Comparison of eddy dissipation rate retrieval techniques in clouds using Doppler measurements

P. Borque[1], E. Luke[2] and P. Kollias[1]

[1] McGill University, Montreal, QC

[2] Brookhaven National Laboratory, Upton, NY

Motivation

- Why Eddy Dissipation Rate is important?

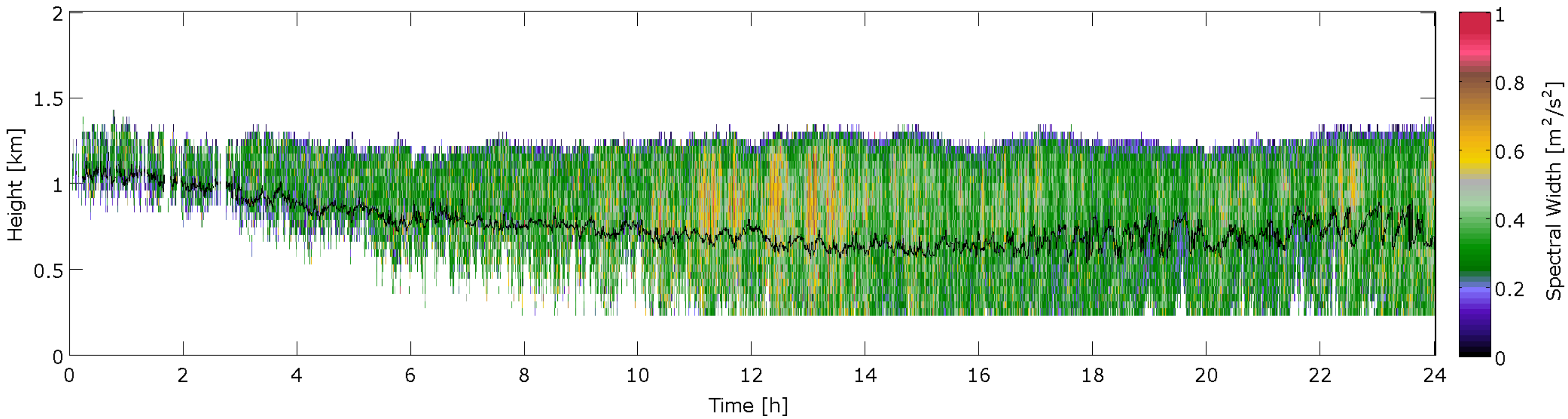
  - Affect the collisional rate of cloud droplets
  - Determine the turbulent mixing time scales
  - Allow deconvolution of microphysical and dynamical effects in radar Doppler spectra

