Spectral Algorithm to Separate Cloud and Drizzle

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Introduction

- A new method to detect, estimate and separate cloud and drizzle echoes from vertically pointing Doppler spectra radar data.
- A parametric model is developed using the recorded radar Doppler spectra data to retrieve the signal spectral moments.
- Goodness of fit parameters are defined that specify features of the Doppler spectrum. If the detection parameters exceed pre-determined thresholds, the signal contains a mixture of cloud and drizzle.
- A drizzle map is specified and processed to reduce uncertainty due to turbulence and to accommodate the location of the cloud base. At the locations where cloud and drizzle co-exist, the model is modified to include drizzle and cloud spectral parameters.
- A similarity-based classifier is implemented to identify which echoes are associated with cloud or drizzle.

Methodology

1. Parametric time domain method (PTDM)

- If N echoes contained in the received signal, the radar power spectrum $S(v)$ can be written as

$$S(v) = \sum_{i=1}^{N} S_i(v) + p_n$$

$$S_i(v) = \frac{P_i}{\sqrt{2\pi}\sigma_i} \exp\left[-\frac{1}{2}\left(\frac{v - \bar{v}_i}{\sigma_i} \right)^2 \right]$$

- Covariance matrix of the measured signal sampled Ts apart

$$R[k,l] = P_p \exp\left(-\frac{8\pi^2 \sigma_p^2 (k-l)^2 T_s^2}{\lambda^2} \right) \exp\left(-j\frac{4\pi \bar{v}(k-l)T_s}{\lambda} \right) +$$

$$+ P_c \exp\left(-\frac{8\pi^2 \sigma_c^2 (k-l)^2 T_s^2}{\lambda^2} \right) + \frac{2T_s}{\lambda} \sigma_N^2 \delta(k-l);$$

$$k,l = 1,\dots,N$$

- The spectral moments of the signals can be obtained by minimizing the negative log-likelihood

$$L(\mu) = \ln(\det(\mathbf{R}(\mu))) + trace\left(\hat{\mathbf{R}} \mathbf{R}^{-1}(\mu) \right)$$

$$\mu = \left[\bar{v}_1, \sigma_1, P_1, \dots, \bar{v}_N, \sigma_N, P_N, p_n \right]$$

where $\mathbf{R}(\mu)$ and $\hat{\mathbf{R}}$ are the sample covariance matrix and the model covariance matrix, respectively.

2. Goodness of fit parameters

When the signal only contains one type of echo, its Doppler power spectrum follows a Gaussian shape (N=1). However, in the present of drizzle and cloud mixture, the resulting spectral shape can depart from Gaussian. In such case, goodness of fit parameters could be used to detect the present of drizzle in the mixture. In this study, we have defined two goodness of fit parameters. One is a normalized trace that is computed as the trace of the quotient matrix between a sample covariance matrix and the model covariance matrix evaluated at the estimated parameters

$$Tr_{\mathrm{var}} = std\left\{diag\left(\hat{\mathbf{R}}\mathbf{R}^{-1}(\mu)\right)\right\}$$

This is a part of the likelihood function with its value close to zero indicating a good fit.

