Extinction Spectroscopy for Characterization of Particulate Matter Size and Concentration in Fugitive Plumes

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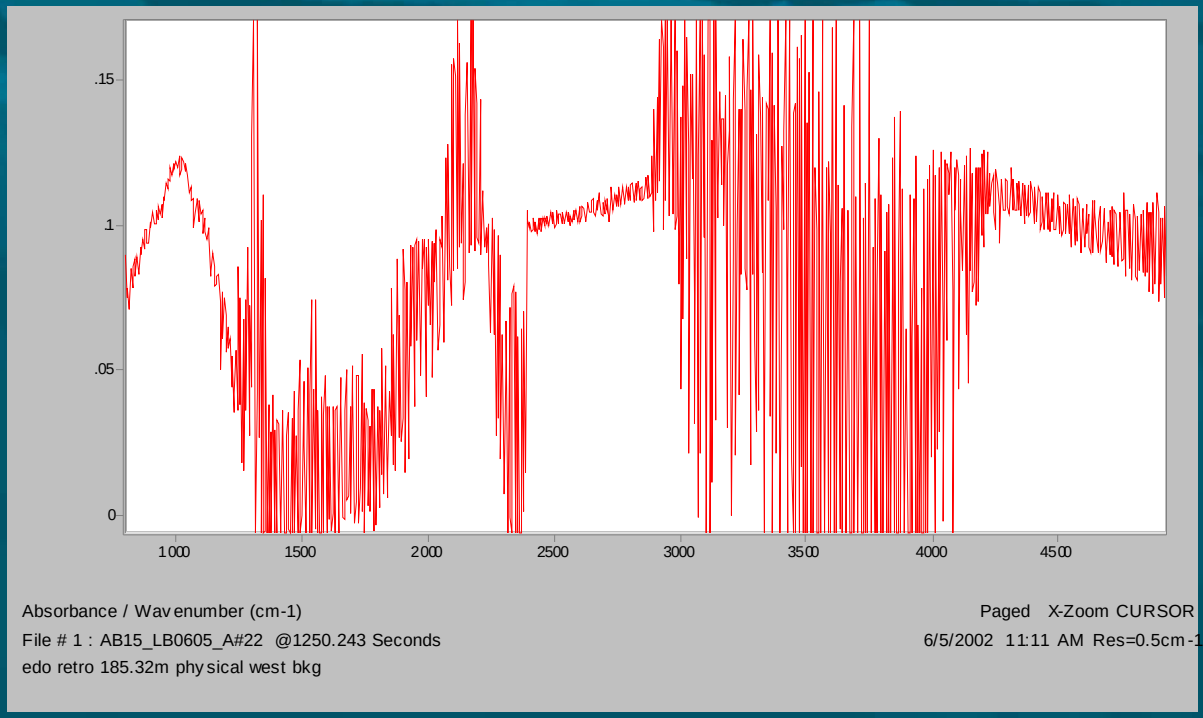
Method Description

- OP-FTIR is an accepted method for gas measurements
- Particulate matter (PM) presence reveals a unique baseline structure (see below)



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Method Description (cont.)

- Baseline structure can be predicted for a given size distribution and optical constants using Mie theory
- We developed an inversion algorithm to retrieve the aerosol size distribution from extinction (scattering+absorption) measurements
- Optical properties (constants) of specific PM may be determined using a bench-top FTIR spectrometer

Mie Theory

Size Parameter α

$$\alpha = \frac{\pi d}{\lambda}$$

d - particle diameter

λ - wavelength

Mie Theory (cont.)

Complex Refractive Index

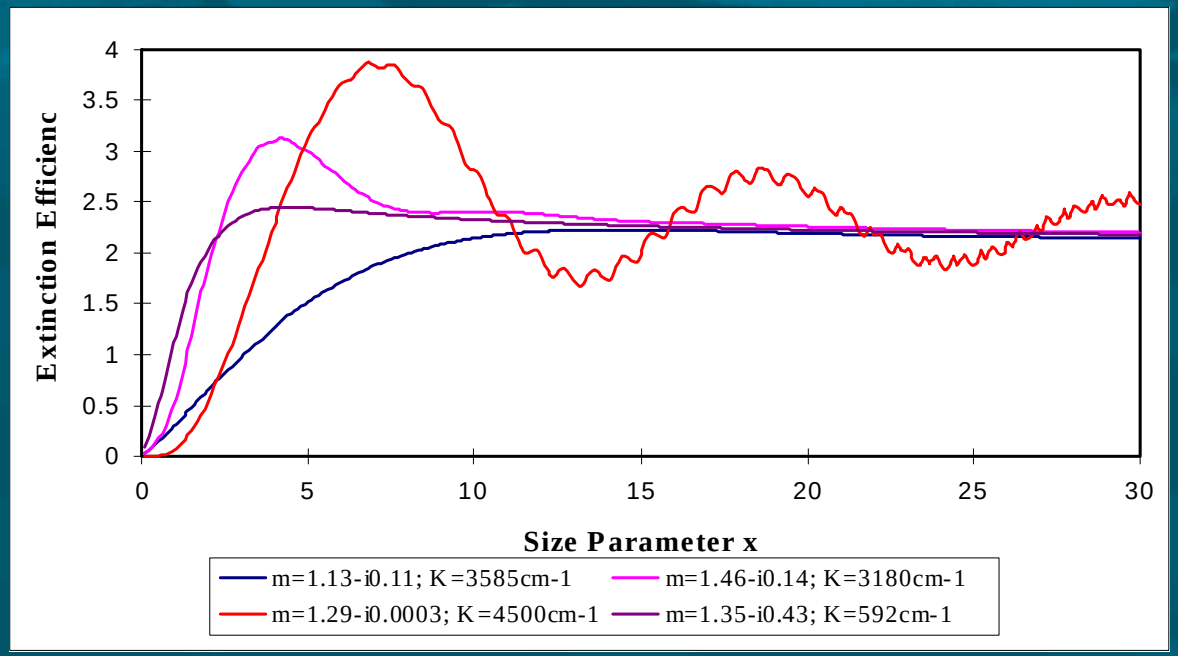
$$m(\lambda) = n(\lambda)\text{-}ik(\lambda)$$

n – scattering term (refraction and reflection)
k – absorption term

Mie Theory (cont.)

Extinction Efficiency:

$$Q_e = \frac{light\ scattered\ and\ absorbed\ by\ particle}{light\ blocked\ by\ particle\ cross\ sectional\ area}$$



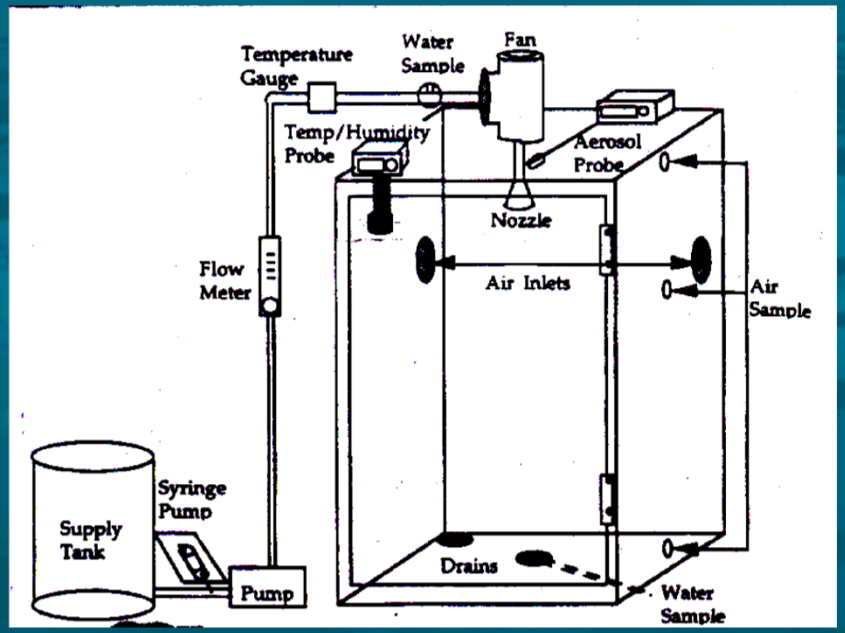
- Extinction efficiency of water in different part of the FTIR spectrum

Extinction as Function of Wavelength

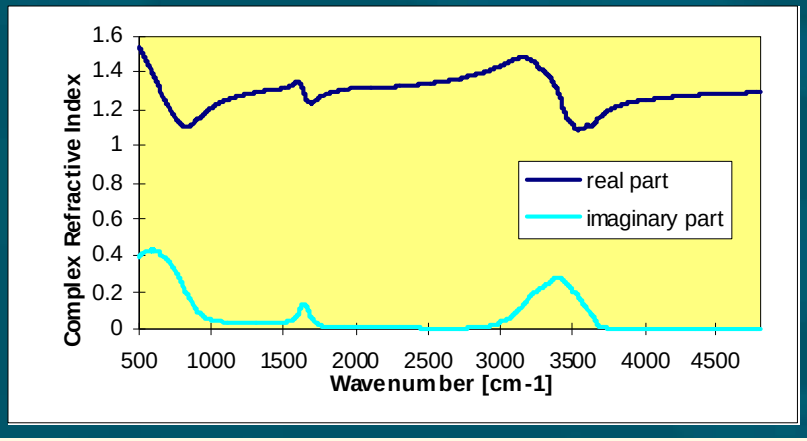
$$\sigma_{e_i} = \frac{\pi}{4} \sum_j Q_{e_{ij}} N_j d_j^2$$

- σ_{e_i} - extinction for the i^{th} wavelength
- $Q_{e_{ij}}$ - dimensionless extinction efficiencies
- N_j - number density for the j^{th} aerosol size
- d_j - is the aerosol j^{th} size class (diameter)

Shower Experiment



- OP-FTIR beam through water condensation aerosol
- Size distribution confirmed by aerosol probe
- Known optical constants (see below)



