

**Tube Attenuation and Flux  
Corrections: Results from the Duke  
Forest AmeriFlux Site**

by

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# Introduction

When utilizing the eddy-covariance technique with concentration measurements by an infrared gas analyzer, two considerations must be accounted for:

1. The lag between concentration measurements and vertical velocity
2. Sampling tube attenuation of turbulent fluctuations.

## Lag Time Estimation:

- Approach 1: Theoretical

If sampling flow rate  $Q$ , tube length  $L$ ,  
internal tube diameter  $d$ , then

$$\text{Travel Time} = \frac{L}{U}$$

$$U = \frac{Q}{\frac{\pi d^2}{4}}$$

Usually, such calculation quantify the lower-limit of the lag time because of finite cell size in analyzer, etc..

- Approach 2: Cross-Correlation

For two flow variables  $x$ ,  $y$  the cross correlation at lag  $\tau$  is defined by

$$CC(x, y, \tau) = \frac{\frac{1}{N} \sum_{i=1}^N x'(i) y'(i + \tau)}{\sigma_x \sigma_y}$$

where:

$$x'(i) = x(i) - \frac{1}{N} \sum_{j=1}^N x(j)$$

$$y'(i) = y(i) - \frac{1}{N} \sum_{j=1}^N y(j)$$

Idea: Find the lag  $\tau_{opt}$  that maximizes

$CC(x, y, \tau)$ .

Several alternatives: Cross-

Correlation between

1) Sonic vertical velocity ( $w$ ) and

Licor H<sub>2</sub>O signal ( $q_l$ ).

2) Sonic vertical velocity ( $w$ ) and

Licor CO<sub>2</sub> signal ( $co_2l$ ).

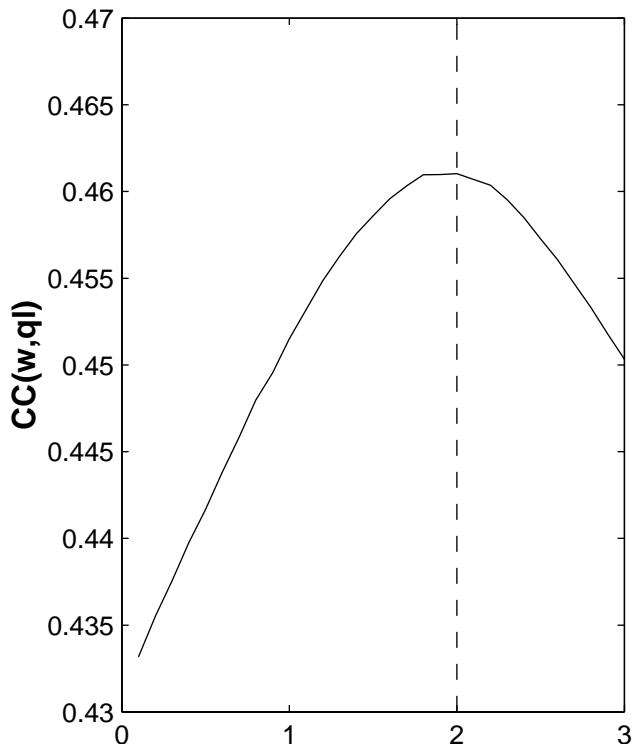
3) Sonic Temperature ( $T$ ) and Licor

H<sub>2</sub>O signal.

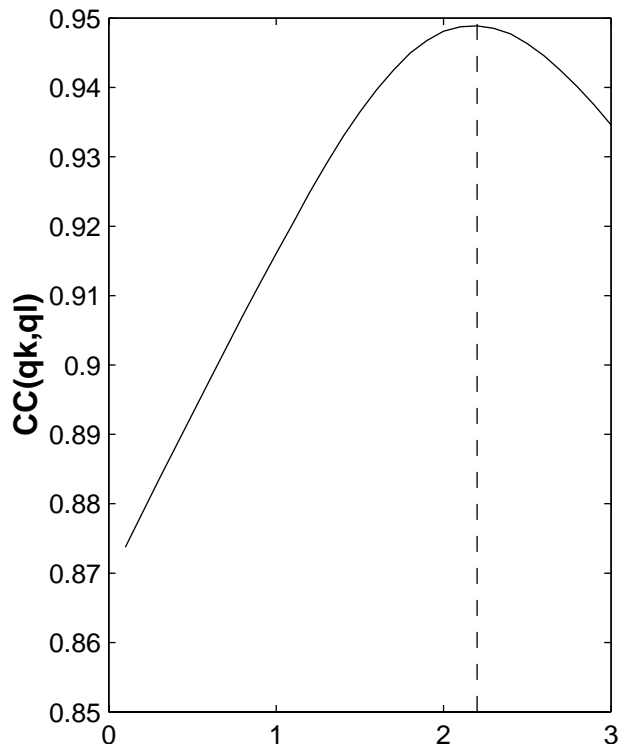
4) Krypton Hygrometer ( $q_k$ ) and Licor