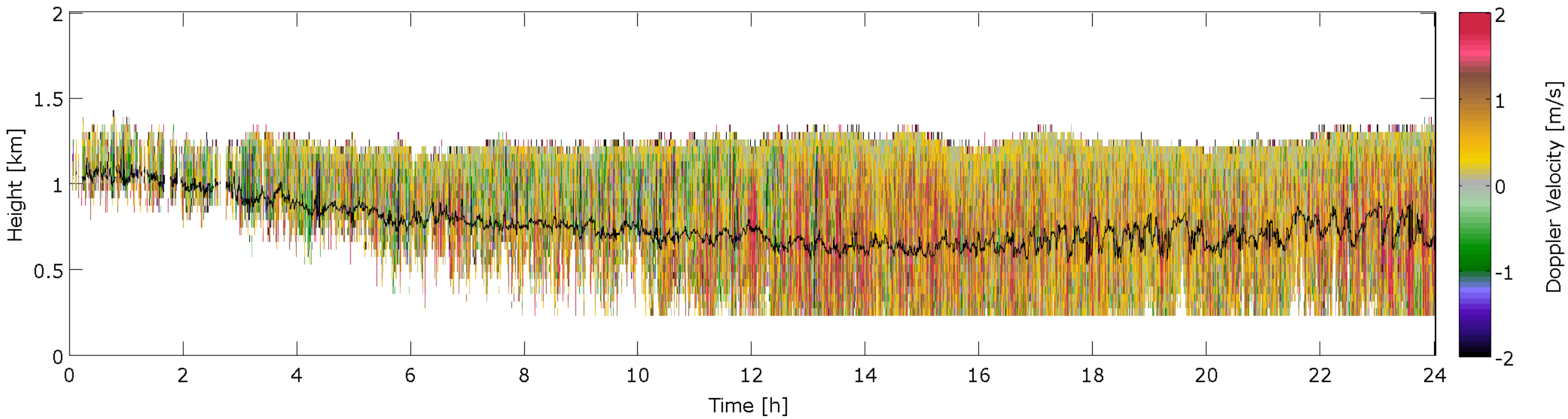
Objectives

- Estimate Eddy Dissipation Rates via different techniques
    - Time-series of Doppler velocity measurements from Cloud Radars
    - Single radar Doppler spectrum width measurements in precipitation-free regions
    - Dual radar Doppler spectrum width measurements in any cloud condition

Case Study

- 15th November 2012 Cape Code





Instrumentation

- Vertical structure of Doppler Velocity and Spectrum Width

W-Band Radar → ARM Cloud Radar (WACR)

W-Band Radar → Scanning ARM Cloud Radar (W-SACR)

- Doppler Velocity at Cloud Base

→ Doppler Lidar

- Cloud Base Height

→ Ceilometer

Methodology I

- Power Spectra Retrieval

In the case of homogeneous and isotropic turbulence, the Kolmogorov hypothesis states that within the inertial subrange the statistical representation of the turbulent energy spectrum S(k) is given by