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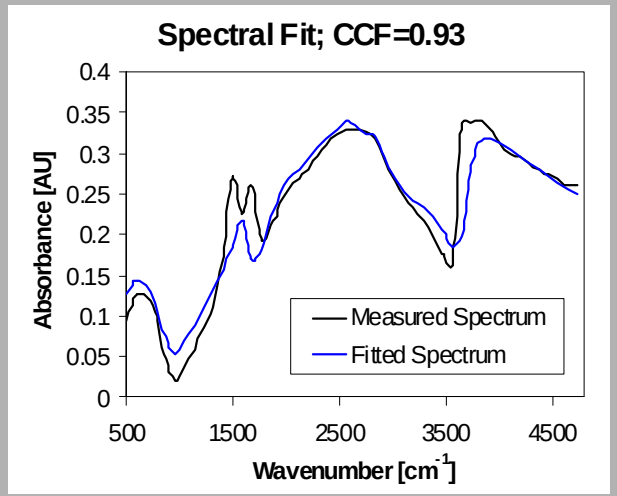
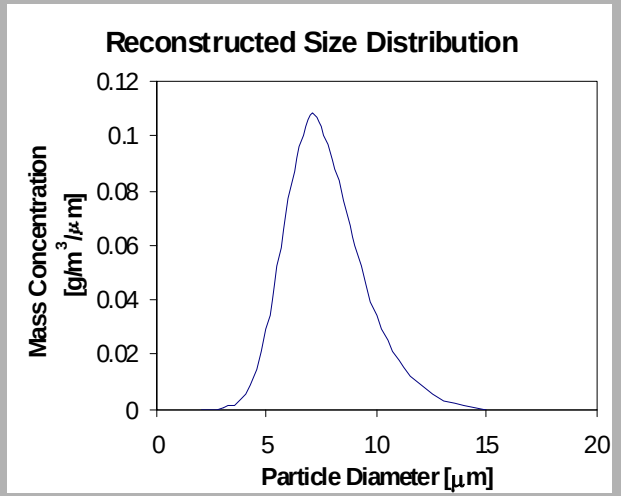
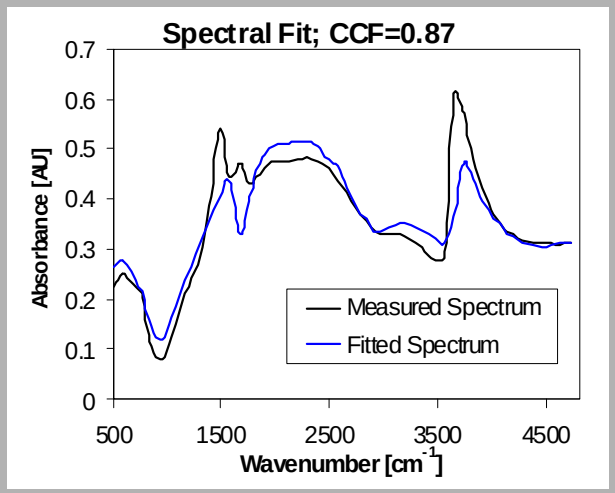
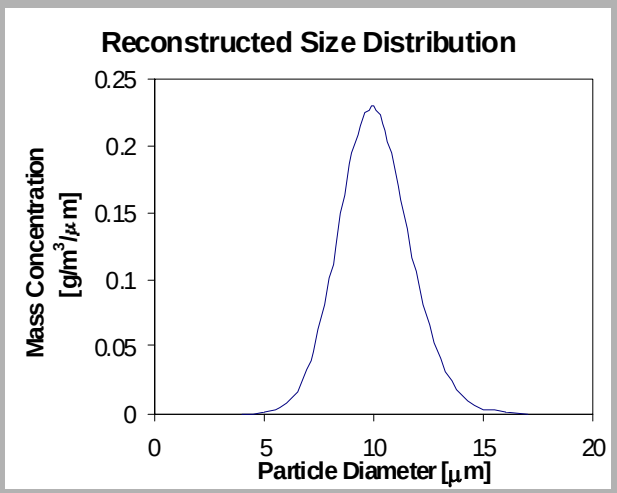
Shower Experiment Results









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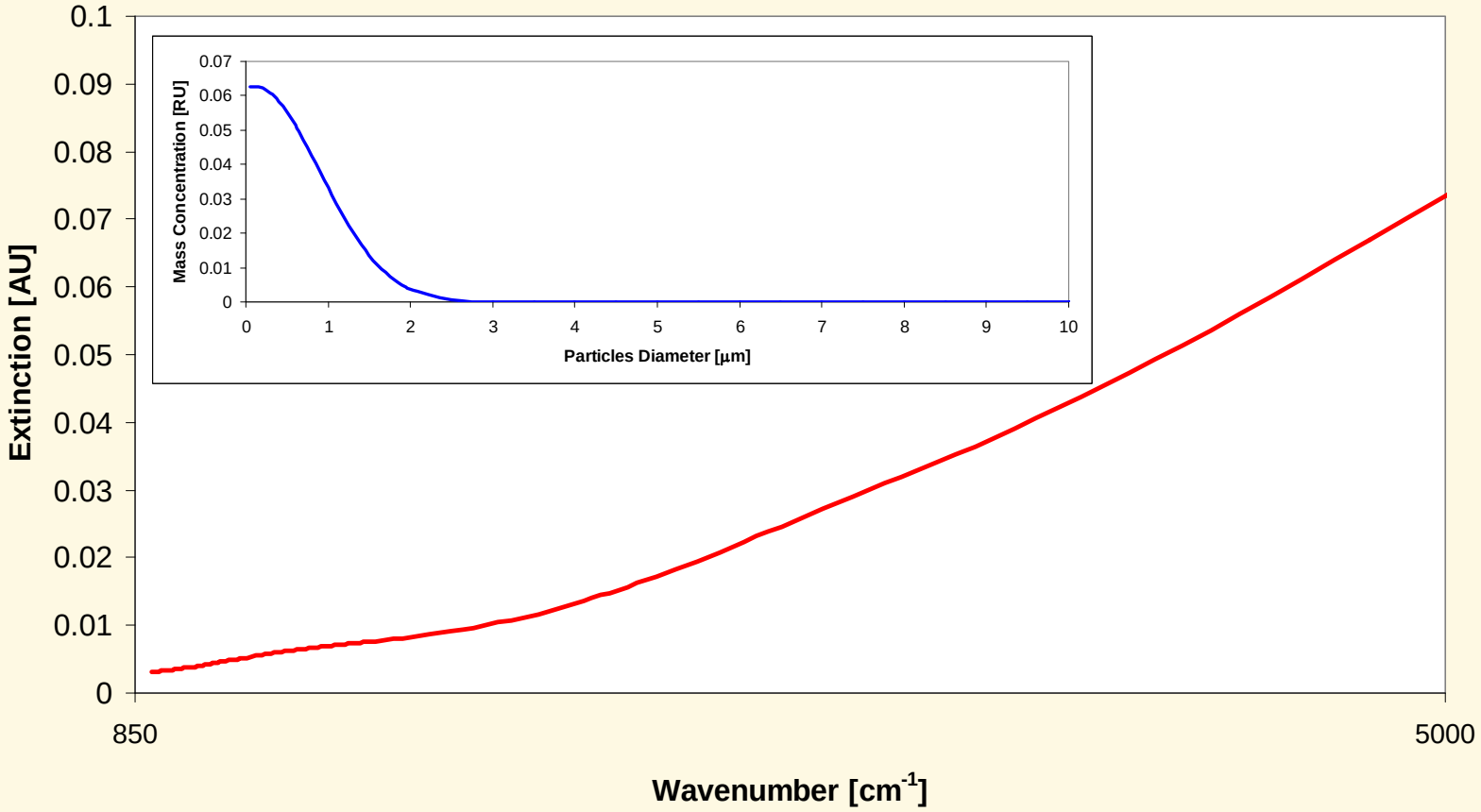
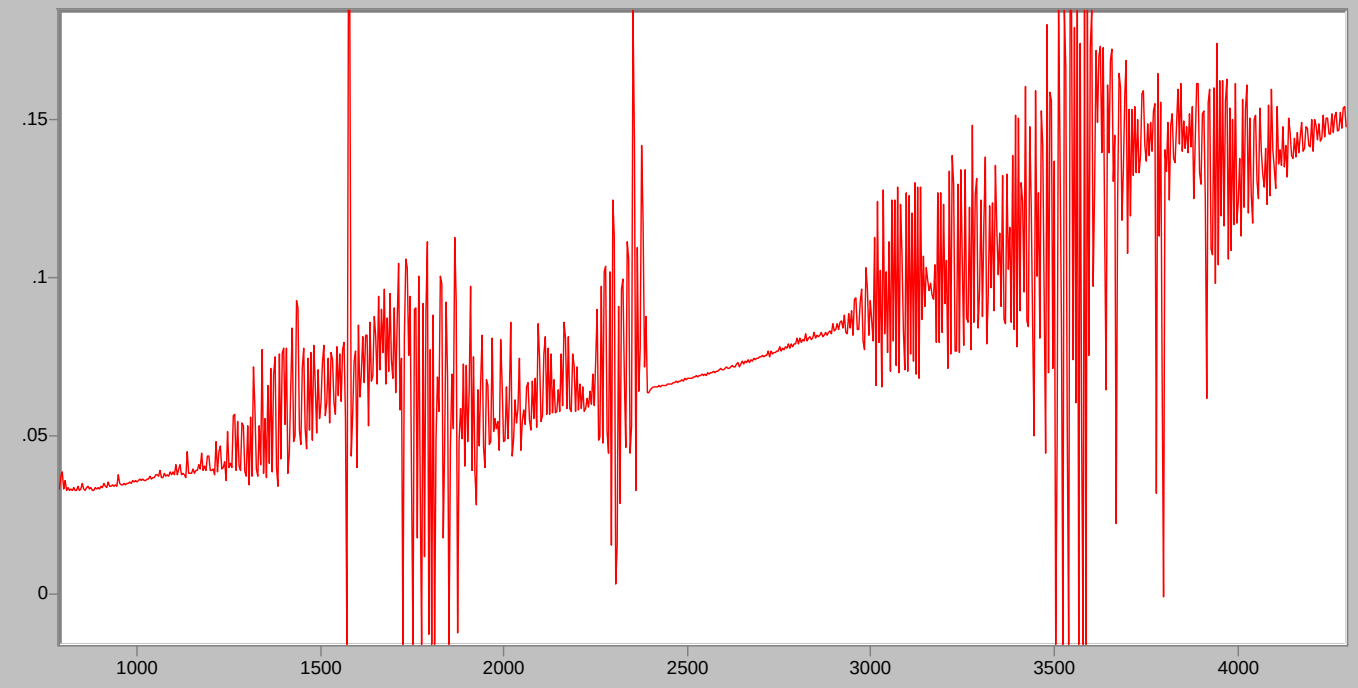
Predicted Smoke Extinction Spectrum



Smoke PM Extinction



Absorbance / Wavenumber (cm-1)

