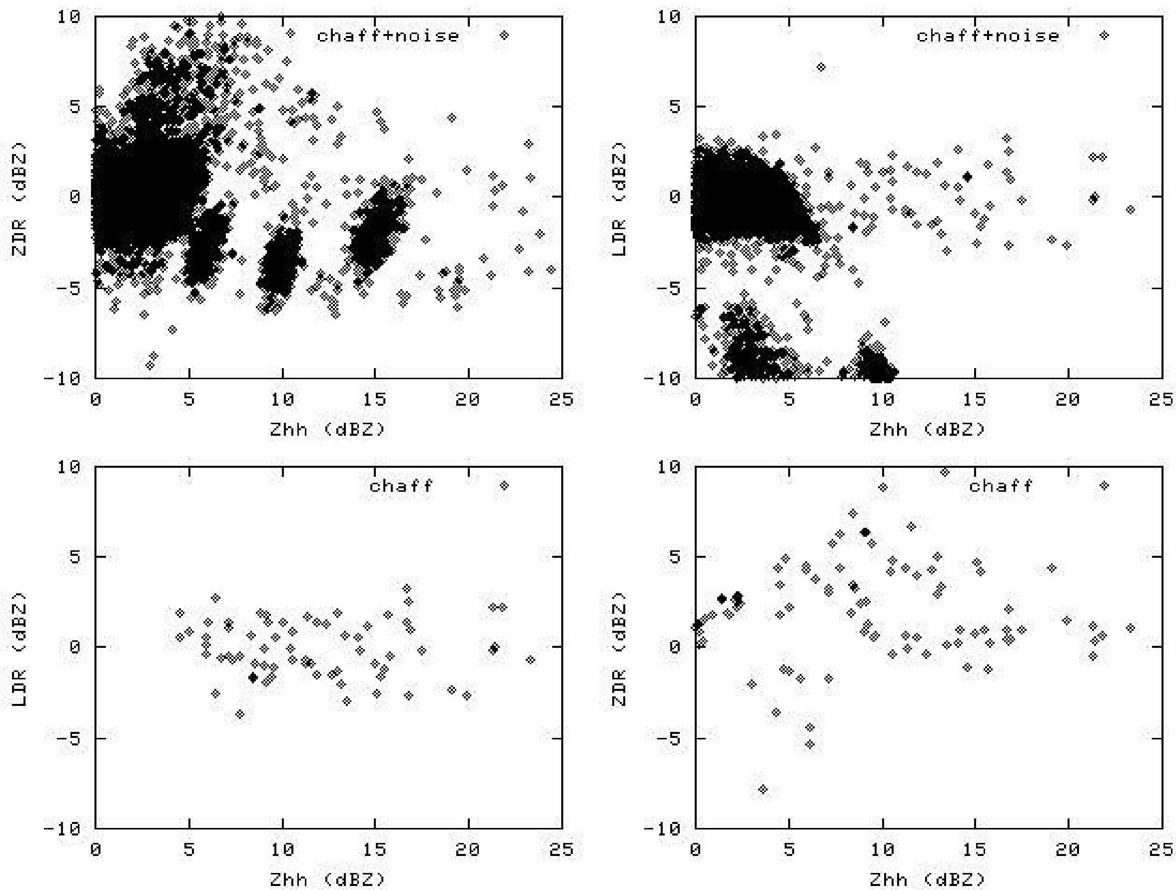

Figure 5. Filtered chaff data using A_{th} 1.0

filter and chaff echoes is the storm tracking experiment.

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References

Battan, L. J., 1973: Radar observation of the atmosphere, Univ. of Chicago Press, Chicago, 17-40

Doviak, R. J. and D. S. Zrnic, 1993: *Doppler radar and weather observation*, Academic Press Inc., 562 pp

Guo, Y. and H. Uberall, 1992: Bistatic radar scattering by a chaff cloud, *IEEE Trans. Antenna Propagat*, **40**, 837-841

Kownacki, S., Screening (shielding) effect of a chaff cloud, 1967*: IEEE Trans. Aerosp. Electron. Syst*., **AES-3**, 731-734

Kumagai, H. et al., 1996: CRL Airborne Multiparameter Precipitation Radar (CAMPR): System description and preliminary results, *IEICE Trans. Commun*., **E-79**-B, 770-776

Moninger, W. R. and R. A. Kropfli, 1987: A technique to measure entrainment in cloud by dual-polarization radar and chaff, *J. Atmos Ocean. Tech.*, **4**, 75-83

Nagl, A., D. Ashrafi and H. Uberall, 1991: Radar cross section of thin wires, *IEEE Trans. Antenna Propagat.*, **39**, 105-108

Reinking, R. F. and B. E. Martner, 1996: Feeder-cell ingestion of seeding aerosol from cloud base determined by tracking radar chaff*, J. Appl. Meteor.*, **35**, 1402-1415

Simpson, J., R. F. Adler and G. R. North, 1998: A proposed tropical rainfall measuring mission (TRMM) satellite, *Bull. Amer. Meteor. Soc.*, **69**, 278-295

Sirmans, D. and B. Bumgarner, 1975: Numerical Comparison of five mean frequency estimators, *J. Appl. Meteor.*, **14**, 991-1003

Van Vleck, J. H., F. Bloch and M. Hammermesh, 1947: Theory of radar reflections from wires and thin metallic strips, *J. Appl. Phys*., **18**, 274-294

Winchester, T. A., 1992: Pulsed radar return from a chaff cloud, *IEEE Proceedings-F*, **139**, 315-320

Widdel, H. U., 1982: Foil chaff clouds as a tool for in-situ measurements of atmospheric motions in the middle atmosphere: their flight behaviour and implications for radar tracking, *J. Atmos. Terrest. Phys*., **52**, 89-101

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