Rain Rate Estimation Process Using Doppler Spectrum of UHF Wind Profiler Radar

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Abstract: In this research, we propose a method for rain rate estimation by using Doppler spectrum's data of wind profiler. The Doppler spectrum is used to calculate the wind velocity and wind direction. But in this research uses the parameters from Doppler spectrum, it calculates the rain rate. The rain rate estimation in this method will be compared to the obtained rain rate from the surface rain gauge. Two equipments are installed in the same area. The correlation coefficient between rain rate measuring method is 0.65.

1. Introduction

The Wind profiler is a pulse Doppler radar designed mainly for wind measurements. It uses three antenna beams in order to measure all three vectors component of wind velocity in the atmosphere. Each beam can measure the radial velocity component along its axis: one beam pointing vertically measures the vertical velocity component, and two others pointing off vertical by small angles (typically about 15 degree toward the east and north) include contributions from both horizontal and vertical winds. Wind profiler transmits radio pulse to the upper air and receives scattered echo by Atmospheric turbulence which receiver signal from Wind profiler are used to calculate Doppler spectrum show in Figure 1.

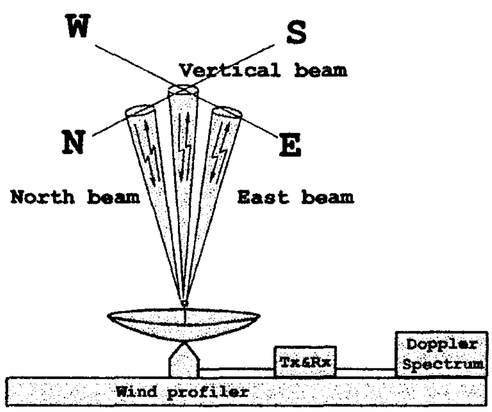

Fig.1. Schematic figure of three of transmitting and receiving radio wave such Vertical beam (azimuth and elevation angle: 0,0), East beam (90,15) and North beam (0,15) and processing of Doppler Spectrum.

2. System Description

In this process use data from Doppler spectrum in vertical beam of UHF Wind profiler operated at 1357.5 MHz. We can apply data for calculate rain rate estimation, two parameters used to calculate drop size distribution and rain rate estimation are peak position spectrum density (dB) of precipitation echo and Doppler velocity (m/s) of atmospheric echo from Doppler spectral. Therefore Doppler spectrum should has obviously double peak i.e. peak of precipitation echo (rain echo) and atmospheric echo (clear air echo) show in Figure 2. Since drop size distribution is one of the most important parameter which is closely related to the nature of the precipitation event under observation.

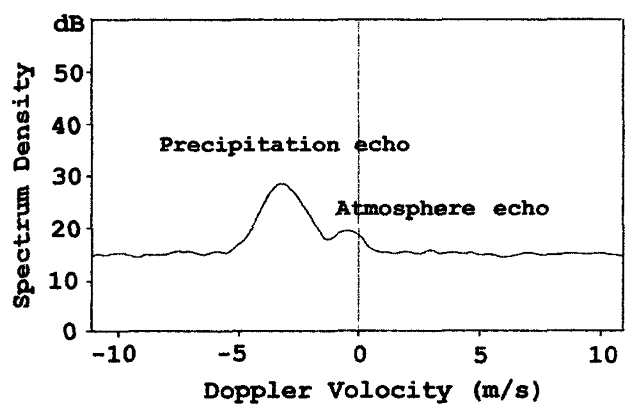

Fig.2. The Doppler spectrum from vertical beam consist of precipitation echo and atmosphere echo.

3. Method Calculation

3.1 Analyze Doppler Spectrum

Analysis to characteristic Distribution of Doppler Spectrum that it is separated 2 part; Spectrum of atmosphere echo and Spectrum of precipitation echo.

3.1.1 Consider Doppler Spectrum from atmosphere echo $S_t(V)$, characteristic of spectrum is same to Gaussian Distribution. Therefore we can describe the occur of spectrum that refer to Gaussian Distribution and consider only the highest parameter

$$S_t(v) = P_o \exp[-(v-w)/2\sigma]^2 \quad (1)$$

Which P_0 is peak power echo from atmosphere.
W is average wind speed (m/s)
σ is wide of spactrum
and v is speed of rain (m/s)

3.1.2 Consider Doppler Spectrum from precipitation echo $S_p(v)$, that D.Altas [1] describe the characteristic of spectrum. It is depend on value of RainDrop Size Distribution (DSD) as follow;

$$S_p(v) = cN(D)\, D^6 \, |dv/dD|^{-1} \quad (2)$$

Which N(D) is Rain Drop Size Distribution
D is diameter of raindrop (mm)
c is constant (it's depend on equipment of radar system)

3.2 Assumption

From research of P.E. Currier [2] is conclude the parameter of RainDrop Size Distribution in equation (2), it will be used Gamma distribution as follow;

$$N(D) = N_o D^{\mu} \exp(-\Lambda D) \quad (3)$$

Which N_o is amplitude of Gamma distribution.
μ And Λ is parameter by set the characteristic of Gamma distribution.

