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Aliasing effect due to convective rain in Doppler spectrum observed by micro rain radar at a tropical location

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Abstract

The spectral reflectivity in terms of Doppler velocity obtained by micro rain radar (MRR) at a tropical location can reveal the splitting of Doppler spectrum of falling rain drops caused by strong downdraft. The phenomenon, known as aliasing, occurs in Doppler spectrum of MRR during intense convective events. In this case, the rain drop velocity exceeds the unambiguous Doppler velocity range that can be sensed by MRR. The downdraft affecting the raindrop velocity significantly causes an ambiguity in the Doppler spectrum of the radar signal scattered from raindrops. The aliasing effect is most prominent near the boundary layer height (0.8–2 km) for convective rain. Also at this altitude range, the resultant height gradient obtained from ECMWF vertical velocity of air mass data and drop terminal velocity, is maximum. The importance of the present study lies in the fact that the split in Doppler spectrum can be utilized to estimate downdraft velocity during rain. The de-aliasing technique has been applied to the raw Doppler spectrum of MRR to retrieve the rain drop size distribution conforming to ground based measurements.

Keywords: Micro rain radar; Aliasing; Spectrum splitting; Convection; Downdraft; Drop size distribution

1. Introduction

The rain rate and other integral rain parameters are directly dependent on the Drop Size Distribution (DSD), and hence an accurate estimation of DSD serves as an input to the rain measurements, weather forecasting and related applications (Leijnse and Uijlenhoet, 2010). A correct estimation of drop size distribution is essential for understanding the process of rain formation (Atlas et at., 1999). Previous studies revealed varying DSD characteristics for different regions as well as for different rain types (Thurai et al., 2014). Generally, the drop size distribution is estimated from the quantification of drop velocity by mechanical or electromagnetic techniques. The micro rain radar (MRR) is a frequency modulated continuous wave (FMCW) radar which measures rain drop size distribution (DSD) by observing the Doppler shift in the backscattered signal from the falling raindrops. The FMCW radar has better sensitivity, spatial and temporal resolution compared to their pulsed counterparts (Frasier et al., 2002). The Doppler velocities of rain drops measured by radars are useful to provide the vertical extent of rain parameters like drop size distribution (Peters et al., 2002). However, due to strong downdraft Doppler dilemma occurs that splits the Doppler spectrum and causes an ambiguity in DSD measurements (Maahn and Kollias, 2012). The aliasing error due to Doppler dilemma results in an incorrect retrieval of the actual drop size distribution. Convective phenomena are accompanied by higher downdraft in comparison with stratiform rain events (Rao et al., 2001; Thurai et al., 2003). In stratiform rain the wind drag effect is not completely absent, but, according to Tridon et al. (2011), the wind draft impact is significant at heights

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greater than 300 m above ground level. The present study location Kolkata experiences frequent convective rain and thunderstorm activities accompanied by strong vertical wind in the pre-monsoon and monsoon period (Chakraborty et al., 2014; Rao et al., 2001; Thurai et al., 2003; Rakshit et al., 2016; Market et al., 2017; Rakshit et al., 2017). This causes Doppler shift of the radar signal beyond the unambiguous measurement range and consequently an aliasing error creeps in the Doppler spectrum (Tridon et al., 2011). An MRR has been operated at the Institute of Radio Physics and Electronics, University of Calcutta, Kolkata (22°34′ N, 88°29′ E), to investigate the height profile of the parameters of the precipitation structure. In this paper, changes in DSD due to aliasing and shifting of the Doppler raw spectrum due to downdraft have been investigated under convective and stratiform raining conditions at the study location and the vertical downdraft has been estimated from spectral splitting. Finally a de-aliasing technique has been proposed for reliable DSD measurements with MRR.