$$S(f) = \alpha \varepsilon^{-2/3} \left(\frac{u}{2\pi} \right)^{2/3} f^{-5/3}$$

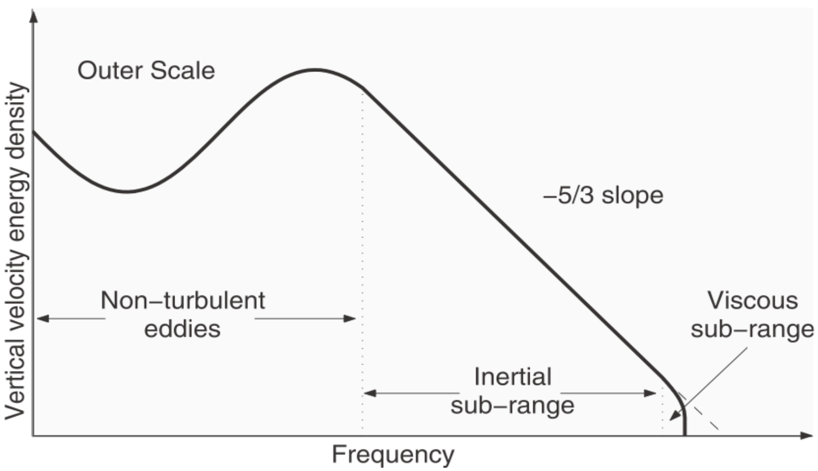
α: Kolmogorov constant

ε : dissipation rate

u : environment wind

Methodology I

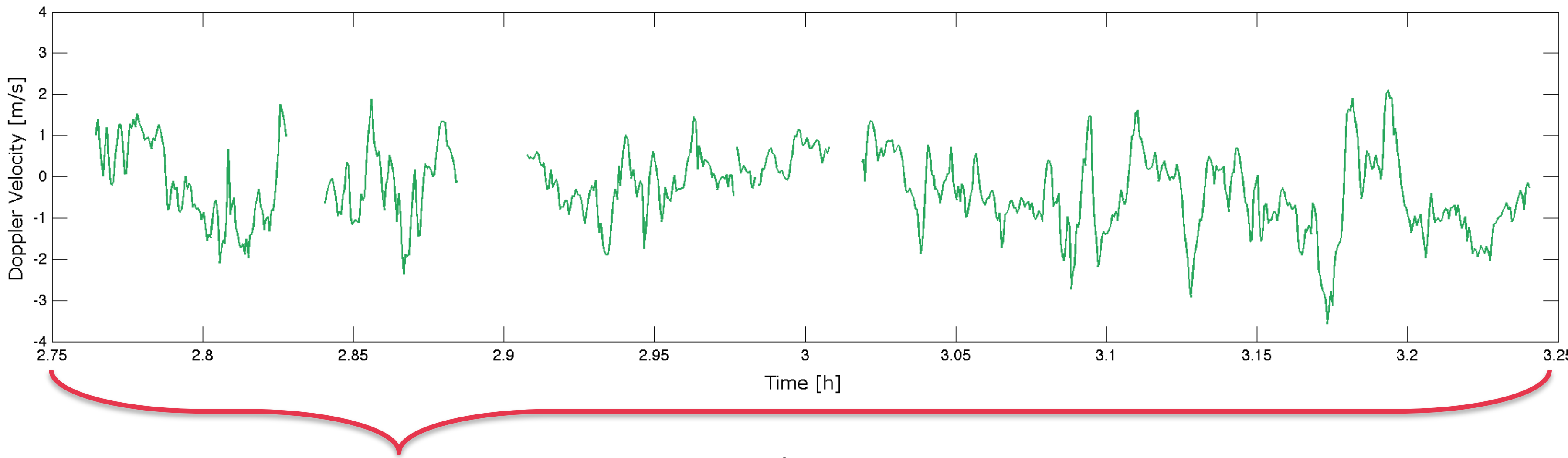
- Power Spectra Retrieval



Large eddies dominate the production of TKE, the size of eddies decreases in the inertial sub-range until the length scales are small enough for molecular diffusion to dissipate kinetic energy into heat in the viscous sub-range

If an observed spectra fit the -5/3 power law then the portion of the spectrum lies within the inertial sub-range and thus EDR can be estimated