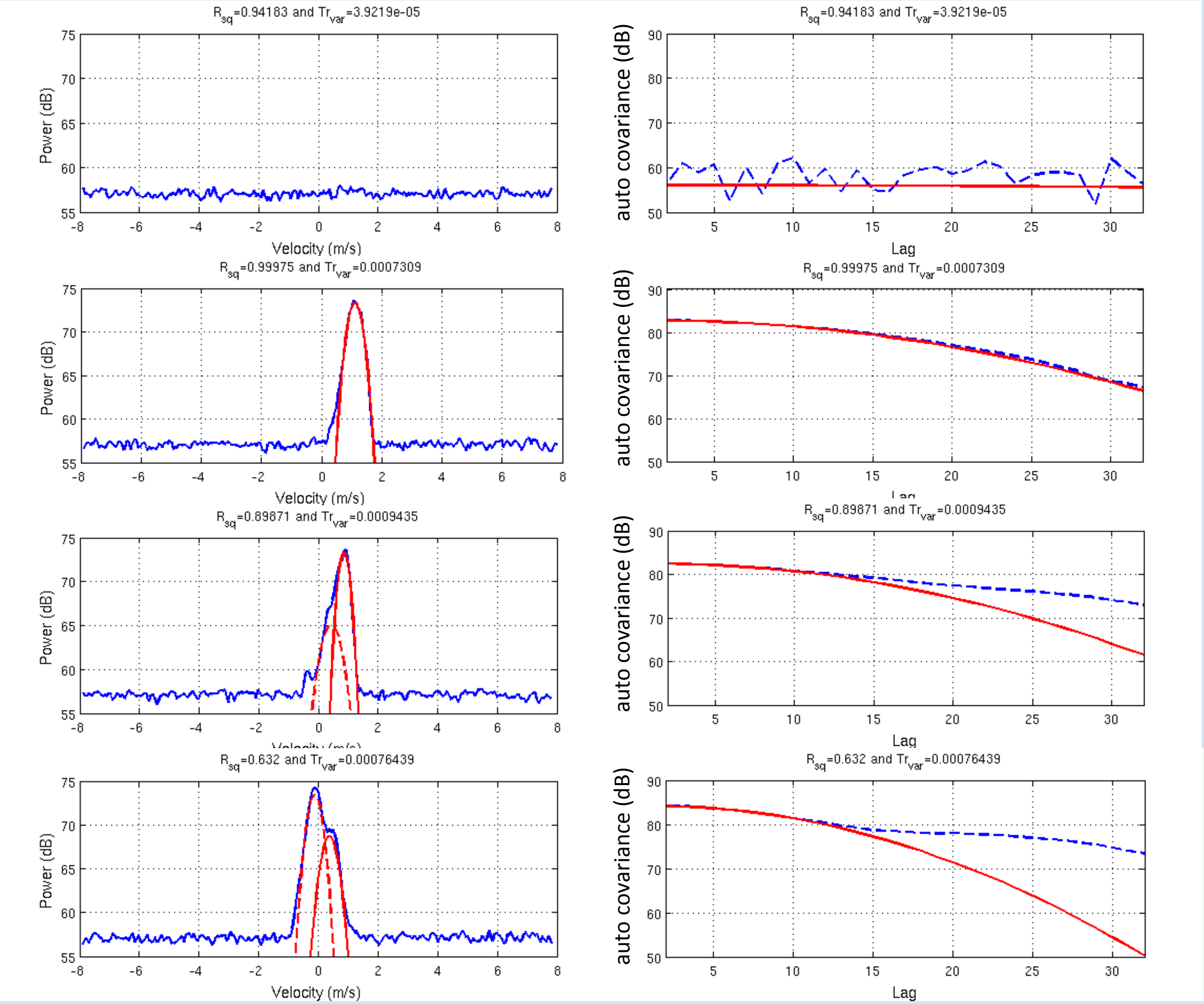
The other goodness of fit parameter is R_{sq} that is a fraction of the total signal variance explained by the model and the closer it is to unity, the better fit.
The performance of these goodness of fit parameters is illustrated using simulated signal spectra (with inputs similar to WSACR) (next slide)