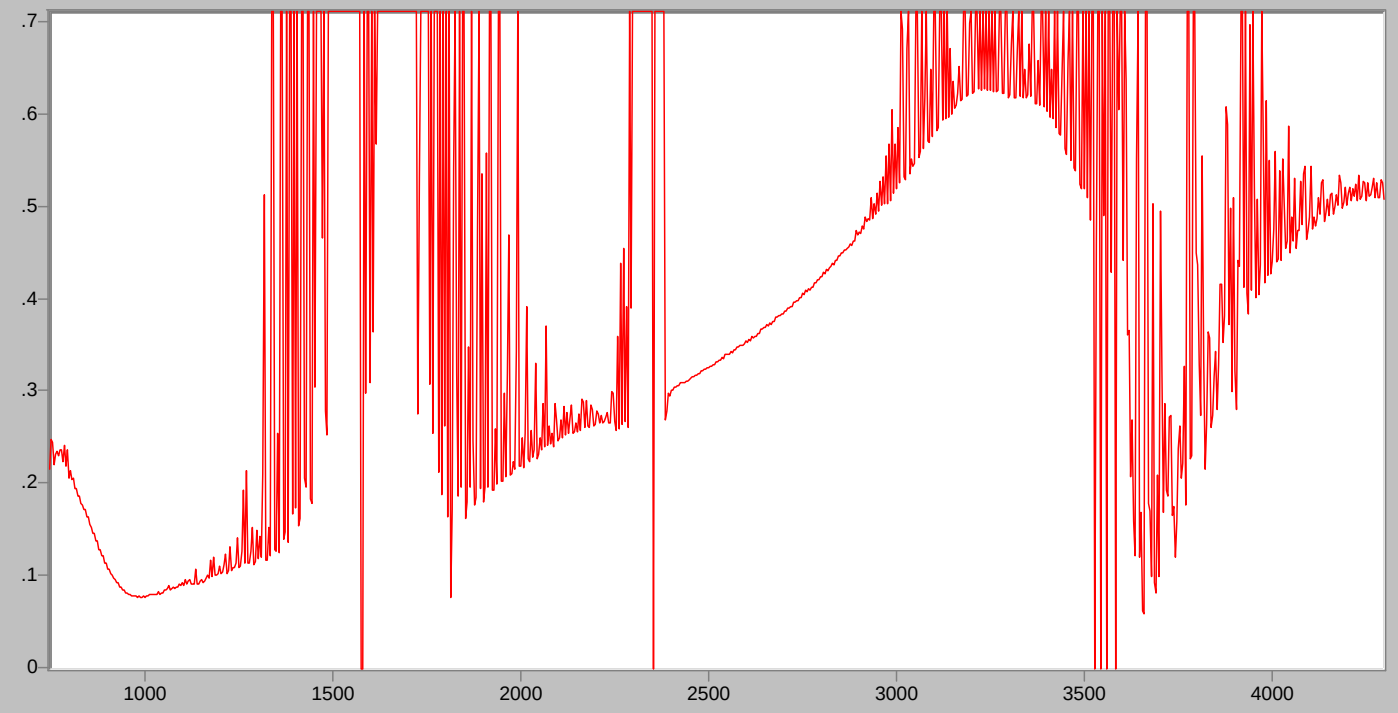
File # 1 : ABS-SMOKE-KAGAN#17 @-5.25 Wavenumber (cm-1)

Burn Test

Paged X-Zoom CURSOR

1/12/2001 9:18 AM Res=None

Water Condensation Aerosol



Absorbance / Wavenumber (cm-1)

File # 1 : ABS-SMOKE-KAGAN#24 @-7.700001 Wavenumber (cm-1)

Burn Test

Paged X-Zoom CURSOR

1/12/2001 9:18 AM Res=None

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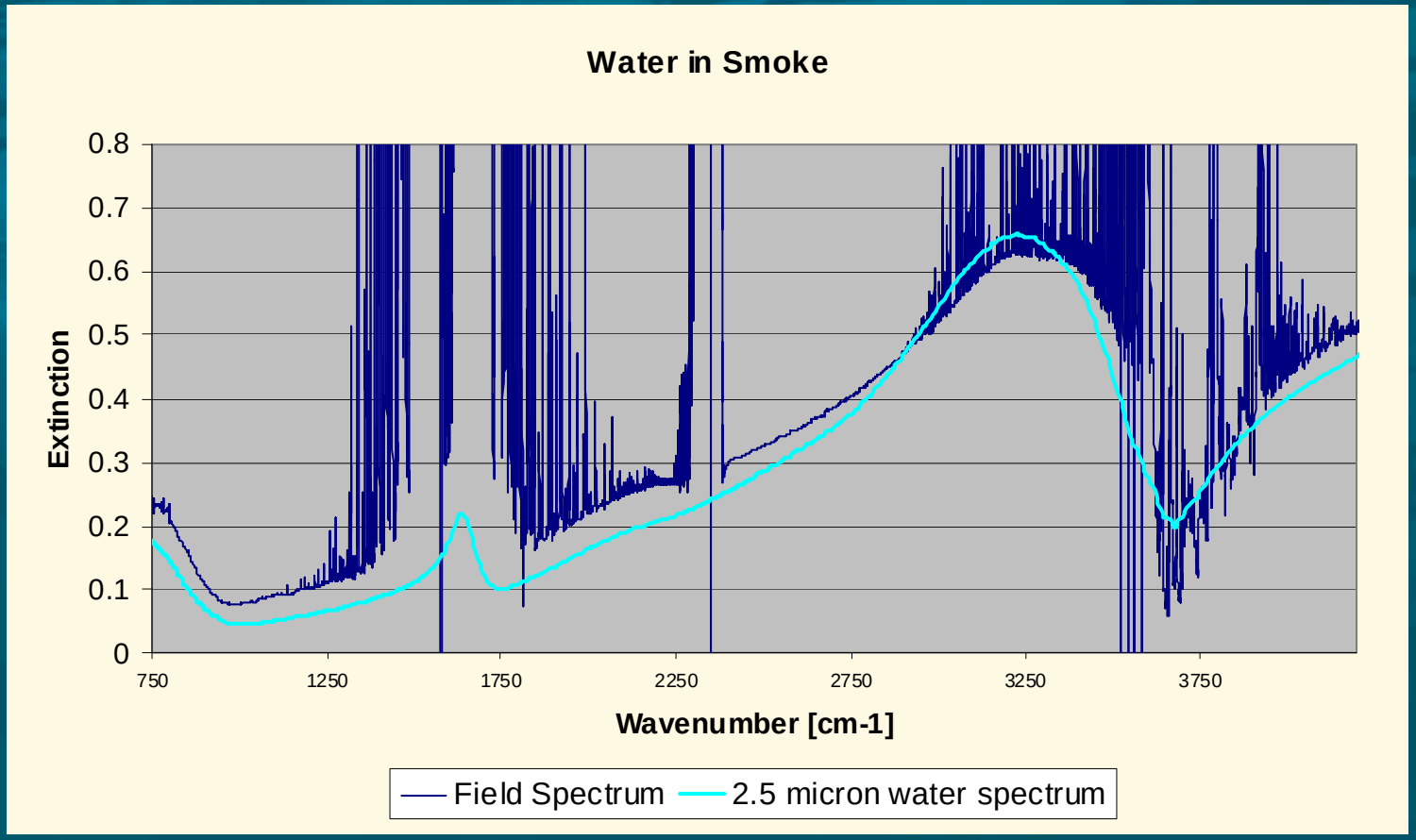
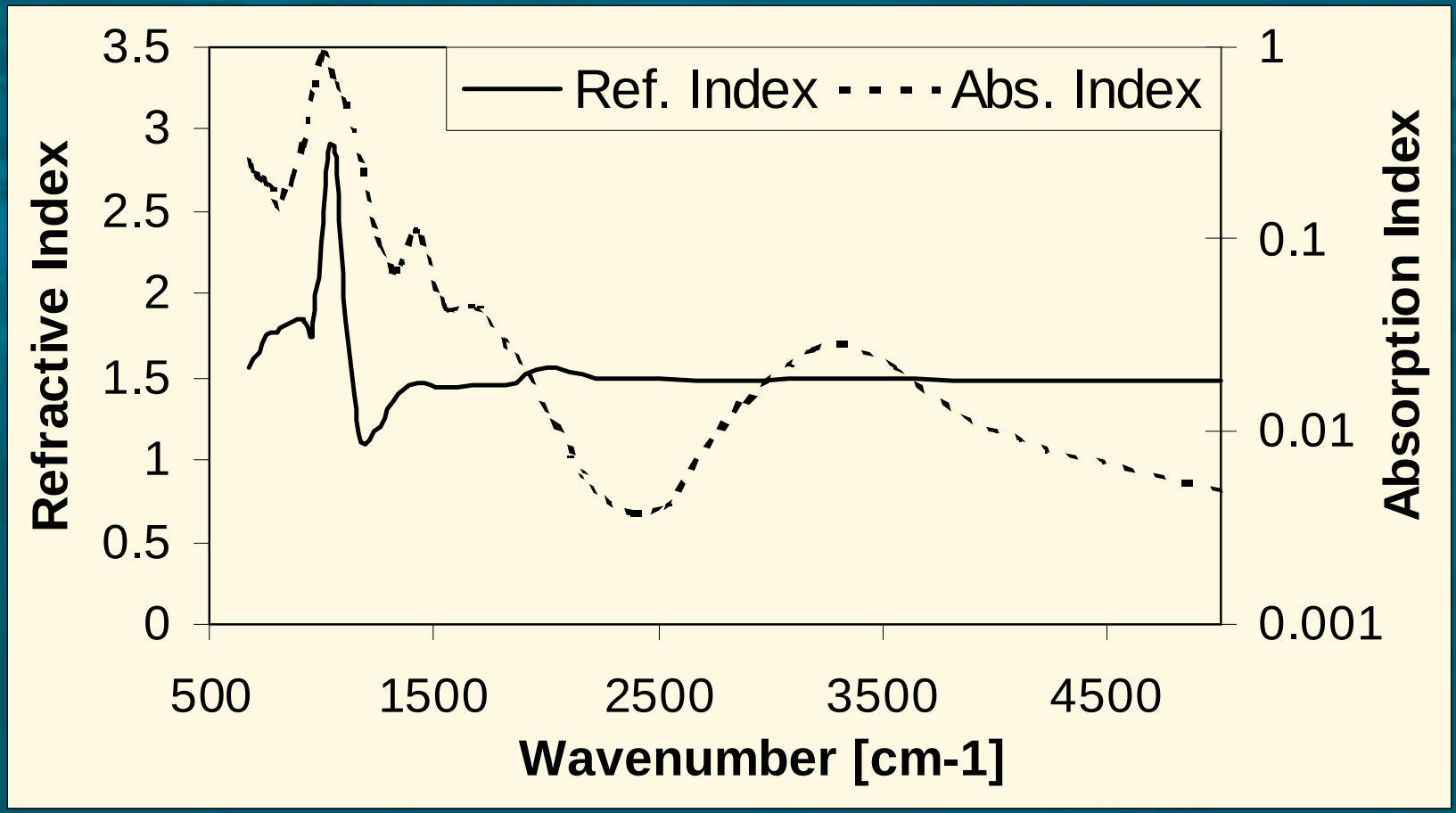
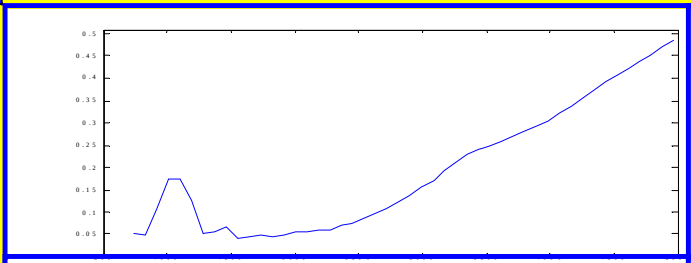
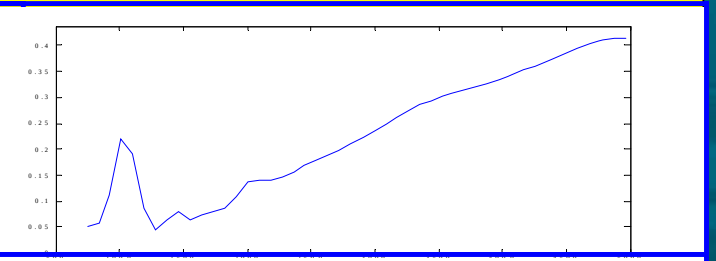
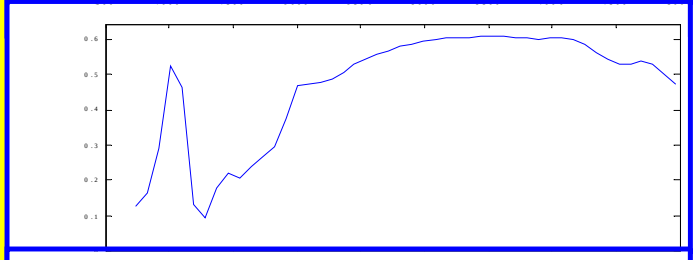
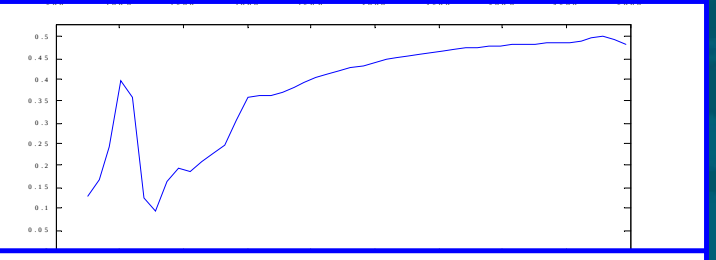
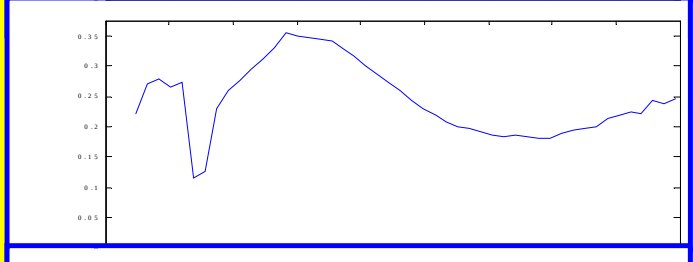
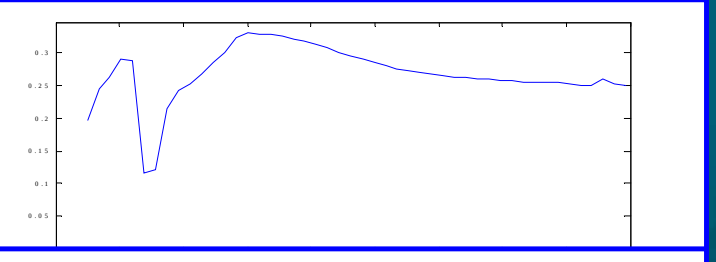
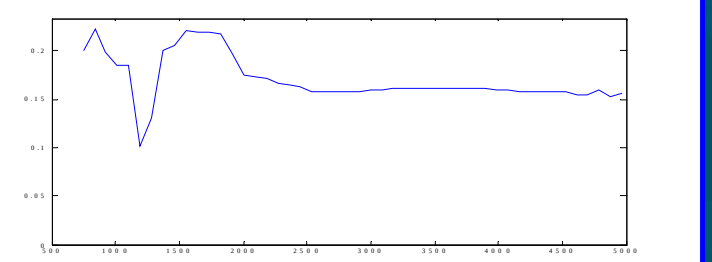
2.5 μm Mean Size; 2 μm SD Gaussian Fit