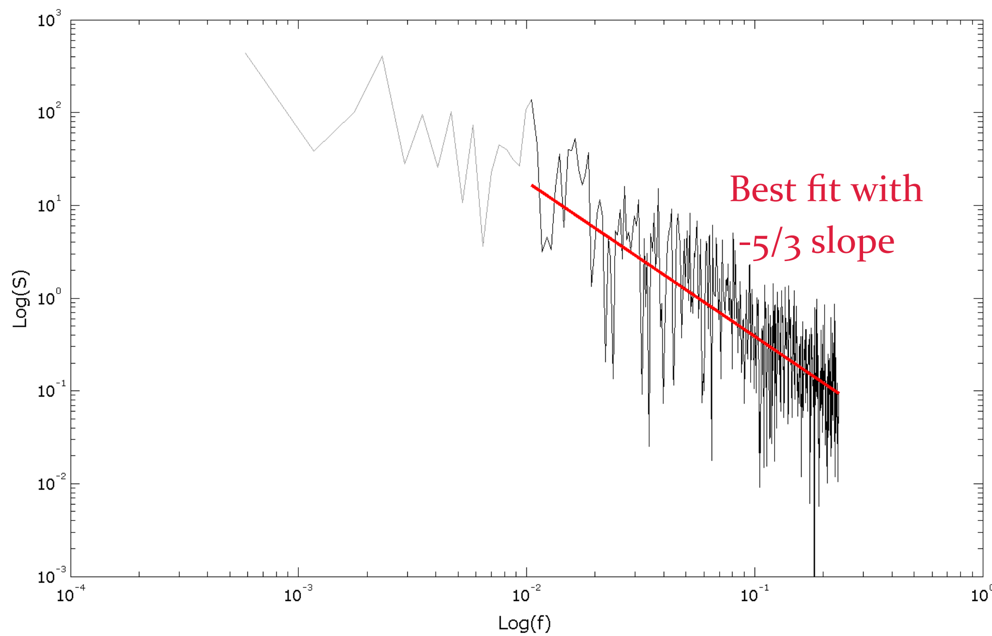
Power Spectra Retrieval



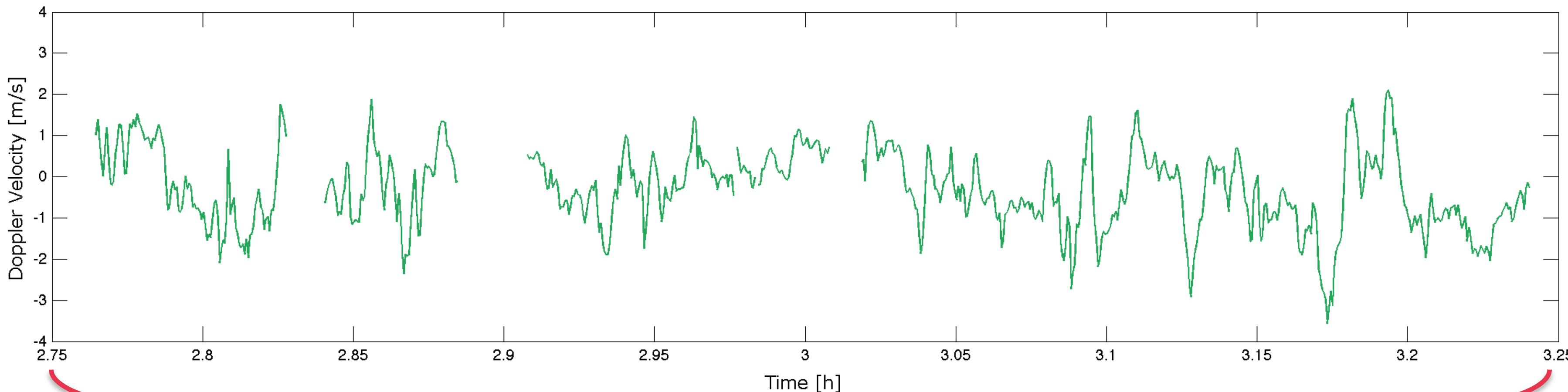
800 samples ~ 30 minute data

$$\varepsilon = \left(\frac{10^b}{\alpha}\right)^{-3/2}\left(\frac{u}{2\pi}\right)$$

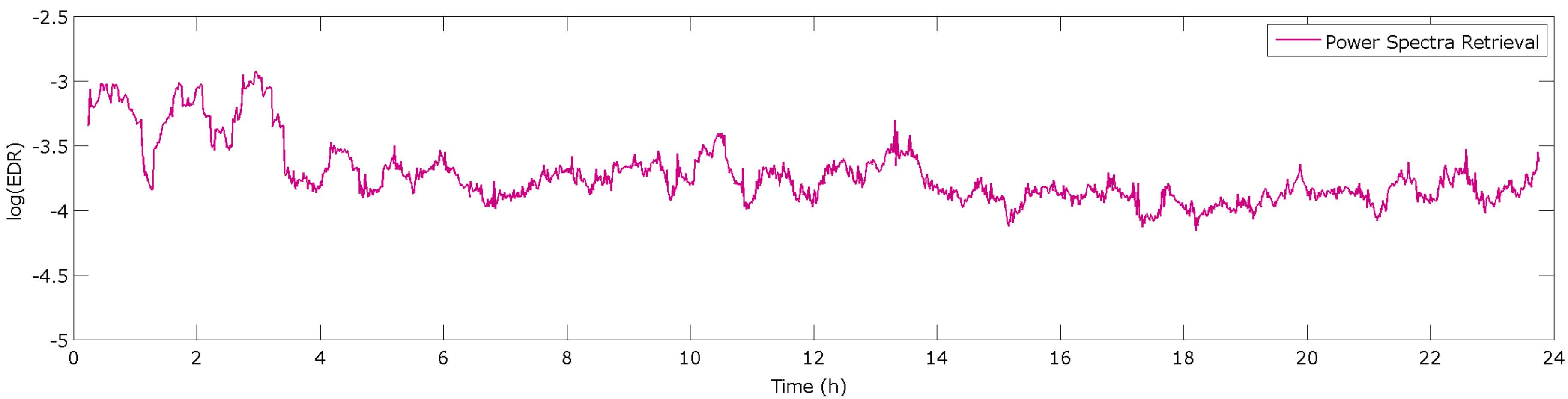
u: advection velocity; α: Kolmogorov constant