Representation of radar Doppler spectra and goodness of fit parameters

noise only

Gaussian spectrum

bimodal spectra



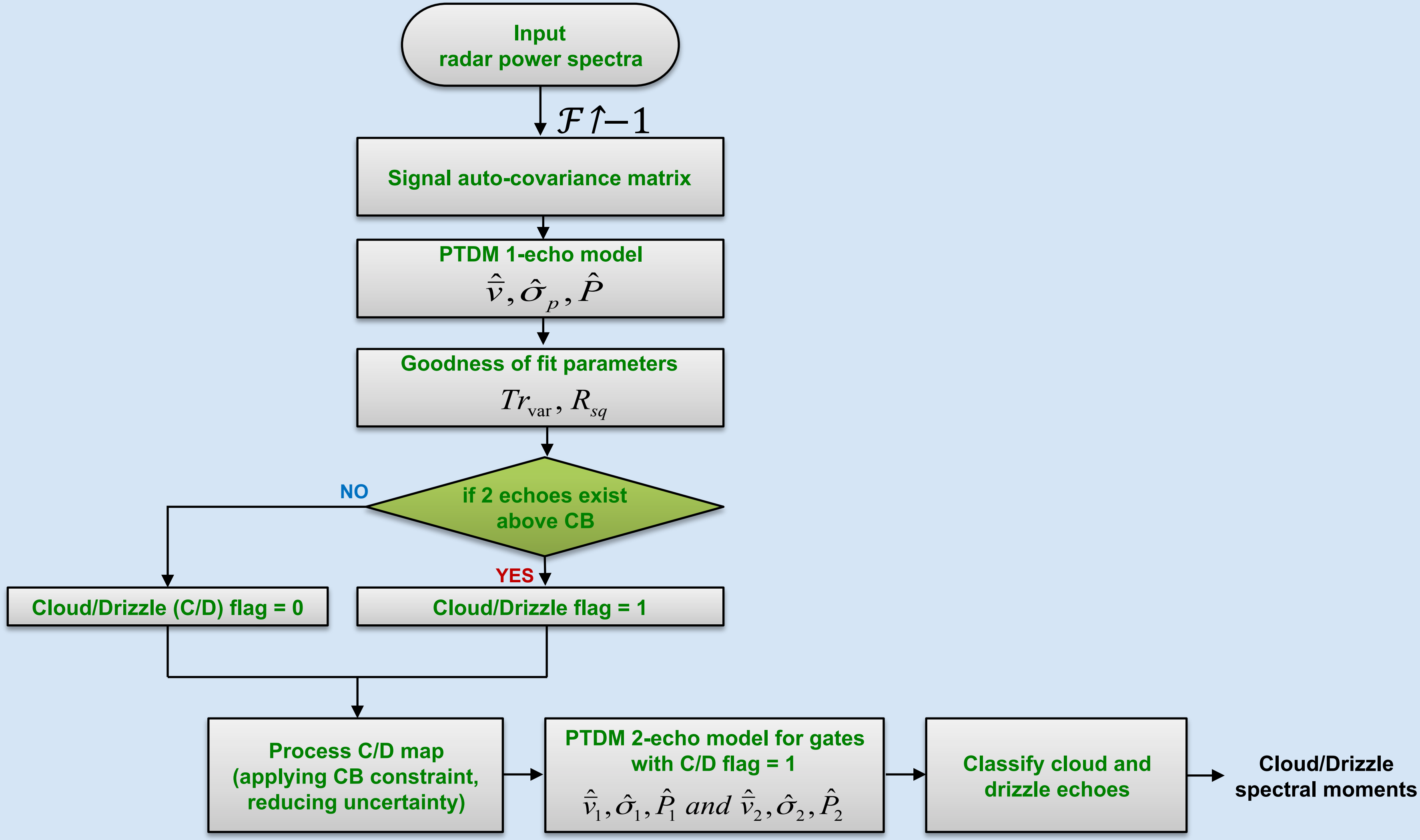
Cloud/Drizzle separation procedure

The cloud base (CB) from the ceilometer provides a constrains in the cloud/drizzle detection algorithm. We assume echoes below CB are drizzle. Mixture of cloud and drizzle only exist at rage gates above CB.

The C/D separation algorithm is summarized as follow:

