Detection of Hydrometeor Fall Speed and Vertical Air Velocity in Coherent Doppler Lidar

Rob Newsom, Pacific Northwest National Laboratory, Richland WA
Erol Cromwell, Pacific Northwest National Laboratory, Richland WA

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Introduction

Although coherent Doppler lidars have been used extensively to study atmospheric boundary layer dynamics under clear-air conditions, much less attention has been devoted to the potential of using these systems to study precipitation. In this study we examine the characteristics of lidar Doppler spectra acquired by a vertically staring Doppler lidar at SGP C1 during several rain events over the course of the LAFE field campaign in August 2017. We show that the lidar Doppler spectra exhibit a distinct bimodal (sometimes trimodal) structure during rain events. A multimodal Doppler velocity estimation algorithm is used to estimate vertical velocities corresponding to the precipitation and aerosol maxima in the Doppler spectra, enabling calculation of the corrected rain drop fall speeds.

ARM Doppler Lidars

The ARM program currently operates nine coherent Doppler lidars (DLs) at various sites, including five systems at the Southern Great Plains site. These instruments, which operate at a wavelength of 1548nm with low pulse-energy (<100mJ) and high pulse repetition rate (15kHz), are configured to perform VAD scans once every 10 to 15 minutes, and stare vertically the rest of the time. The lidar's real-time signal processor provides height- and time-resolved measurements of radial velocity, attenuated aerosol backscatter, and wide-band signal-to-noise ratio (SNR). In addition to these processed data, the systems can also be configured to log raw "spectral" data.

SGP Doppler lidar – Halo Photonics StreamLineXR	
Wavelength	1548nm
Pulse Energy	~100μJ
Pulse Width	150ns
PRF	15kHz
Sample Frequency	50MHz
Nyquist Velocity	19.4 ms^{-1}
Number of I&Q Samples	4000
FFT size	1024

Doppler lidar Spectral Data: The new dlacf.a1 datastream

When raw data logging is enabled, the DL generates files containing ungated autocovariance functions (ACF) that have been averaged over a predefined pulse integration period (typically ~1sec). The autocovariance and the power spectrum are Fourier transform pairs. Thus, the Doppler spectrum is given by the real part of the Fourier transform of the ACF.

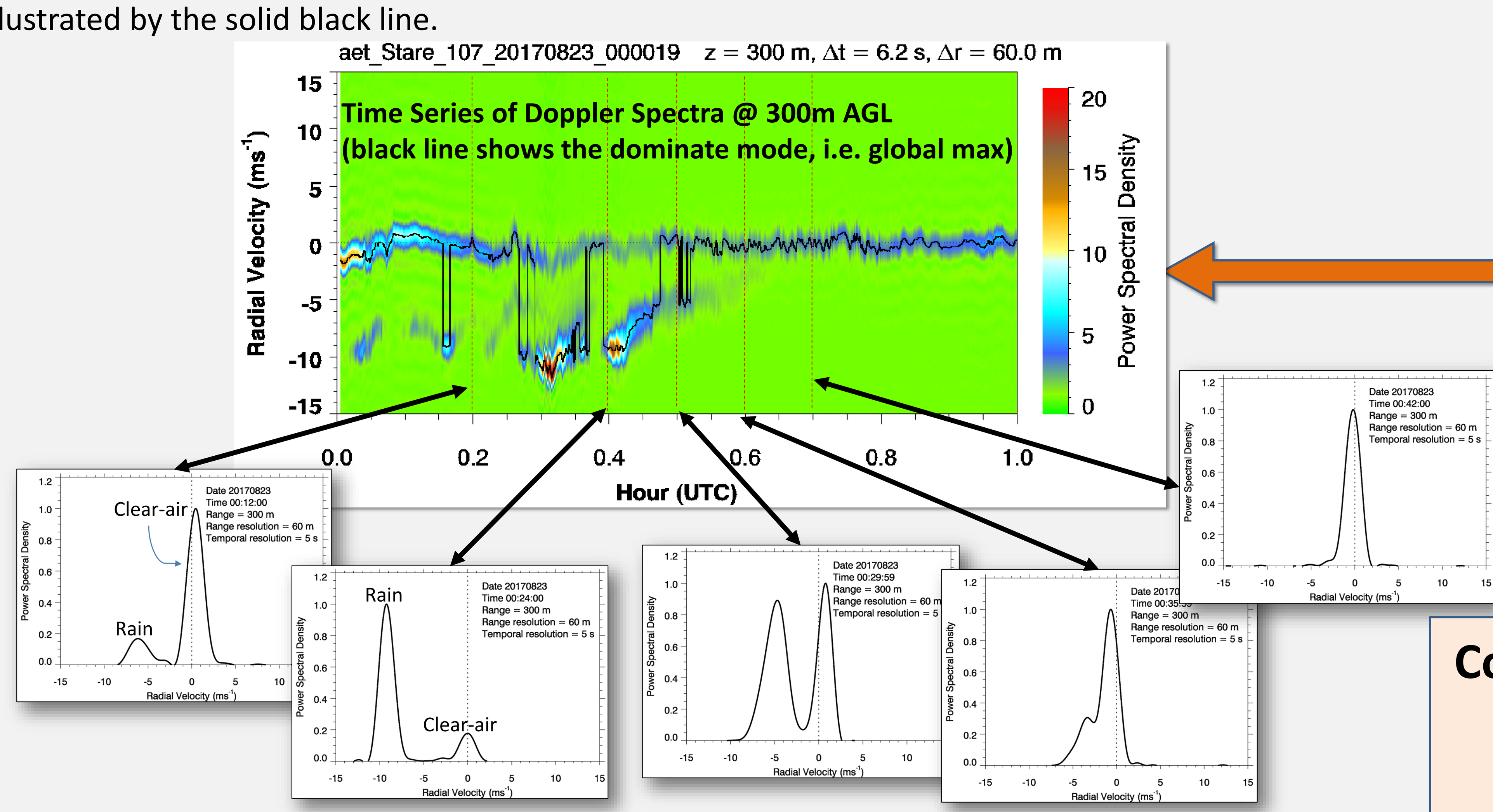
For each I&Q sample location, the k^{th} lag of the ACF can be expressed as