Sahara Dust Optical Constant



SD [µm] / mean [µm]	0.5	2
1		
4		
7		
10		

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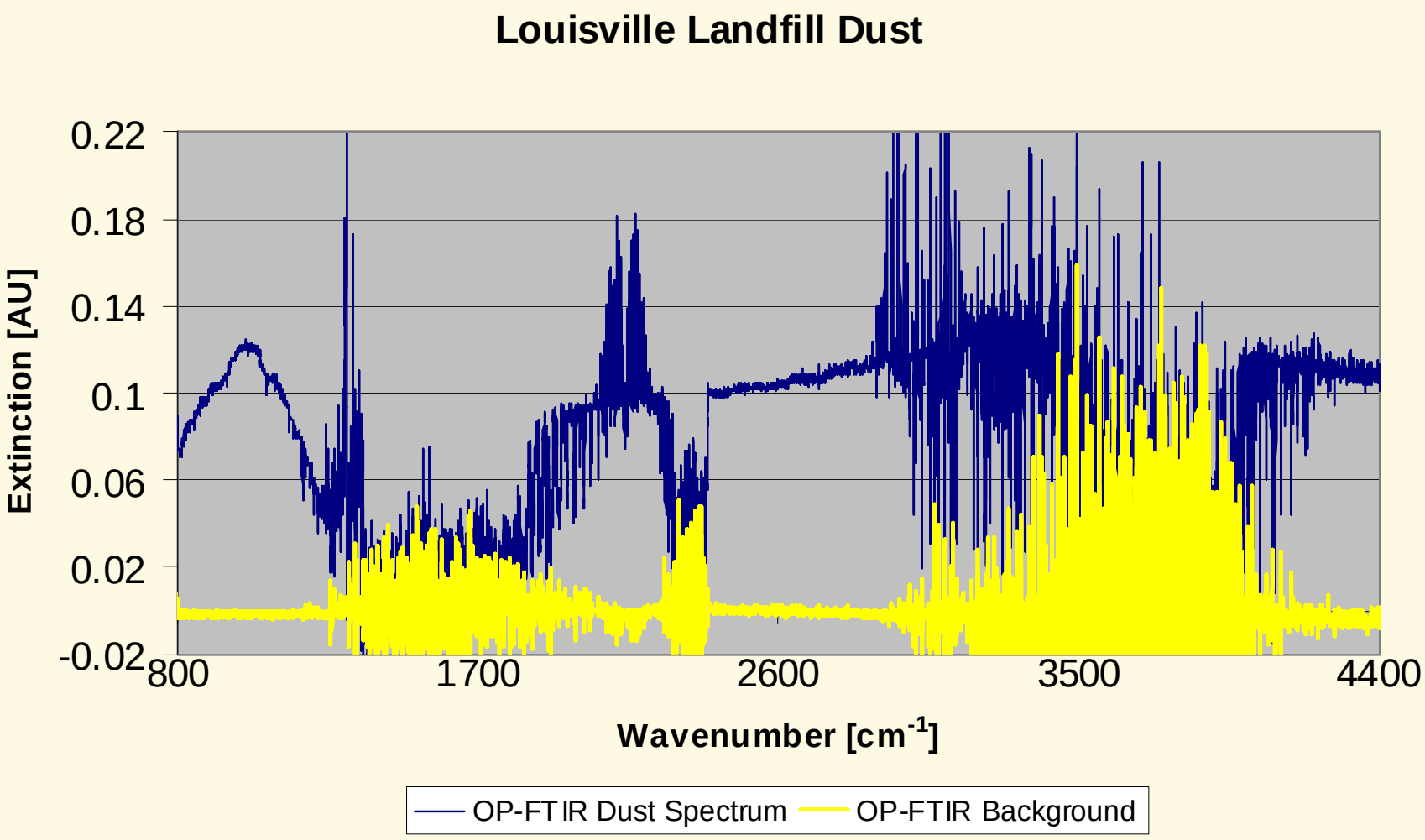
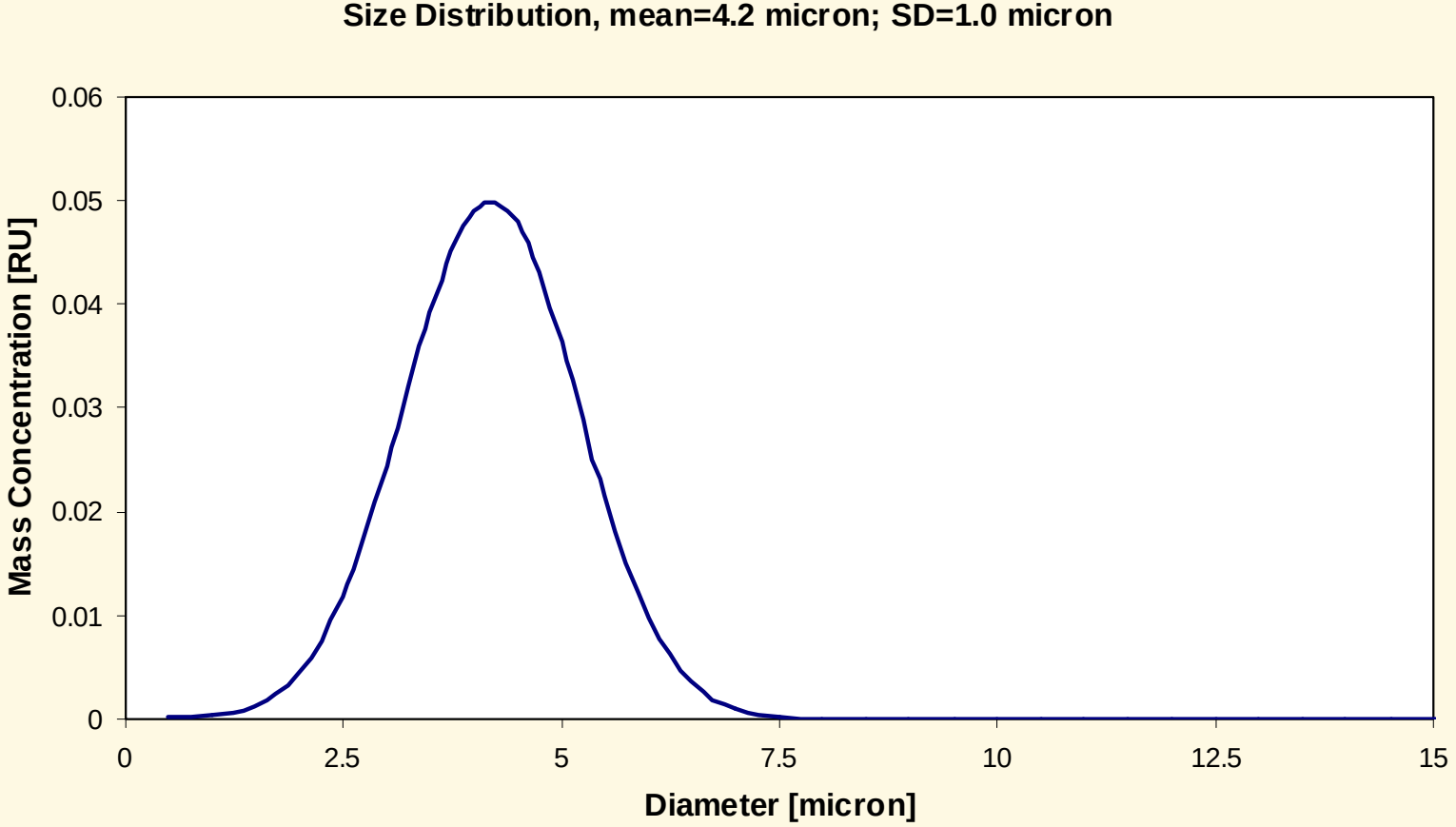
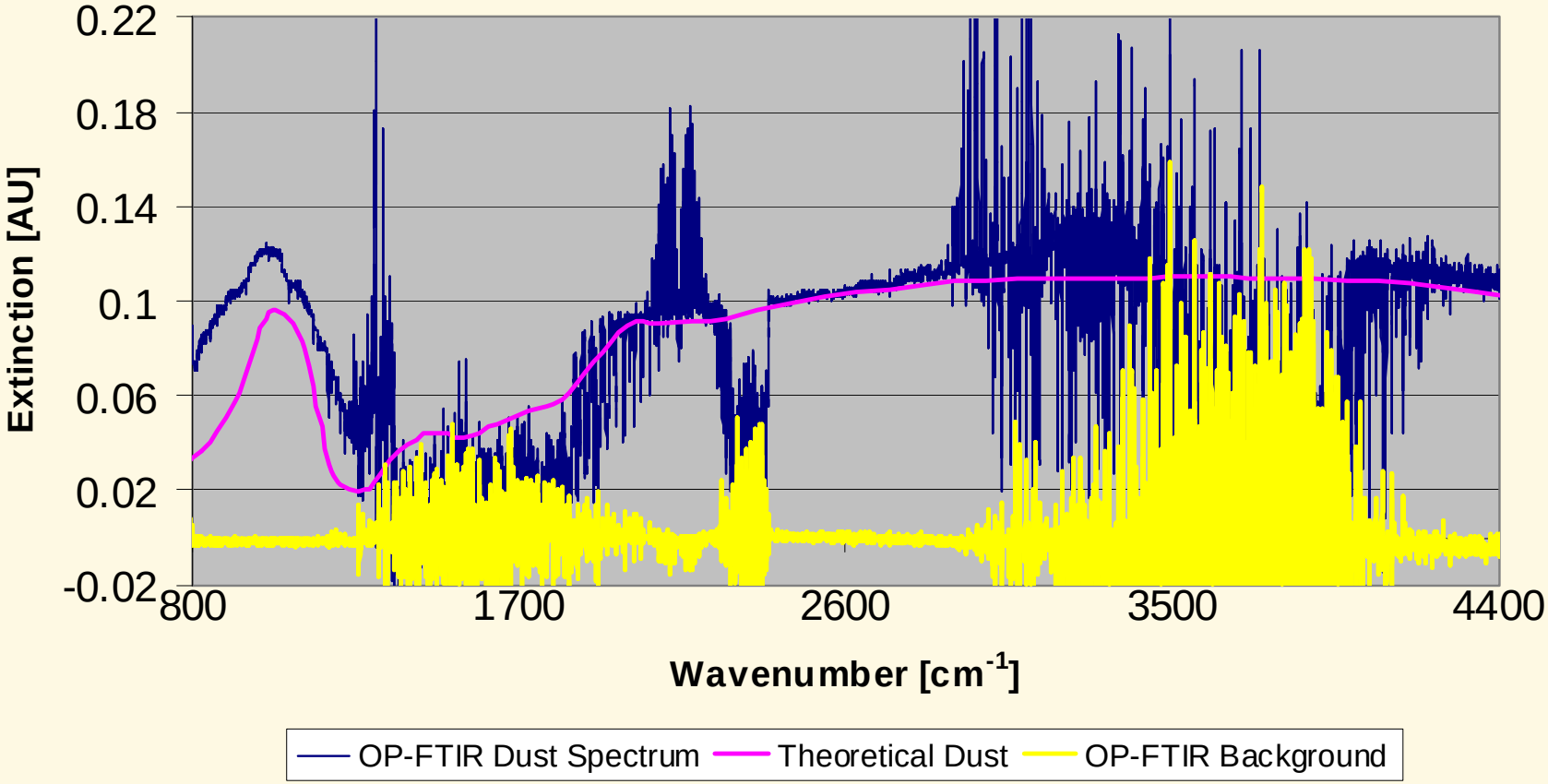
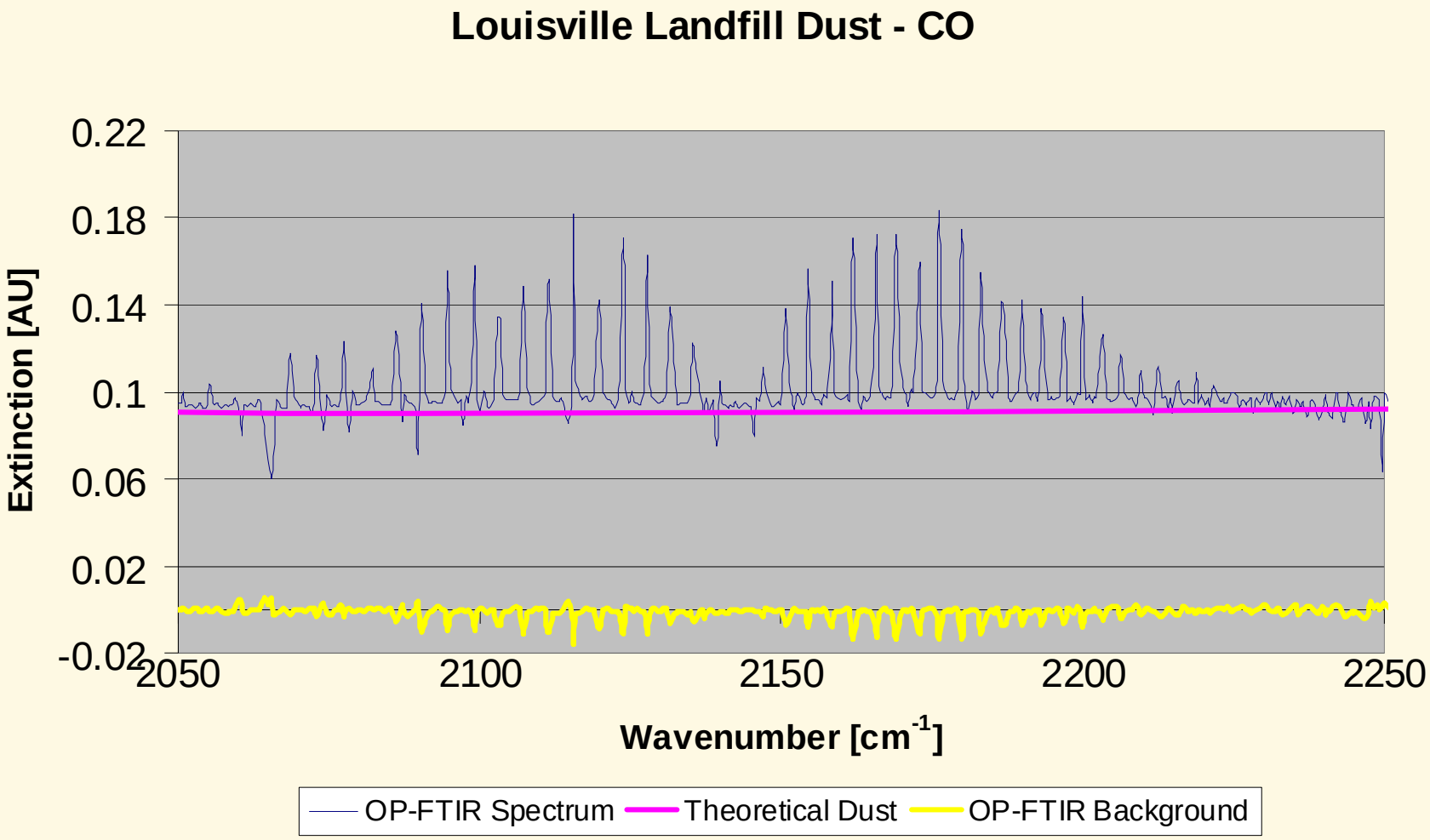
Louisville Landfill Set-Up


Louisville Landfill Dust
0.22
0.18
0.14
0.1
0.06
0.02
-0.02
Extinction [AU]
800
1700
2600
3500
4400
Wavenumber [cm-1]
OP-FTIR Dust Spectrum
OP-FTIR Background