H<sub>2</sub>O signal.

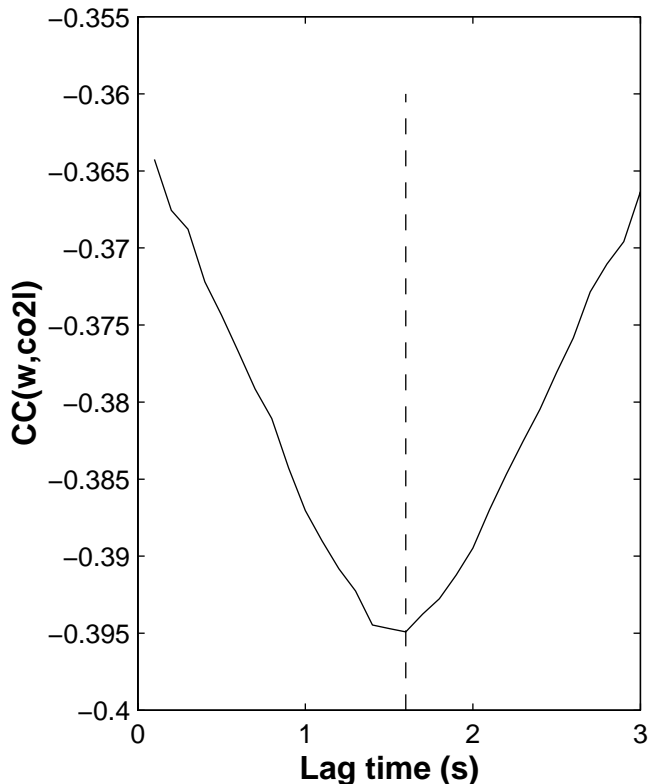
**Cross Correlation: w/Licor**



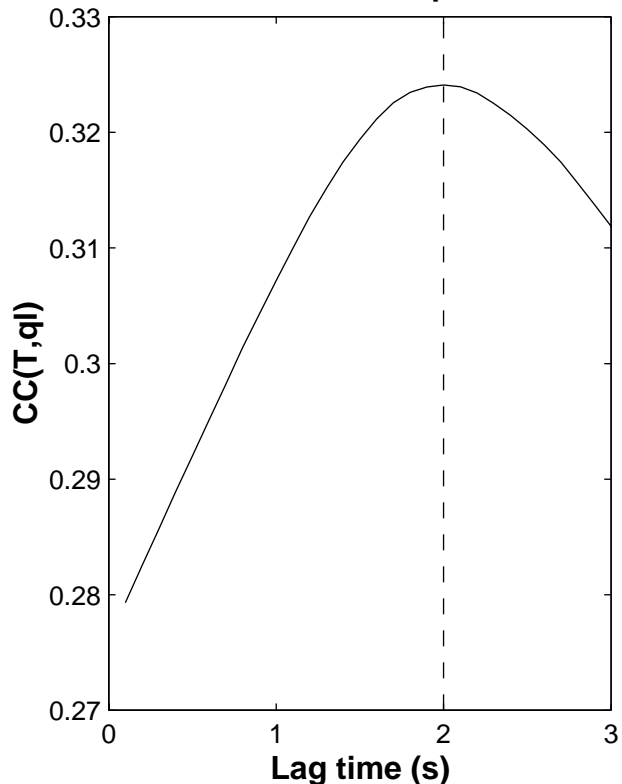
**Cross Correlation: KH2O/Licor**



**Cross Correlation: w/CO2 Licor**



**Cross Correlation: Temperature/Licor**



## Summary of Lag Analysis:

Theoretical	1.2 s
CC(w,ql)	2.0 s
CC(w,CO2 - licor)	1.6 s
CC(qk, ql)	2.2 s
CC(T, ql)	2.0 s