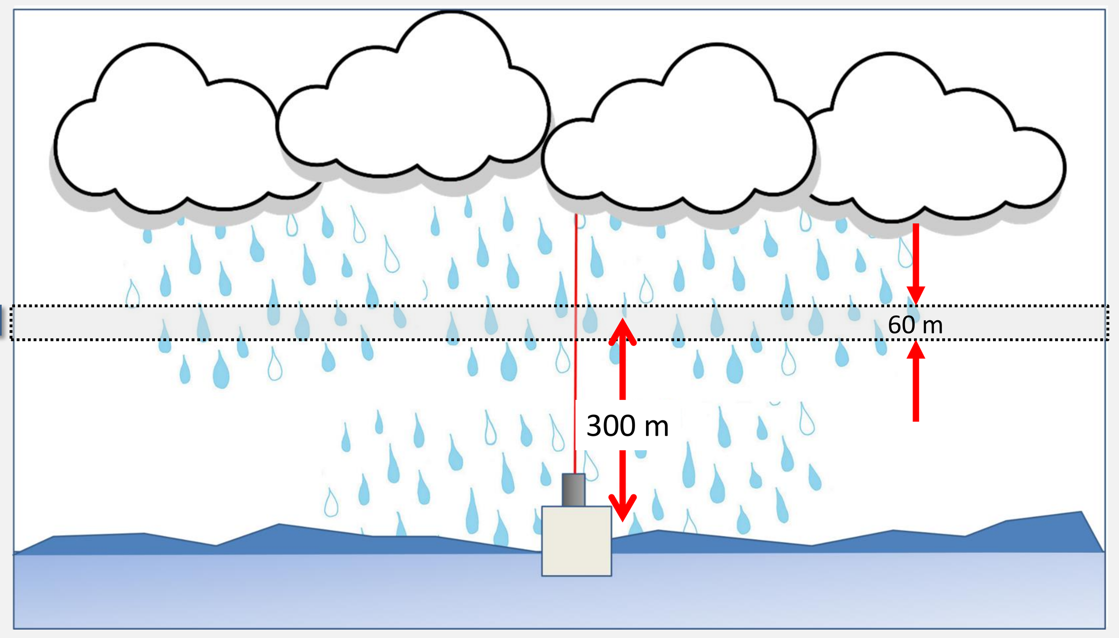
$$ACF_k = \frac{1}{N-k}\sum_{j=0}^{N-k-1} s_{kj}$$

where $s_{kj} = \langle f_j f_{k+j}^* \rangle$, $f_k = I_k + iQ_k$, N is the total number complex of I & Q samples in the return (currently 4000), and $\langle\cdot\rangle$ denotes a temporal average over a prescribed number of pulses (i.e. the pulse integration time). The new dlacf.a1 datastream stores the complex s_{kj} values, where k is the I&Q sample index and j is the lag index. The maximum number of lags that are currently stored in the dlacf.a1 output is 20.