2. Data and methodology

MRR is a Doppler radar, operates at Ka- band (24.1 GHz) frequency providing profiles of rain parameters at an interval of 200 m height up to 6.2 km with 31 range gates which can be adjusted as per requirements (Rakshit and Maitra, 2016). MRR basically measures Doppler velocity spectrum from the backscattered power of falling rain drops at 64 Doppler velocity bins (MRR-2, Physical Basis, 2005). The spectral volume reflectivity $\eta\ (r,f)$ as a function of Doppler frequency (f) is related to the spectral power $p(r,f)$ received from radar range gate (r), and is given as follows.

$$\eta(r,f)df = p(r,f)(df)C\left(\frac{r^2}{\delta r}\right)(t^{-1})r \tag{1}$$

To calculate the rain DSD, the spectral volume reflectivity is needed to be expressed in terms of drop sizes ($\eta(D_{nn})$) instead of drop velocity which is expressed by

$$\eta(D_{nn})[\mathrm{m^{-1}\ mm^{-1}}] = \eta(r,f) \times (990.02)\ (\exp(-0.6\ \mathrm{mm^{-1}}D\ [\mathrm{mm}])) \tag{2}$$

Here, C is a calibration constant containing radar parameters such as transmit power and antenna gain (Peters et al. 2002). The transmission is represented by $t(r)$ which is the fractional power of a plane wave penetrating a layer of thickness (r) and is related to the scattering by rain drops (Peters et al. 2002). From the spectral volume reflectivity, DSD ($n(D)$) is calculated from the following relation.

$$n(D) = \frac{\eta(D_{nn})}{\sigma(D)} \tag{3}$$

$\sigma(D)$ is the single particle scattering cross section which is calculated using Mie-theory. The spectral reflectivity is used to calculate drop fall velocity $v(D)$ (MRR-2, Physical Basis, 2005; Kneifel et al., 2011). The rain rate (RR) is calculated using drop fall velocity and DSD (Eq. (4)).

$$RR = \frac{\pi}{6}\int n(D)D^3 v(D)dD \tag{4}$$

The terminal drop velocity is converted into drop diameter using the relation given by Atlas et al. (1973). MRR retrieves the Doppler velocity (V_D) information of the rain drop on a sweep-to-sweep basis by analysing the frequency of the echo from falling rain drops. If the sweep time of MRR is T, then Nyquist Doppler frequency is $1/2T$, and the maximum velocity (V_{max}) interval which can be detected unambiguously is given as,

$$|V_{\max}| \leqslant \frac{\lambda}{4T} \tag{5}$$

Here λ is the wavelength (1.24 cm) of the radar signal. The MRR has a peak repetition frequency (PRF) of 2 kHz which corresponds to Nyquist velocity of ±6 m/s (Maahn and Kollias, 2012). From the Nyquist velocity range the Doppler velocity can be derived from Eqs. (6) and (7).

$$R_{max} = \frac{c}{2PRF} \tag{6}$$

$$V_{max}R_{max} = \pm\frac{c\lambda}{8} \tag{7}$$

Here R_{max} is the maximum range measured by MRR, c is the velocity of light. If only positive swing is taken then V_{min} and V_{max} would be 0 m/s and 12 m/s respectively. So the total span of velocity within which MRR can determine Doppler velocity unambiguously will be 0–12 m/s**.** Considering the height normalized velocity range of 0.78 m/s to 9.34 m/s the rain drop diameter range measured by MRR is 0.246 mm to 5.03 mm (Tridon et al., 2011; MRR-2, Physical Basis, 2005). The aliasing, is an ambiguity in Doppler spectrum defined as velocity folding in the recorded Doppler velocity (V_D) above V_{max} (12 m/s) or below V_{min} (0 m/s). This phenomenon is also named as Doppler dilemma (Maahn and Kollias, 2012). The V_D value which exceeds 12 m/s appears at the lower end of the spectrum indicating very low Doppler velocities. When V_D is below 0 m/s, the corresponding Doppler velocity will appear at the higher end of the spectrum of V_D. So if V_D appears at the lower end of the spectral reflectivity spectrum due to aliasing, the actual Doppler velocity (V_{Dact}) and the measured velocity (V_D) are related as follows,

$$V_{Dact} = V_{max} + V_D \quad [\text{if } V_{Dact} > V_{max}] \tag{8}$$

and, when V_D appears at the upper end of the reflectivity spectrum, then V_{Dact} is given by

$$V_{Dact} = V_D - V_{max} \quad [\text{if } V_{Dact} < V_{min}] \tag{9}$$

In the present study, the downdraft during intense convection causes the Doppler velocity to exceed the maximum measuring range of MRR. So de-aliasing can be done according to Eq. (8) to get the corrected reflectivity