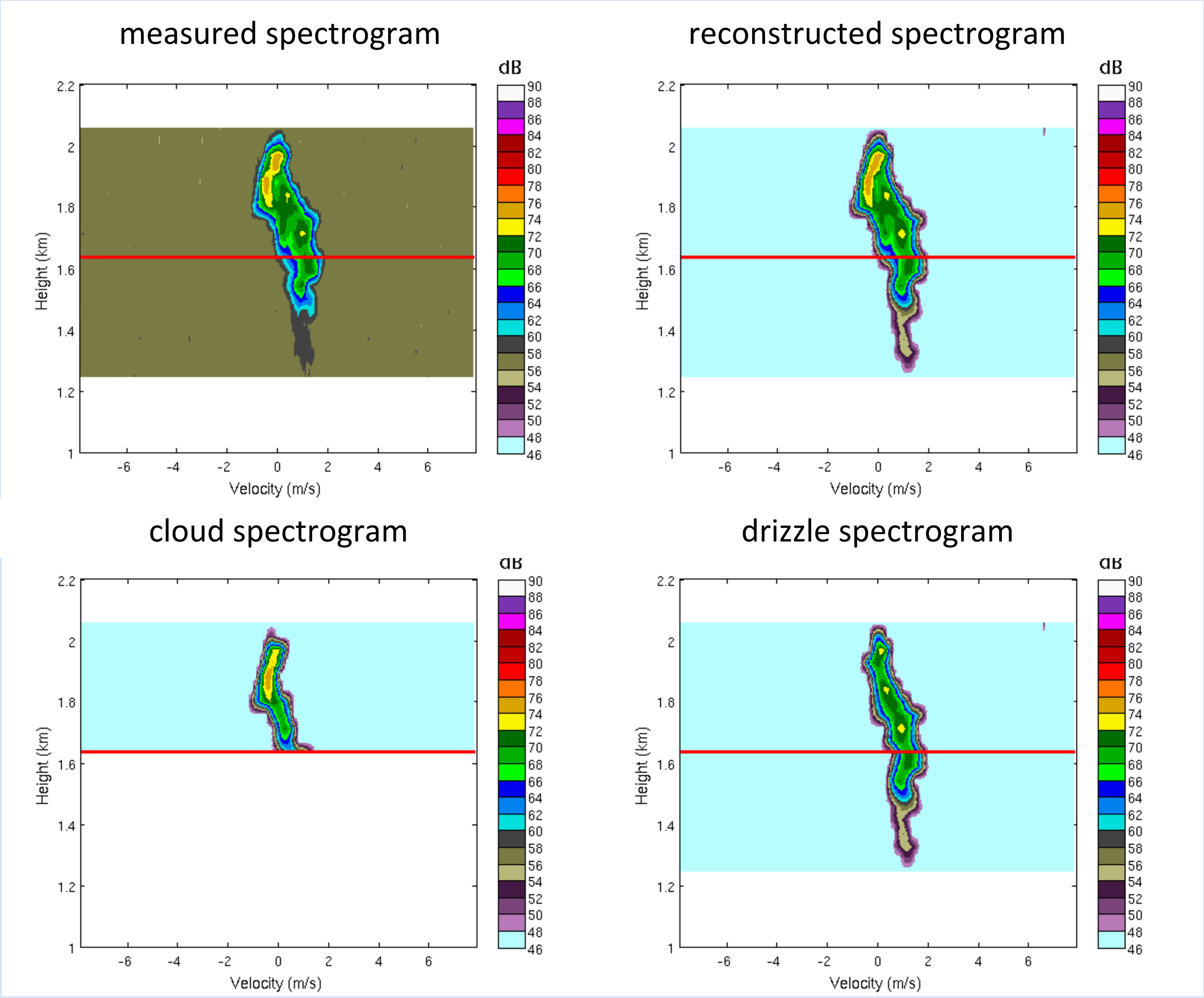
- First, the cloud, drizzle map (C/D map) is created using PTDM goodness of fit parameters. It is noted that PTDM is only applied to signals above CB.
- The C/D map is processed (smoothened) to reduce the estimate uncertainty.
- Re-apply PTDM with two-echo model for the gates with the present of drizzle.
- Classify cloud and drizzle echoes in a way so that it remains the continuity of drizzle signals below and above the CB.