3.3 Relation

Gunn-Kinzer is inform to relation between speed of rain (v) and diameter of rain drop size as follow;

$$v = [\,-\alpha_1+\alpha_2 \exp(-\alpha_3 D)\,]\,(\rho_o/\rho)^{0.4} \quad (4)$$

Which $\alpha_1 = 9.65$ m/s, $\alpha_2 = 10.3$ m/s
$\alpha_3 = 0.6\ \text{mm}^{-1}$
ρ_o = density of air surface
ρ = density of over air surface

When equation (3), (4) instead in equation (2). By equation (4) differential with diameter of rain drop (D) as follow

$$S_p(v) = [cN_o/(\alpha_2\alpha_3\beta)]D^{(\mu+6)} \exp[(\alpha_3-\Lambda)D] \quad (5)$$

Which $\beta = (\rho_o/\rho)^{0.4}$

3.4 Rain rate calculation

D.Atlas [1] use the relation between speed of rain and RainDrop Size Distribution for calculates rain rate (R) as follow;

$$R = 6\pi \times 10^{-4} \int_0^{\infty} D^3\, v\, N(D)\, dD \quad (6)$$

Which N (D) is Estimation of rain rate.
R is Rain rate (mm/hr)
And v is speed of rain (m/s)
D is diameter of raindrop (mm)

In this research, we applied to use speed value of Doppler spectrum that occur from precipitation echo (v_p) and instead in equation (4), derive equation for calculate diameter of rain drop as follow;

$$D = -\log_e [(\alpha_1 + (v_p-w)/\beta)/\alpha_2]/\alpha_3 \quad (7)$$

Which v_p is speed of Doppler Spectrum that it's must minus wind speed (w) and instead parameter speed of wind in equation (4).

For N_o is amplitude of Gamma Distribution that can calculate by use high parameter of precipitation echo S_p (v) in Doppler Spectrum instead of equation(5), derive N_o as follow;

$$N_o = S_p(v)\,\alpha_2\alpha_3\,\beta\, \exp[(\alpha_3-\Lambda)D]\,/\,cD^{(\mu+6)} \quad (8)$$

Which Λ is describe to slope that it have relation with rain drop size (D), ALI Tokay [4] is explain relation in equation;

$$\Lambda = [(\mu+6)/D] + \alpha_3 \quad (9)$$

Instead equation (3), (4) in equation (6), that parameter from integrate is equation (10). It can use rain rate estimation by use parameter that read from Doppler spectrum instead in equation.

$$R=6\pi \times 10^{-4} N_o \beta \Gamma(\mu+4)[(\alpha_1/\Lambda^{\mu+4})-(\alpha_2/(\Lambda+\alpha_3)^{\mu+4}) \quad (10)$$

Which $\Gamma(\mu+4)$ is Gamma function because when integrate equation (6), it's inform Factorial that hard for calculate. Therefore use Gamma function instead equation by Gamma function and Factorial have relation as follow $\Gamma(\mu) = (\mu-1)!$

Example $\Gamma(7) = 6! = 720$

4. Result

Doppler spectra from 14 Jan to 29 July 2001 are used for testing the availability of this rain rate estimation process. Data of 300 meters observation range of vertical beam are used for comparison. For time interval of vertical beam observation by UHF Wind profiler and rain rate measured by a surface rain gauge are 5 minutes. Which distance of two equipment is 10 meter.

Consider in Figure 3, describe the comparison between rain gauge and wind profiler. The dash line shows the rain rate measured by surface rain gauge and the solid line shows the rain rate estimation from calculation in equation (10). We can see the result of wind profiler and rain gauge surface that it has different in some interval but most of parameter is corresponding. And when consider the result at 1:50-2:00am, we can see the rain rate estimation by wind profiler at 1.50am occur because wind profile can detect to vary of turbulence in atmosphere, that it begin merge to precipitation. It's characteristic of wind profiler, that advantage more than other gauge. After 10 minute, it's raining at 2:00 that is time to rain gauge start record data.

Consider in figure 4, curve as show the rain rate (R) from calculate in this method R=0.3 to R=30(mm/hr.) By use data from Doppler Spectrum of wind profiler compare with size of black circle, that can see corresponding to the rain rate from 2 equipment.

Consider in figure 5, compare the parameter of 2 equipment. Some of quite good agreement can be seen below 30 mm/hour. Rain rate from calculating and parameter measurement from rain gauge have the correlation coefficient between both rain rates is 0.65.