# Tube Attenuation Correction:

Function of Q, L, and d

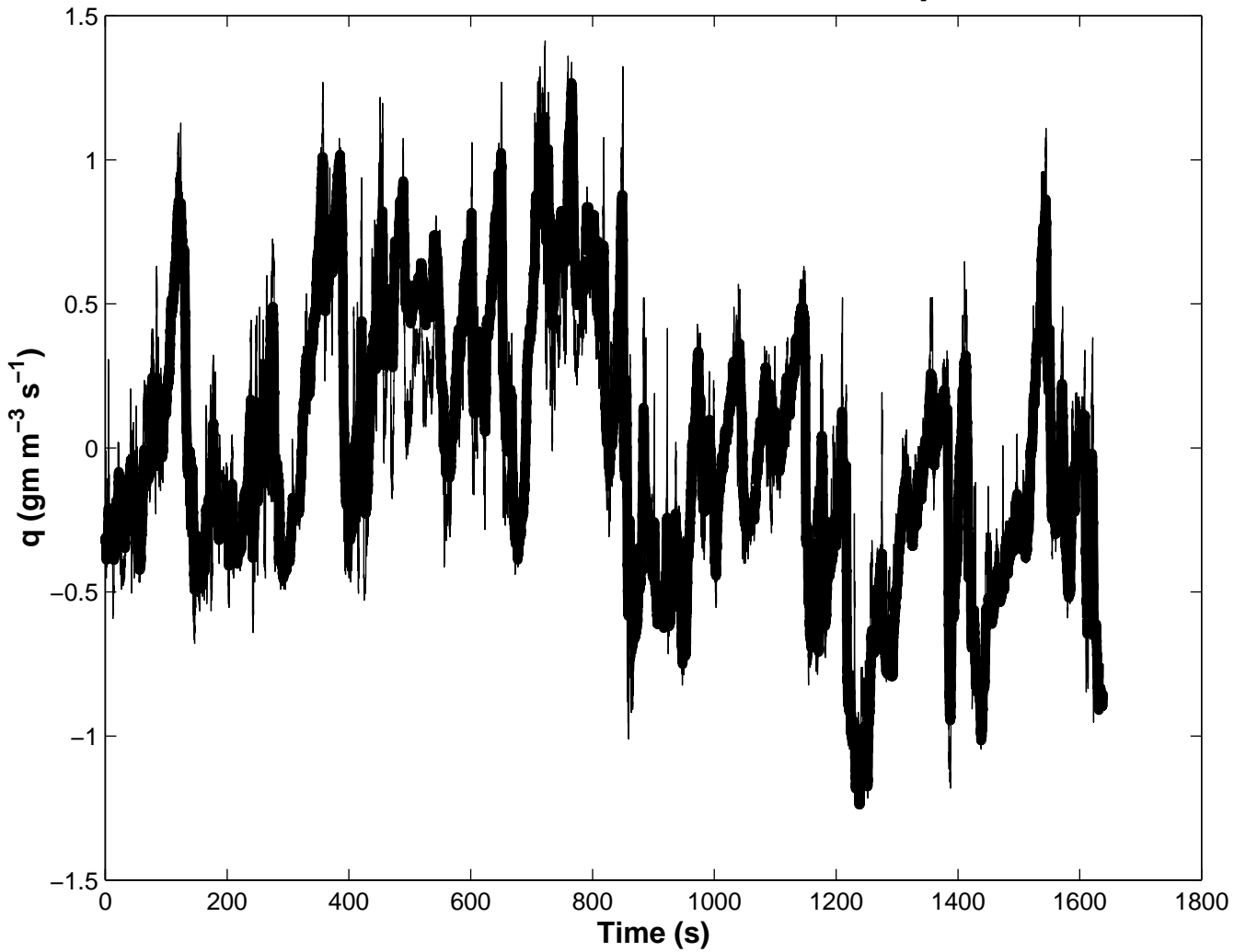
Frequency  $f$  after which attenuation is critical (Lenschow and Raupach, 1991):