Power Spectra Retrieval



Applying a moving average of 25 points for the 24-hour period



Methodology II

- Single Radar Spectral Width Retrieval

Eddy dissipation rate can be estimated via the Doppler spectral width. From Doviak and Zrnic (2006) the total spectrum variance (σ^2) can be determined by

$$\sigma^2 = \sigma_s{}^2 + \sigma_d{}^2 + \sigma_t{}^2 + \sigma_\alpha{}^2 + \sigma_o{}^2$$

where, σ, σ_α, σ_d, σ_o, and σ_t, represent the variance due to mean wind shear within the scattering volume, hydrometeor's terminal velocity spread, air turbulence, antenna rotation, and hydrometer's oscillation and/or wobbling respectably

Methodology II

- Single Radar Spectral Width Retrieval

In non-precipitating stratocumulus clouds the following assumptions are needed to estimate the eddy dissipation rate for a single frequency radar system:

- The spread of the terminal velocities of hydrometeors is small thus σ_d^2 can be neglected
- The contribution due to hydrometer's oscillation/wobbling is small thus σ_o^2 can be neglected
- The radar beam is stationary thus the variance due to antenna rotation (σ_α^2) can be neglected

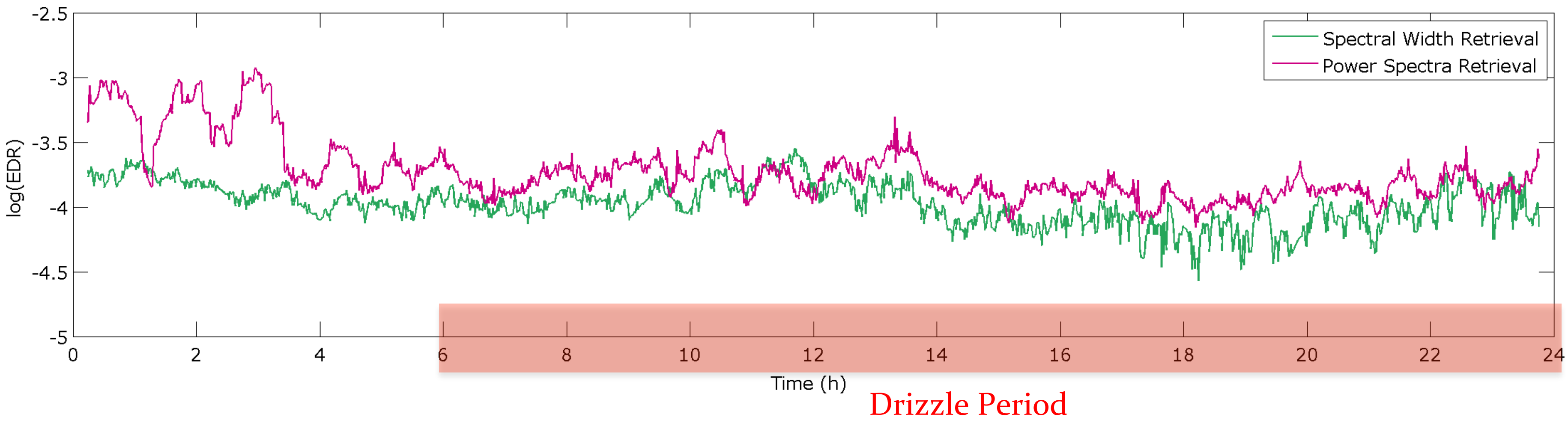
$$\sigma^2 \approx \sigma_s^2 + \sigma_t^2$$