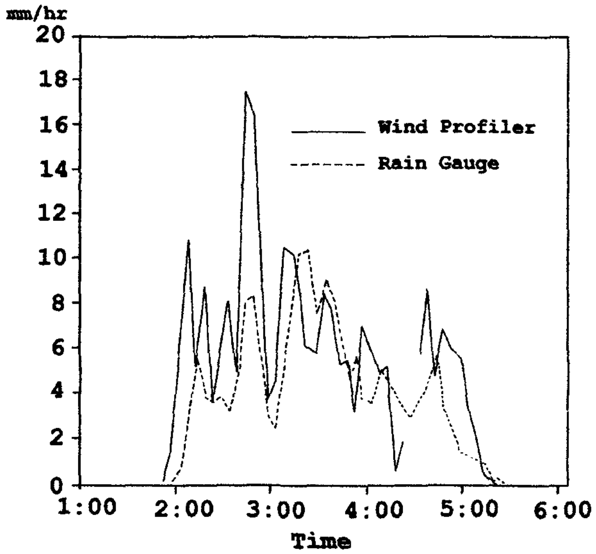

Figure.3 Time series of rain fall rate estimation by Wind Profiler (solid line) and rain rate from rain gauge (dash line)

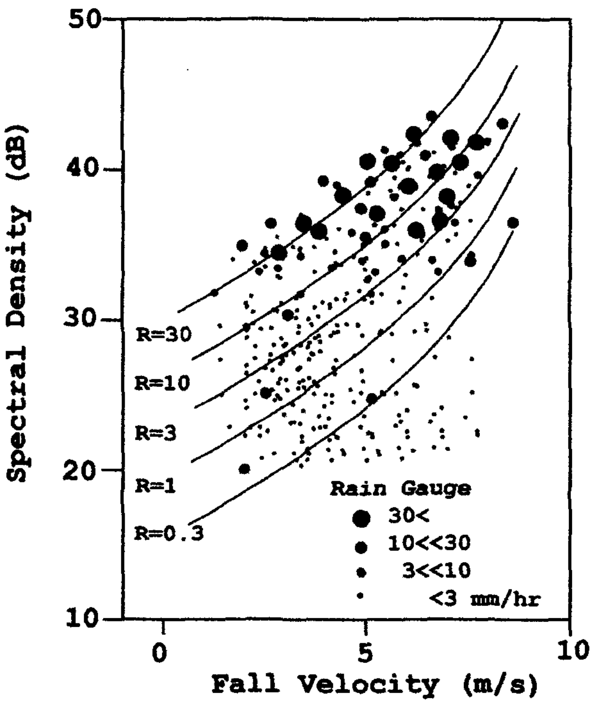

Figure.4 The comparison between rain rate estimation from Doppler Spectrum of wind profiler observation and rain gauge measurement.

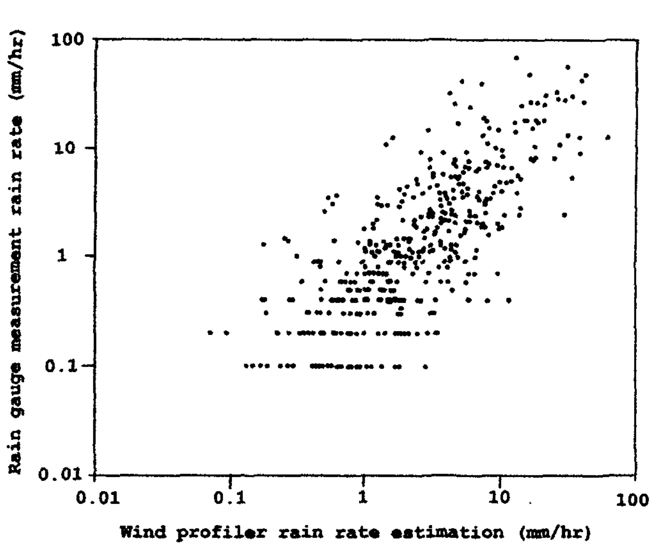

Figure.5 Scatter plot diagram of the estimation rain rate from Doppler spectrum of Wind profiler and rain rate from rain gauge measurement.

5.Conclusion

Rain rate estimation by this method uses the highest 2 parameters from Doppler spectrum. (The highest parameter of precipitation echo and the highest of echo from turbulence in atmosphere) However, rain rate over 30 mm/hour does not correspond to the rain gauge since the Doppler spectrum is saturated because of too strong rain echo. There are some case that estimated rain rate are zero even though it rains. It is because the program does not estimate the rain rate when the precipitation echo do not have adequate signal to noise ratio (S/N) for reducing bad estimations due to noise spectra. Therefore the method is the another way for rain rate estimation in level rain rate not high by use differential equation applied data from Doppler spectrum of wind profile.

For develop, we need to collect perfect data and adequate data for verify, accurate of this method higher.

References

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[2] P. E. Currier, S. K. Avery, B. B. Balaley, K. S. Grae and W. L. Ecklund, "Combined use of 50 MHz and 915 MHz wind Profilers in the estimation of raindrop size distribution", Geophysical Research Letters, Vol. 19, No. 10, pp.1017-1020, May 22, 1992.

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