$$f = n_o \left( \frac{d}{2} L \right)^{-0.5}$$

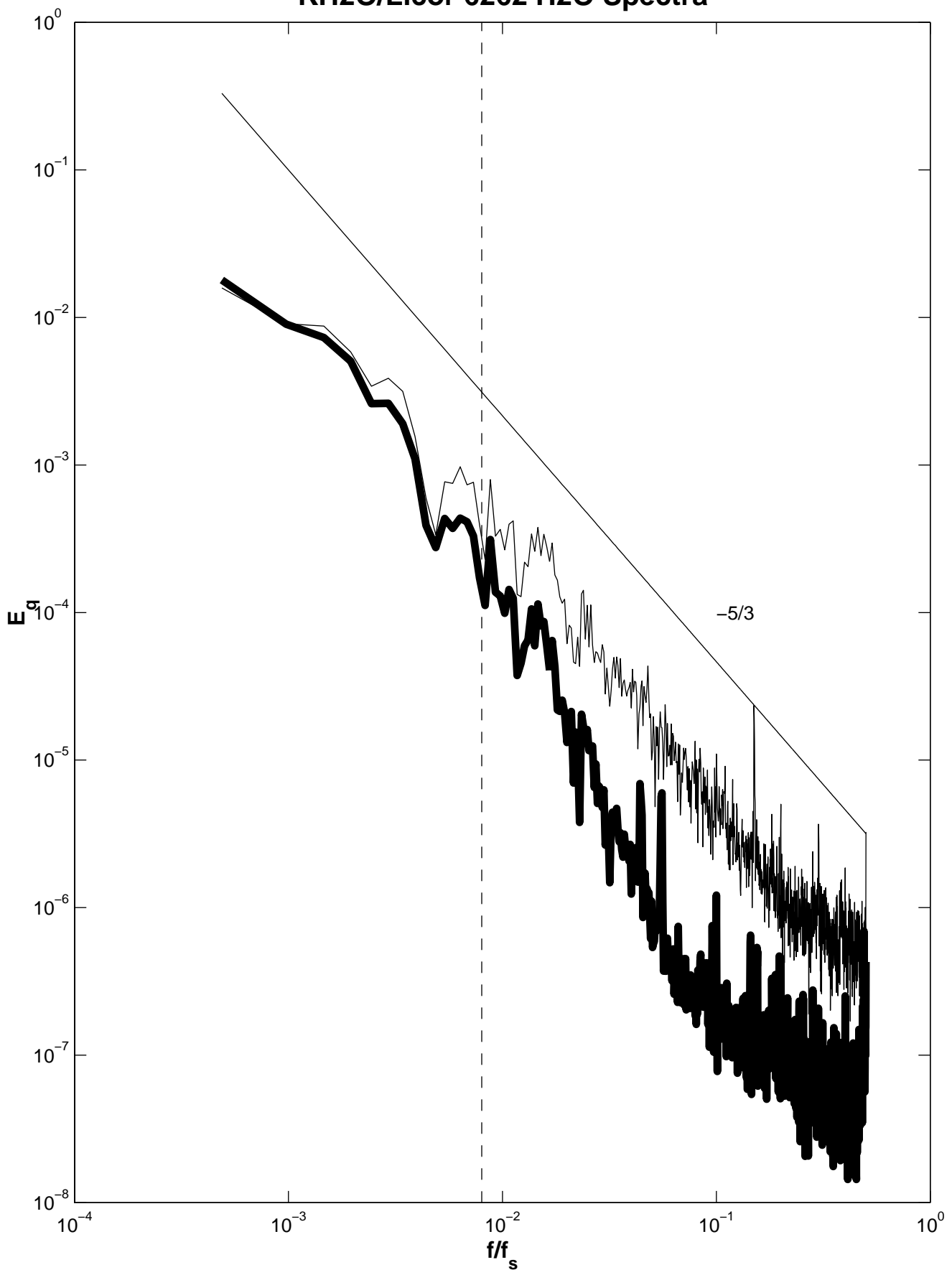
Massman (1991):