Lidar Doppler spectra during a rain event

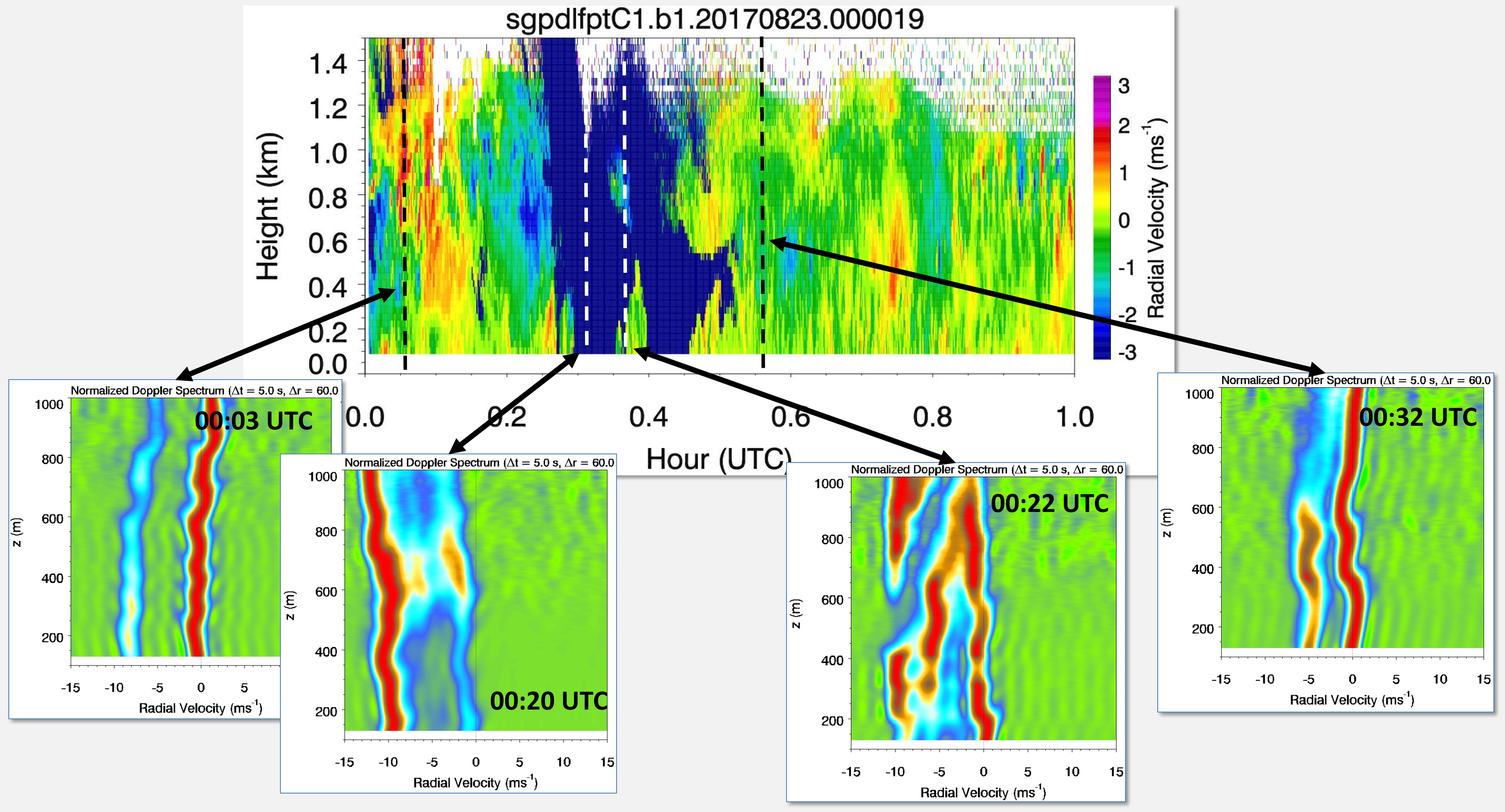
A vertically staring Doppler lidar is often able to "see" many 100s of meters through precipitation. The return signal is effected by both the falling rain drops and the clear-air motion. As a result, the Doppler spectra show a distinctive bimodal (sometimes trimodal) structure that enables unambiguous discrimination between the clear-air (aerosol) and the precipitation vertical velocities. The figure below shows a time-series of lidar Doppler spectra acquired during a rain event at SGP C1 (between 00:00 and 01:00 UTC on 23 August, 2017). The standard velocity estimation algorithm always reports the velocity associated with the dominate spectral mode, i.e. the global maximum. As a result, when precipitation is present the estimator often "mode hops" between clear-air (aerosol) and precipitation peaks, depending on which is the dominate mode. This behavior is illustrated by the solid black line.