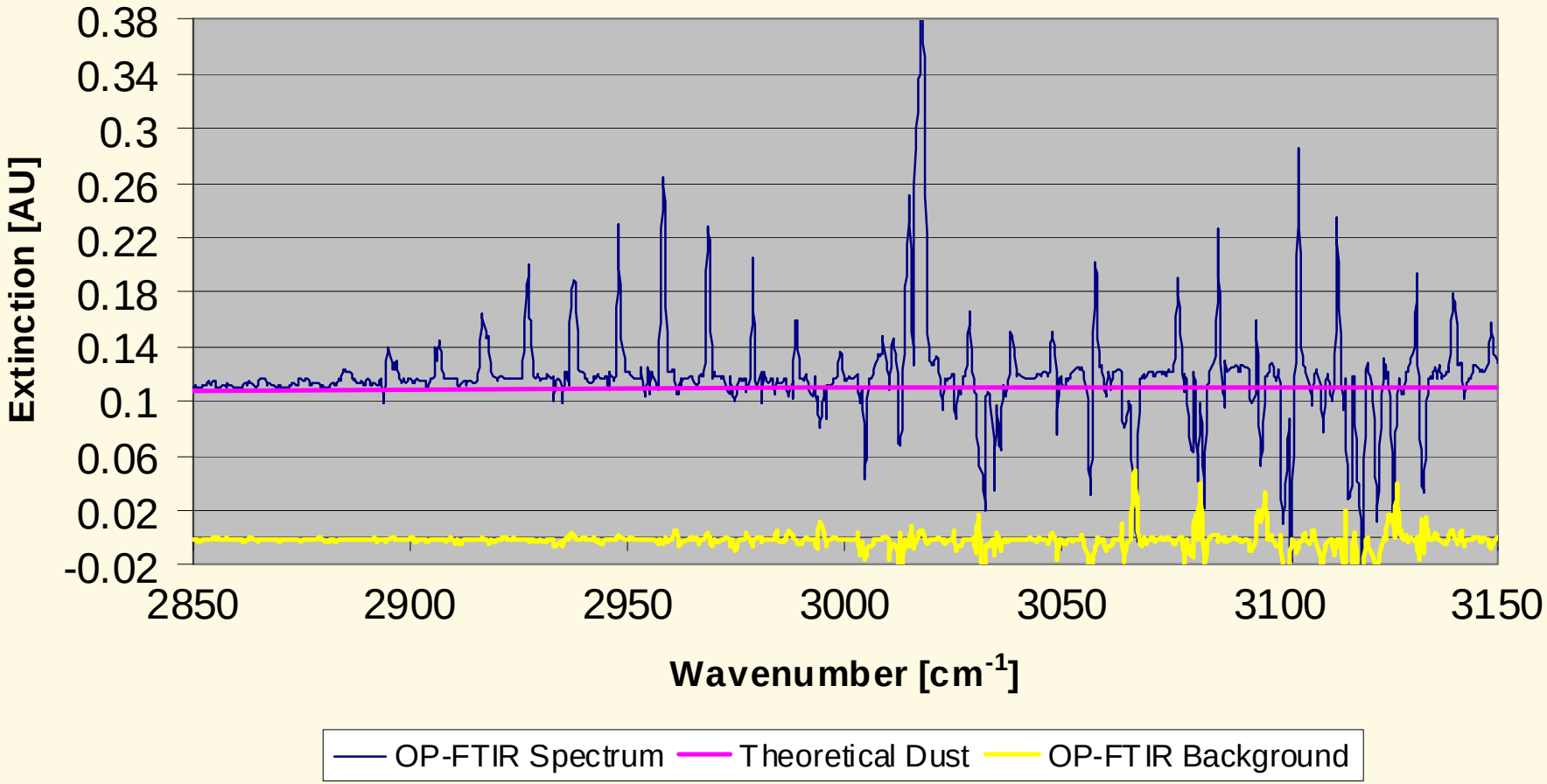

Size Distribution, mean=4.2 micron; SD=1.0 micron
Mass Concentration [RU]
0.06
0.05
0.04
0.03
0.02
0.01
0
0
2.5
5
7.5
10
12.5
15
Diameter [micron]

Louisville Landfill Dust




Louisville Landfill Dust - CO
0.22
0.18
0.14
0.1
0.06
0.02
-0.02
Extinction [AU]
2050
2100
2150
2200
2250
Wavenumber [cm-1]
OP-FTIR Spectrum
Theoretical Dust
OP-FTIR Background

Louisville Landfill Dust - Methane



Diesel PM

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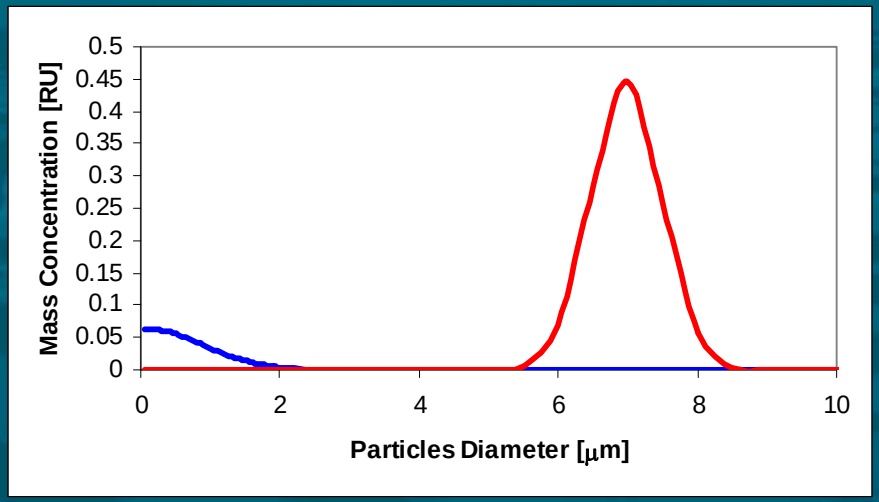
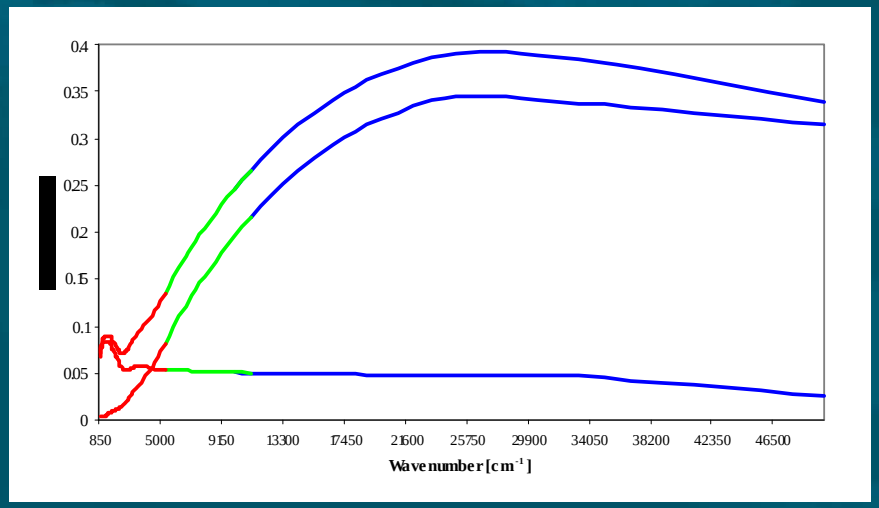
Predicted Diesel Spectrum





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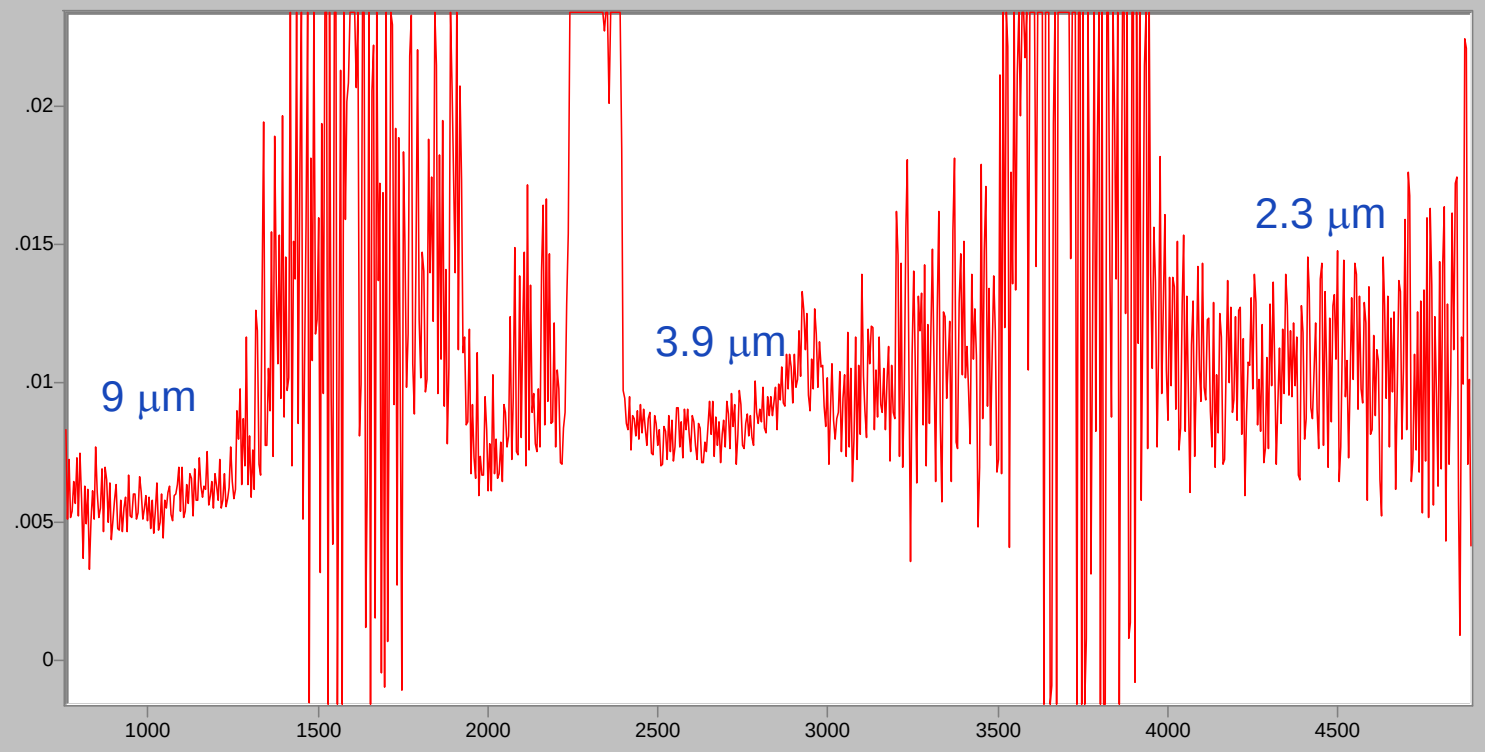
Diesel Extinction Spectrum



Absorbance / Wavenumber (cm-1)
File # 1 : ABSORB#24 @106.4511 Seconds
bistatic 10m 2 resolution