Cloud/Drizzle separation procedure diagram



Azores data analysis

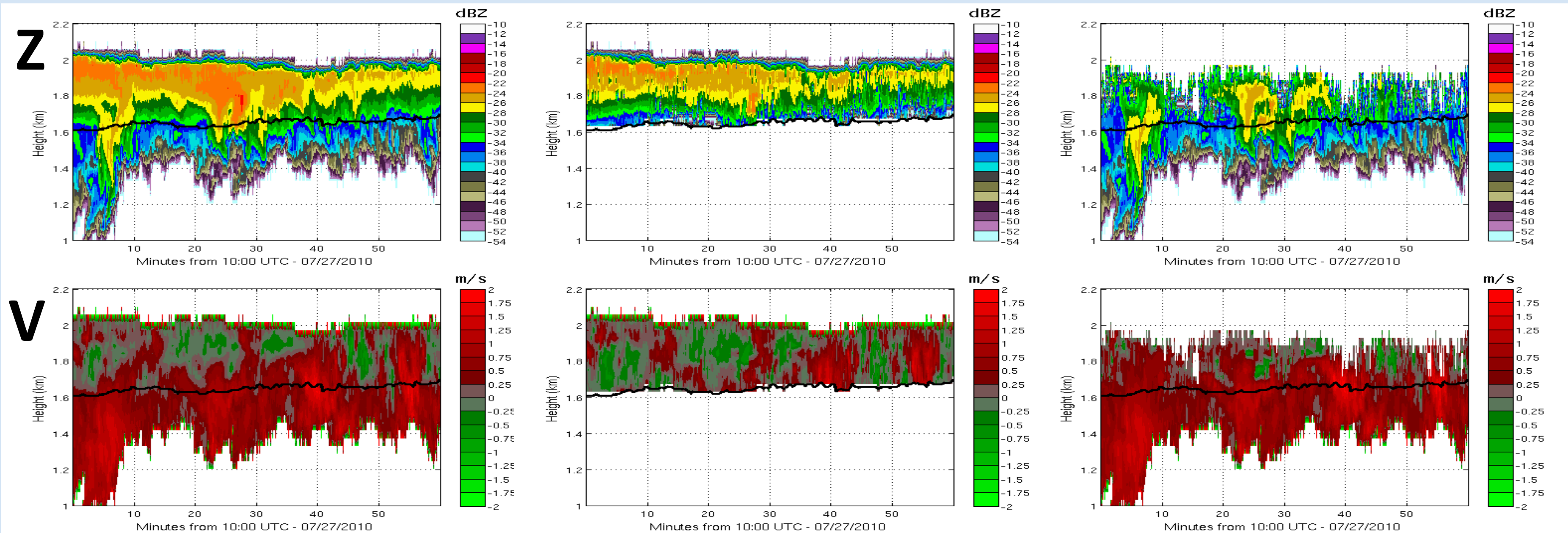
Example of cloud/drizzle decomposition for one spectrogram



Radar Doppler spectrogram collected at 10:23:04 UTC on 27 July, 2010 by the W-band ARM cloud radar (WACR) on Graciosa Island in the Azores. The red line is the cloud base (CB).