Function of

- Environment Variables (wind magnitude and vertical and horizontal shear of vertical wind
- Radar Parameters (frequency, beamwidth, and Pulse Length)

Single Radar Spectral Width Retrieval

- Comparison of 24-hour EDR retrievals from WACR



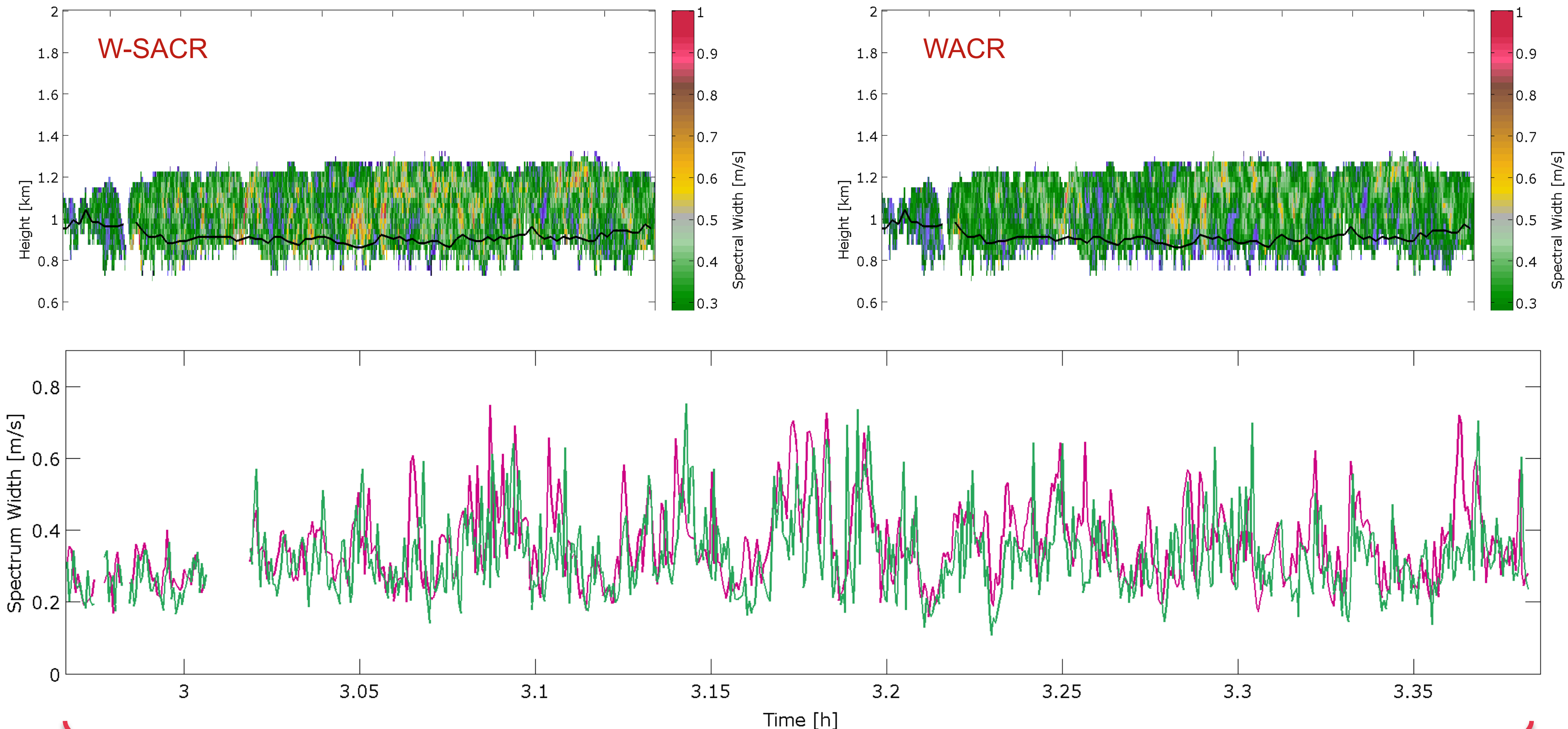
Methodology III

- ## Dual-Frequency Spectral Width Retrieval

With a dual radar system under the assumption that both radars will be influence in a similar way by the drop fall velocity (drop size distribution is independent of the radar) then less assumptions are needed in the calculation of eddy dissipation rates and the results could be extended to more complex cases and not only to non-precipitating clouds.

$$\sigma_1^2 = \sigma_2^2 \qquad \sigma_{d_1}^2 = \sigma_{d_2}^2 \qquad \varepsilon_1 = \varepsilon_2$$

Dual-Radar Spectral Width Retrieval