Paged X-Zoom CURSOR
6/18/2002 1:29 PM Res=2 cm-1

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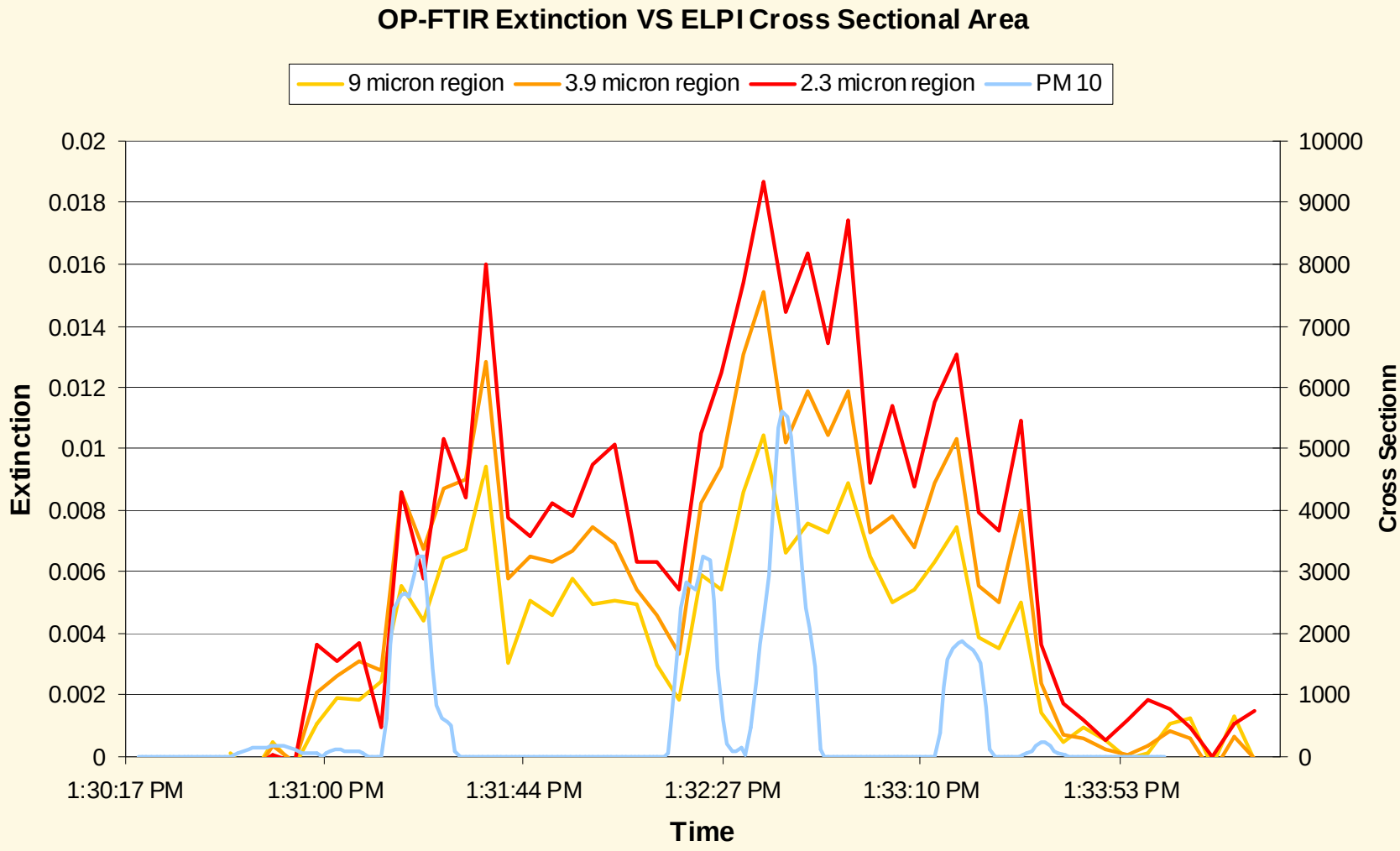