$$n_o = f(\text{Re})$$

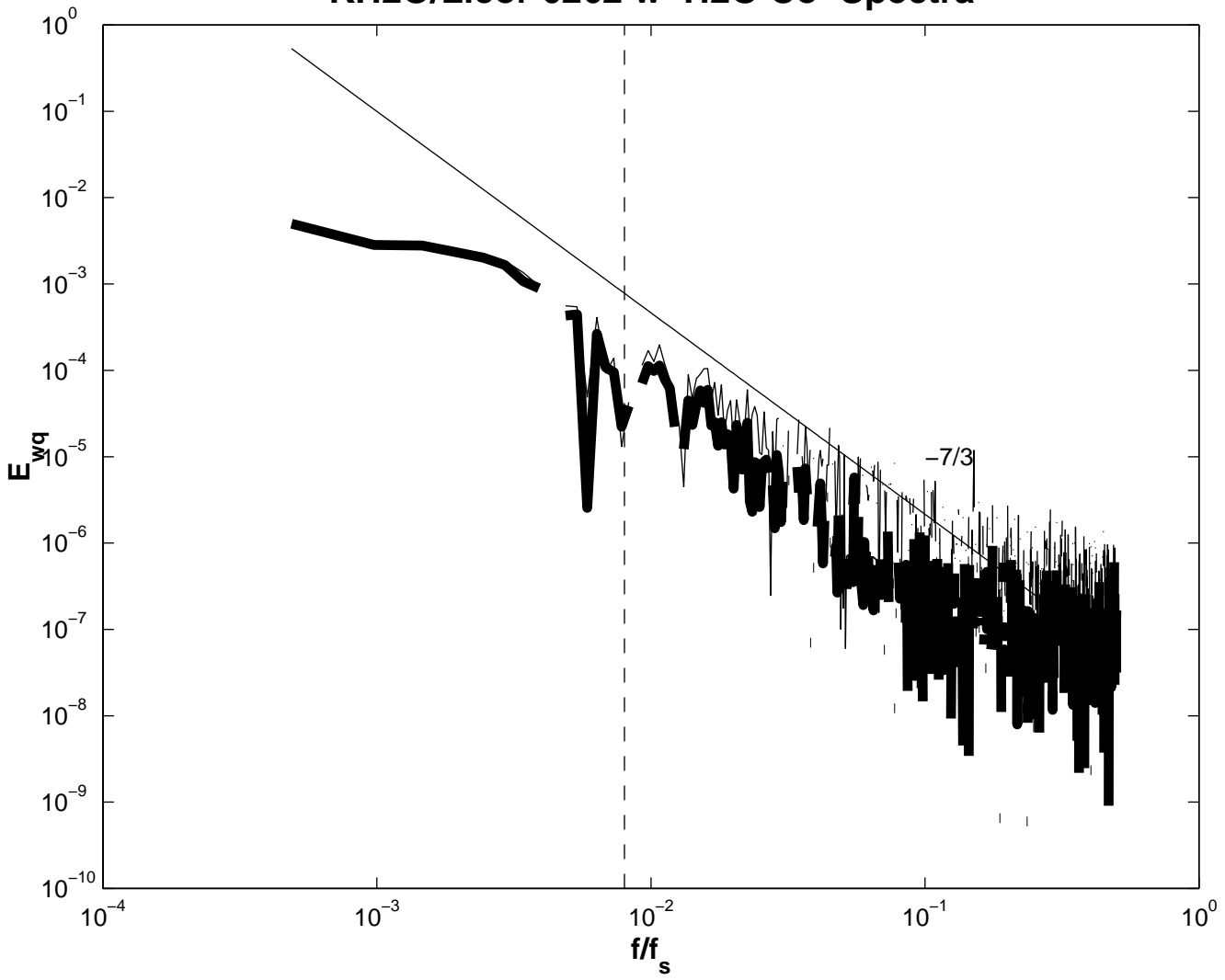
# KH2O/Licor 6262 H2O Fluctuation Comparisons



# KH2O/Licor 6262 H2O Spectra



# KH2O/Licor 6262 w-H2O Co-Spectra



Applications:

The Lenschow-Raupach-Massman (1991) approach predicts well the threshold frequency at which tube attenuation becomes critical.

# Summary of Results

## Co-variances:

KH <sub>2</sub> O - LE	219.4 W m <sup>-2</sup>
Unadjusted LE	206.5 W m <sup>-2</sup>
Lag Adjusted LE	220.1 W m <sup>-2</sup>
Lag and Spectral LE	221.1 W m <sup>-2</sup>

## Variances

Krypton	0.466 gm m <sup>-3</sup>
Licor	0.459 gm m <sup>-3</sup>

## Conclusions:

- Lag Correction (~6%) more important than attenuation correction for scalar flux (0.5%).
- Separate correction for H<sub>2</sub>O and CO<sub>2</sub> signals are needed when maximizing cross correlation with  $w$  (lags differed by 0.4 s).
- Variances are much more impacted by tube attenuation than co-variances.