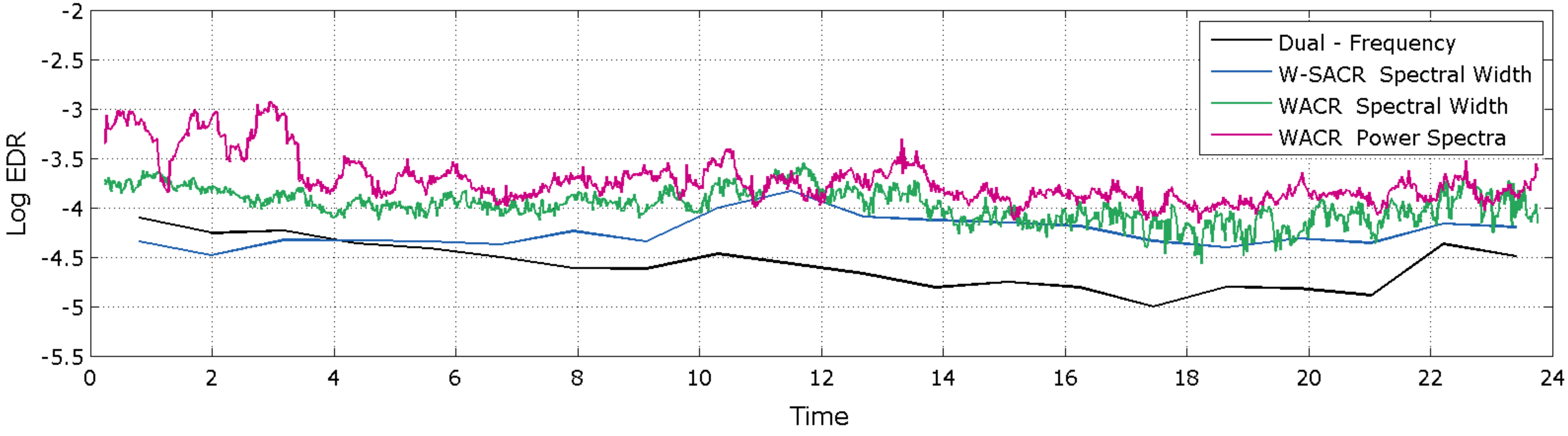


~ 700 samples

~ 25 minute each sampling mode

Comparison between all methodologies

- Diurnal variation of the 3 methods



Summary and Conclusions

- There is some coherency in structure of the diurnal variation of different Eddy Dissipation Rate (EDR) retrievals techniques
- EDR from Single-Frequency and Power Spectra techniques seems converge to the same result
- EDR from Dual-Frequency Technique tends to present lower values, probably due to an underestimation of the DSD effect in the previous techniques

Summary and Conclusions

- Further analysis needs to be performed to generate an objective validation of the techniques
- Apply these techniques to other fix ARM sites and future AMS deployments
- Comparison with in-situ data is needed for a better analysis

Thank you for your attention!