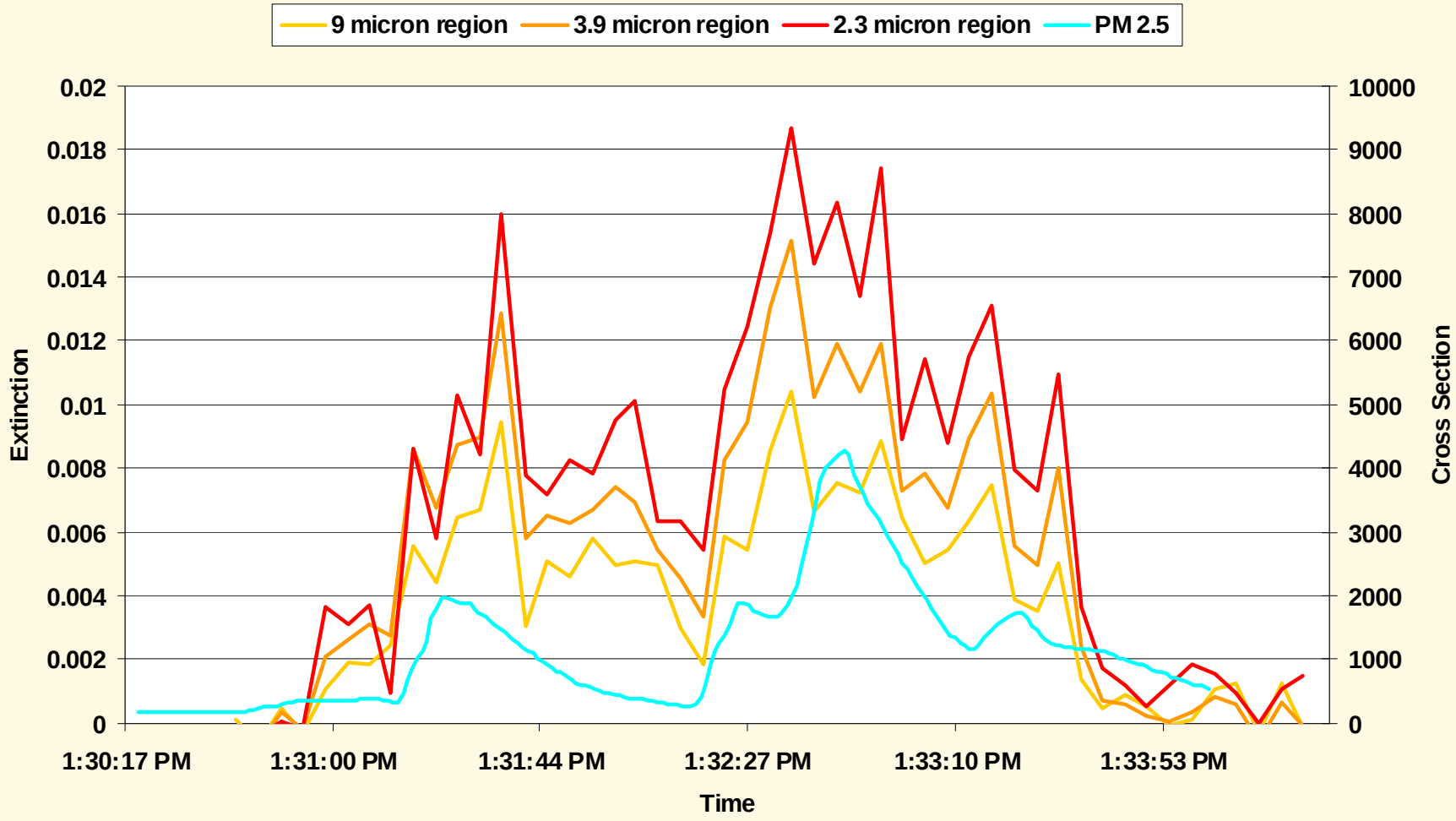
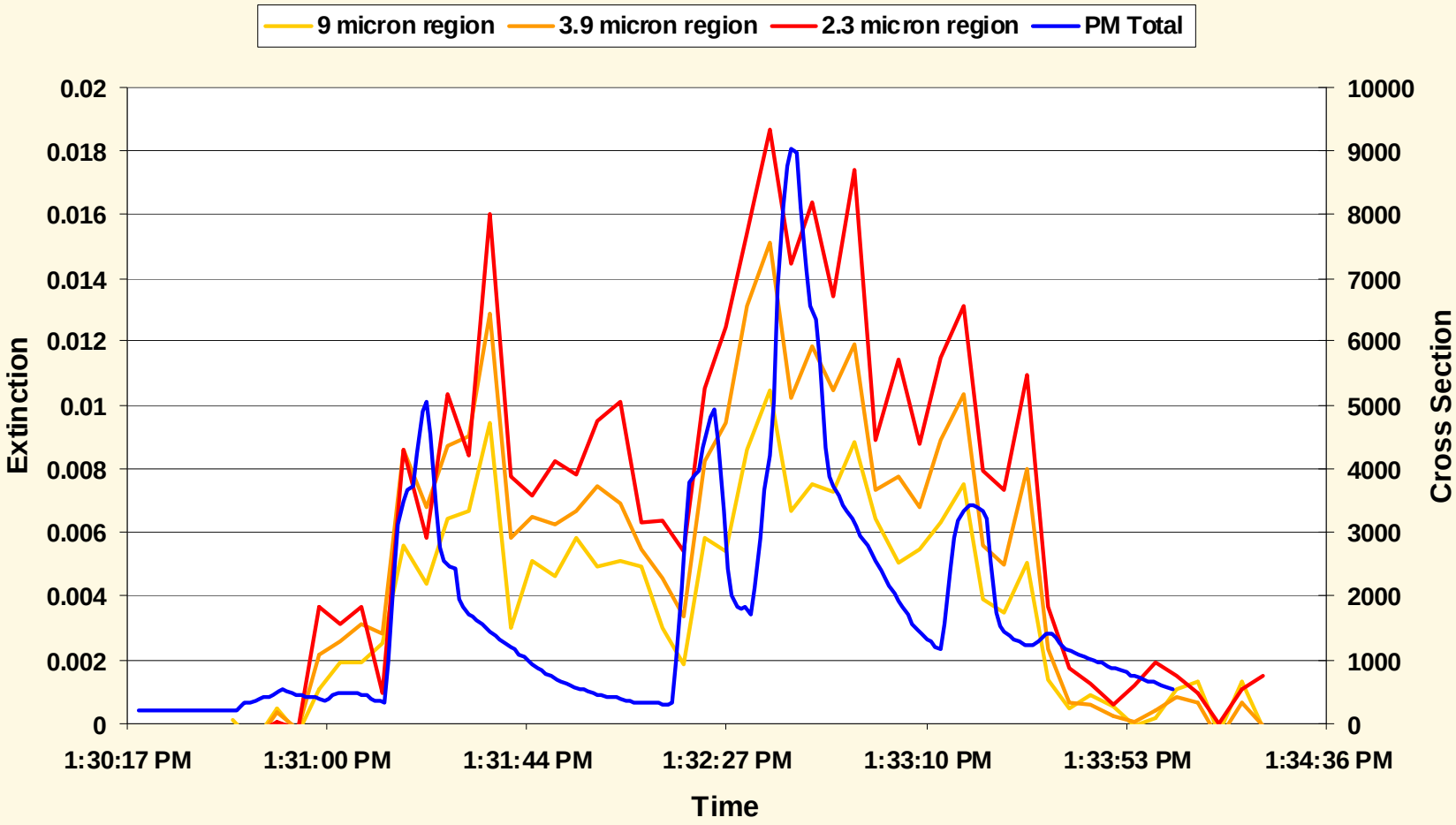
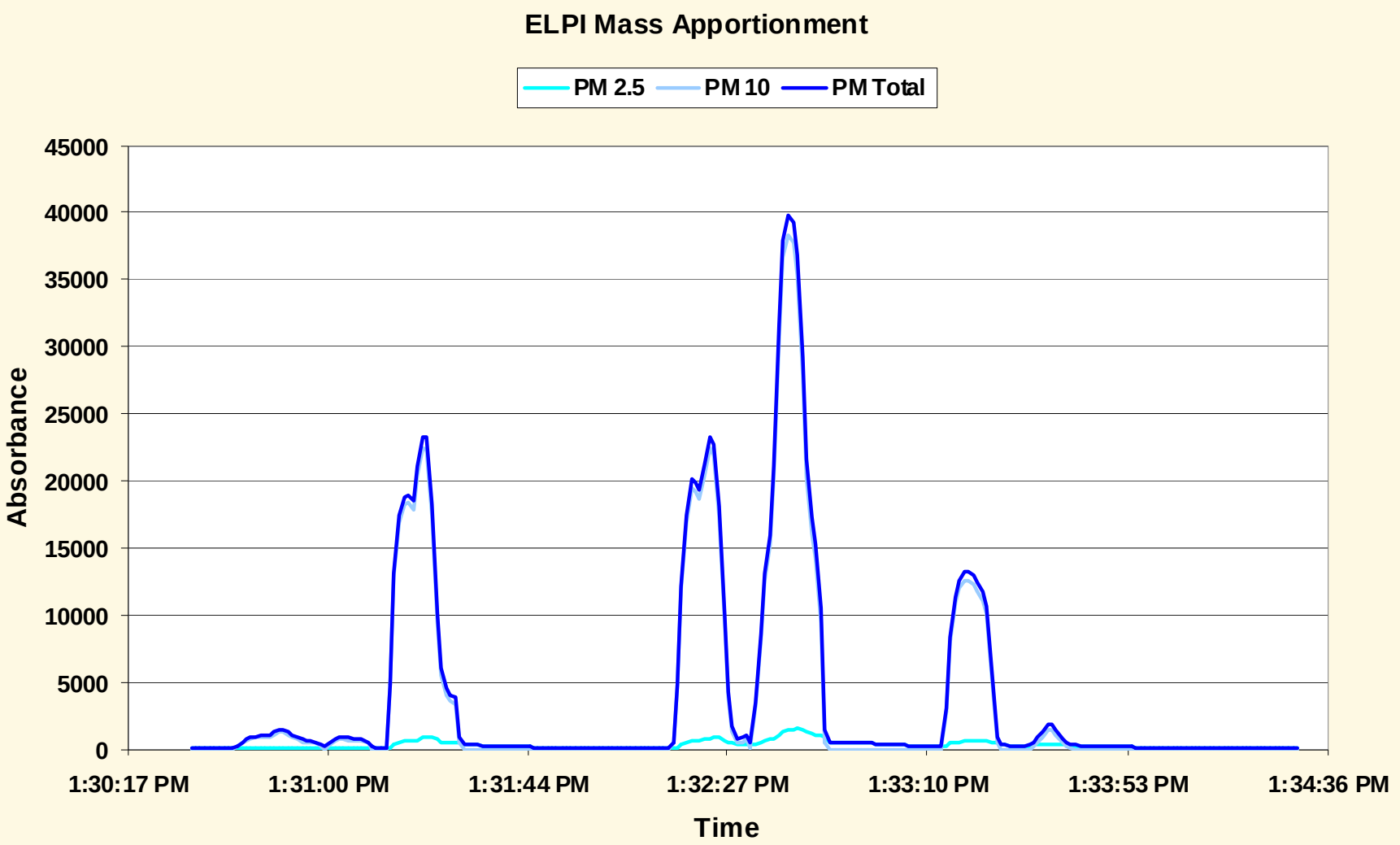
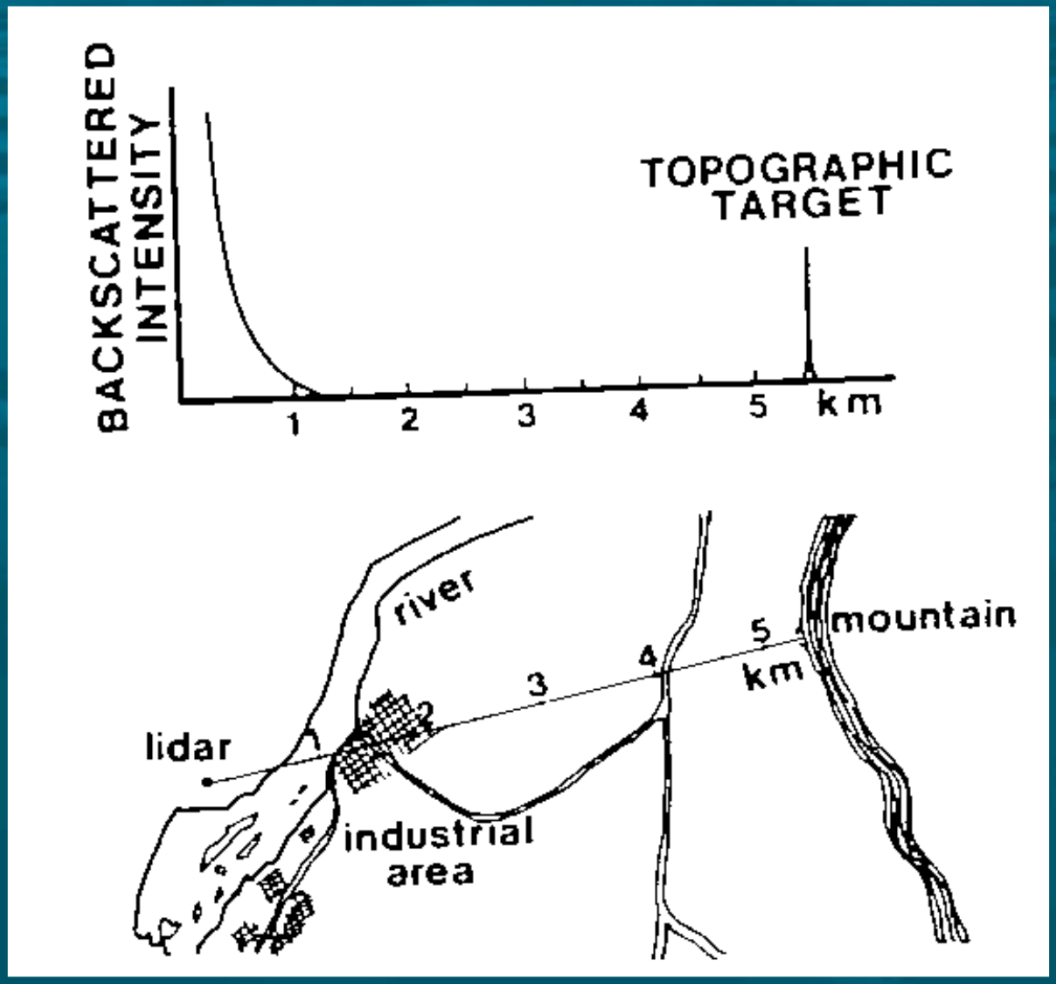