Azores data analysis: July 27 2010 case

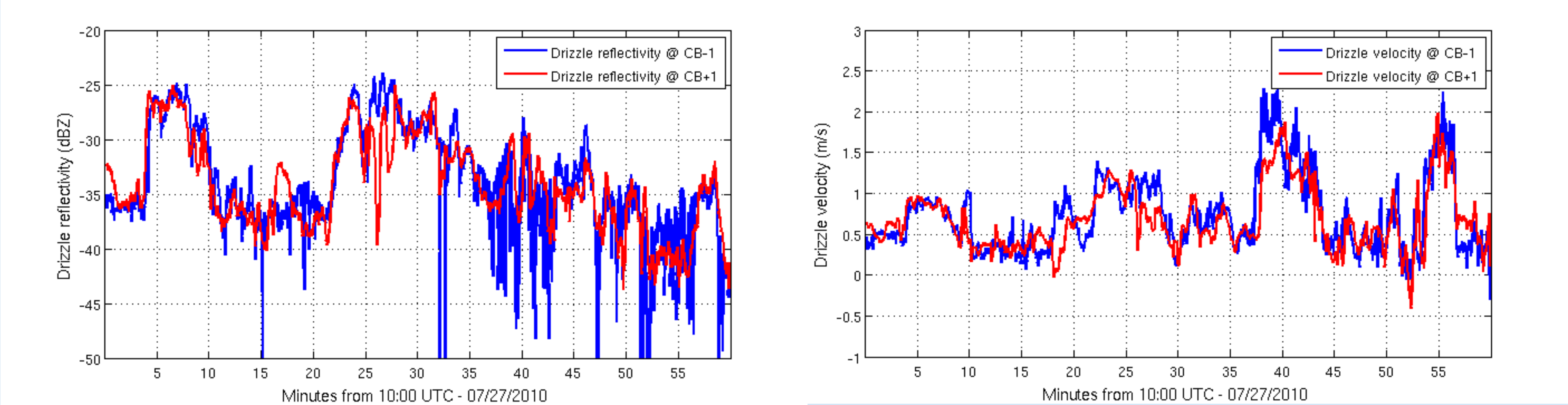
Measured **Cloud** **Drizzle**



Data collected by ARM WACR on 27 July 2010 from 10:00:04 UTC to 11:00:01 UTC in the Azores. Measured reflectivity and velocity (left column), retrieved reflectivity and velocity for cloud (middle column) and for drizzle (right column). The black line is the cloud base.

Algorithm verification

One way to verify the performance of the algorithm is to compare reflectivity and velocity profiles one gate above and below the CB. Within such small spatial distance, one would expect the profiles are almost identical. The figure below shows that comparison for the July 27 case.

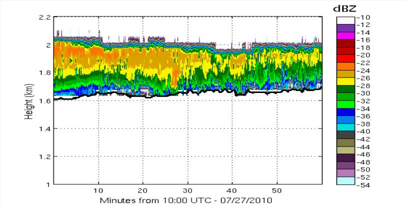


Comparison of retrieved drizzle reflectivity one gate above cloud base (CB +1) and one gate below (CB-1) (a). (b) as (a) but velocity.

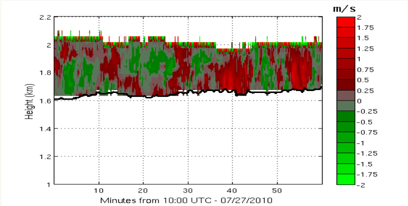
Comparison of Cloud Drizzle Separation Methods

Nguyen *et al.*

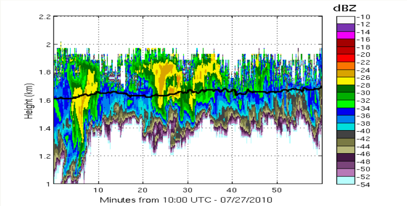
Cloud Z



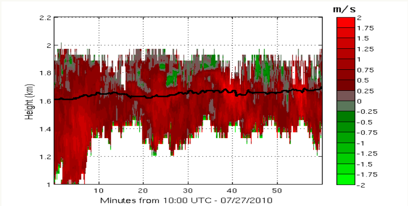
Cloud V



Drizzle Z

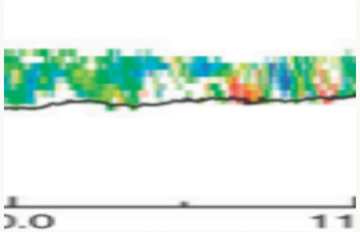


Drizzle V

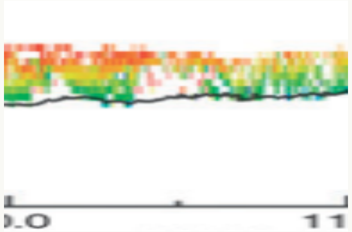


Luke *et al.*

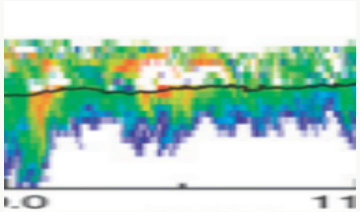
Cloud Z



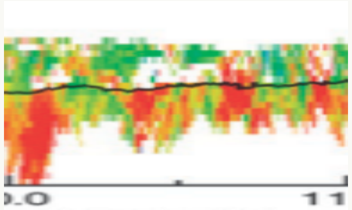
Cloud V



Drizzle Z



Drizzle V



Note: figures are cropped from Fig. 7 (Luke et al. ,2013)

Summary

- The new method works with a single radar power spectra profile and performs well in most scenarios.
- Drizzle reflectivity can be obtained accurately without the need of a compensation factor when cloud and drizzle echoes overlap heavily.
- The applications of the technique include inference of the vertical air motion, the particle size distribution of the drizzle and the dynamical and microphysical processes during the transition from cloud to drizzle.

Thank you and Questions?