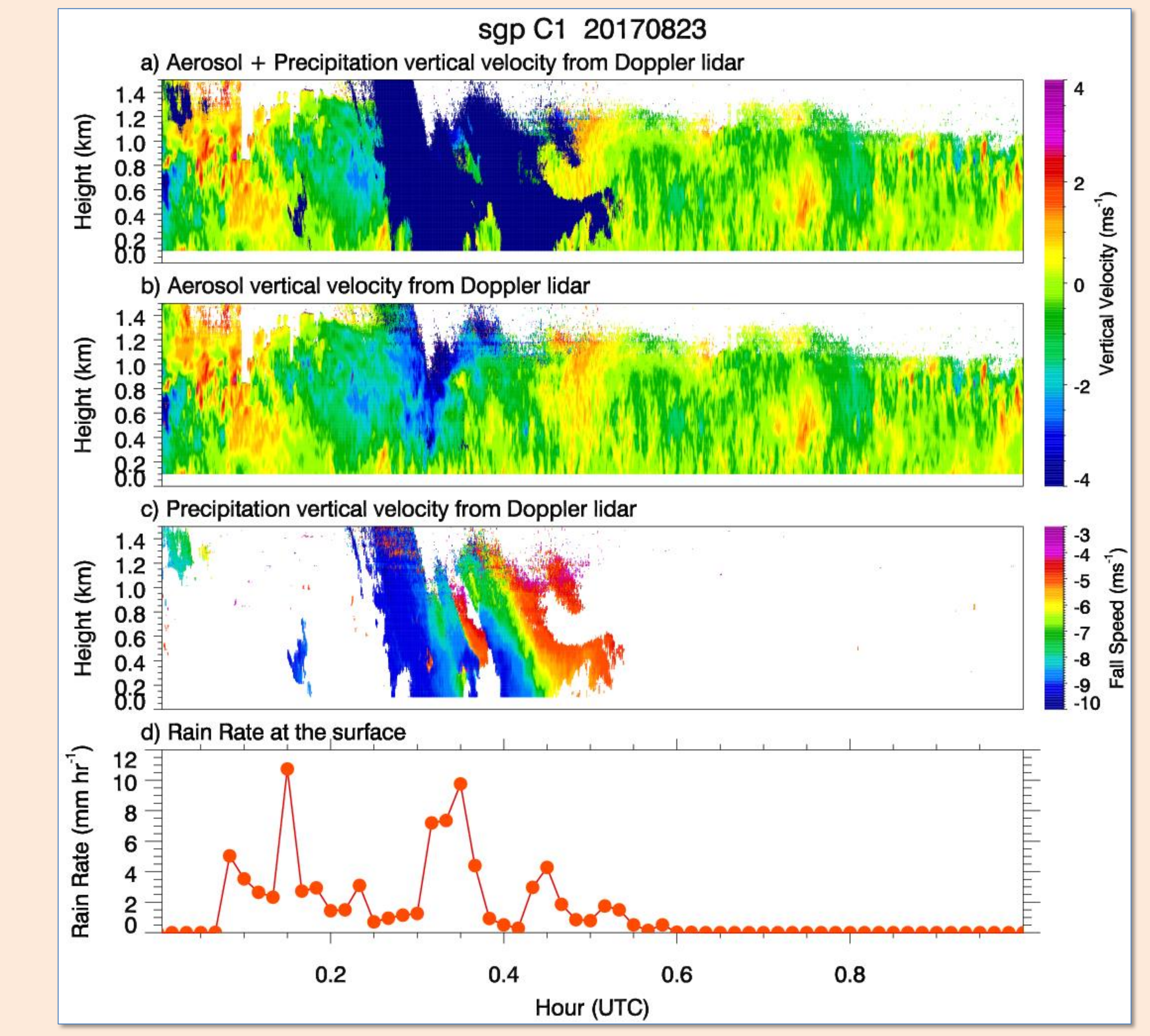


Lidar Doppler spectra during a rain event

The figure below shows a time-height cross-section of the dominate spectral mode (i.e. the standard data product) from vertical staring data acquired between 00:00 to 01:00 UTC on 23 August 2017 at SGP C1. The dark blue (off scale) patches are regions where the precipitation signal is the dominate mode. Also shown are profiles of Doppler spectra at selected times during the precipitation event.



Corrected Rain drop fall speed estimation



a) Time-height cross section of the dominate spectral mode.
b) Time-height cross-section of the spectral mode closest to zero, which is likely the clear-air vertical velocity.
c) Time-height cross-section of the corrected rain drop fall speed as given by the difference between panels a) and b), i.e. a)-b)
d) Time-series showing the rain rate as measured by the surface met station.

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