OP-FTIR Extinction VS ELPI Cross Sectional Area
9 micron region
3.9 micron region
2.3 micron region
PM 10
Extinction
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Cross Sectionn
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1:30:17 PM
1:31:00 PM
1:31:44 PM
1:32:27 PM
1:33:10 PM
1:33:53 PM
Time


OP-FTIR Extinction VS ELPI Cross Sectional Area
9 micron region
3.9 micron region
2.3 micron region
PM 2.5
Extinction
Cross Section
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1:30:17 PM
1:31:00 PM
1:31:44 PM
1:32:27 PM
1:33:10 PM
1:33:53 PM
Time

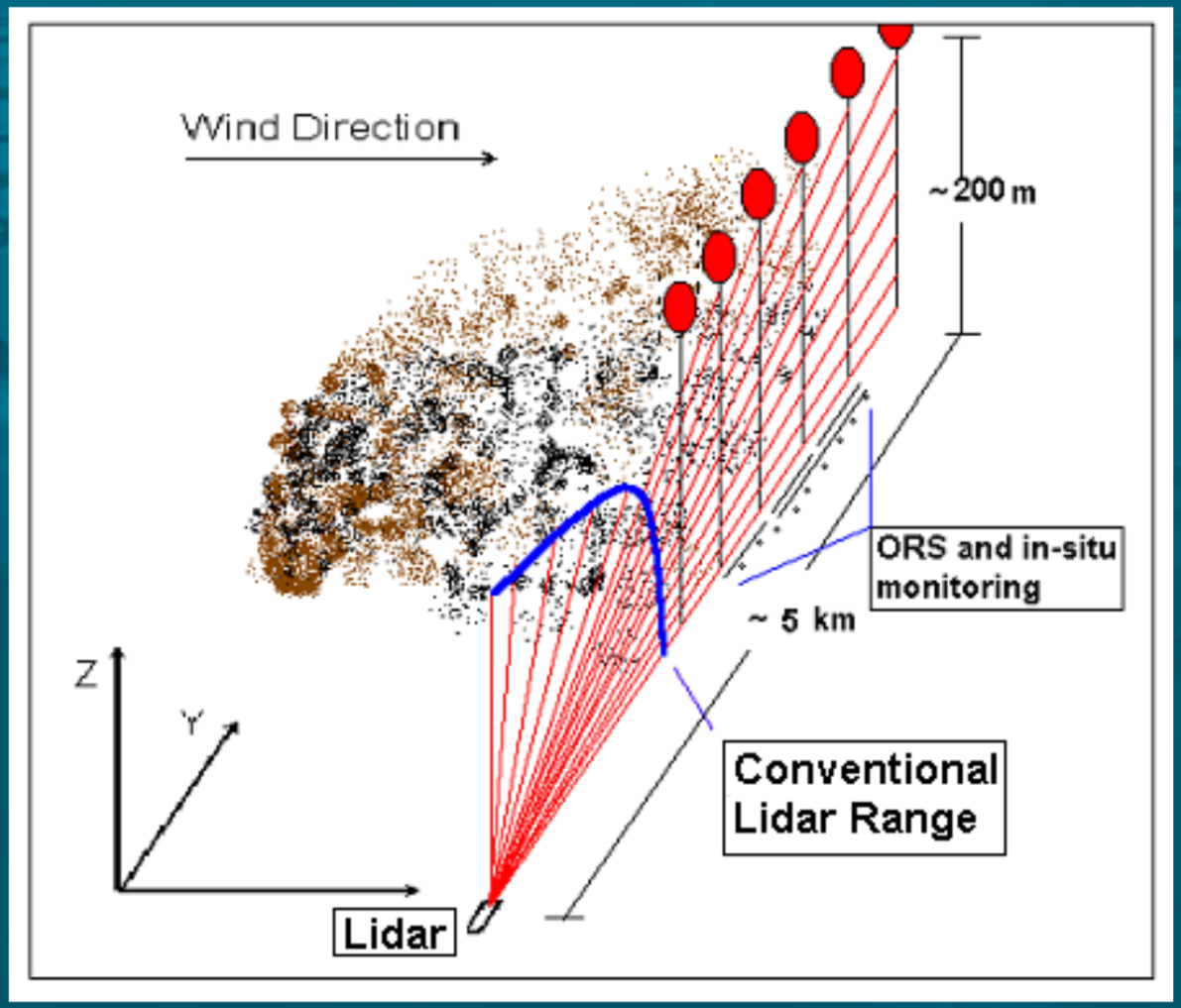

OP-FTIR Extinction VS ELPI Cross Sectional Area
9 micron region
3.9 micron region
2.3 micron region
PM Total
Extinction
Cross Section
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1:30:17 PM
1:31:00 PM
1:31:44 PM
1:32:27 PM
1:33:10 PM
1:33:53 PM
1:34:36 PM
Time


ELPI Mass Apportionment
PM 2.5
PM 10
PM Total
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Absorbance
1:30:17 PM
1:31:00 PM
1:31:44 PM
1:32:27 PM
1:33:10 PM
1:33:53 PM
1:34:36 PM
Time

Path-Integrated Lidar



Enhanced Range Lidar



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Conclusions

- The first open-path optical technique to obtain real-time fugitive dust measurement and sizing
- Measurement of liquid aerosol like water or pesticide drift
- OP-FTIR can be used in field to gather multiple gases and PM emission data simultaneously
- Extending the spectral range to the UV/VIS range will allow sizing of submicron PM