Center of Excellence for Aerospace Particulate Emissions Reduction Research

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An Advected Plume Study of Commercial Aircraft Take-off PM Emissions

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August 15, 2007

Delta – Atlanta Hartsfield Study

Part 1:
A study to:

- •Measure PM emissions close to exhaust nozzle from stationary in-service commercial aircraft using state of the art extractive sampling techniques.
- •Evaluate the viability of characterizing PM emissions using remote sensing of the exhaust plumes with a LIDAR source.

Part 2:
A study to:

- **Explore feasibility of measuring PM emissions and plume geometry in advected exhaust plumes during normal operations at a major commercial airport.**

Science Team:

Extractive Sampling

UMR

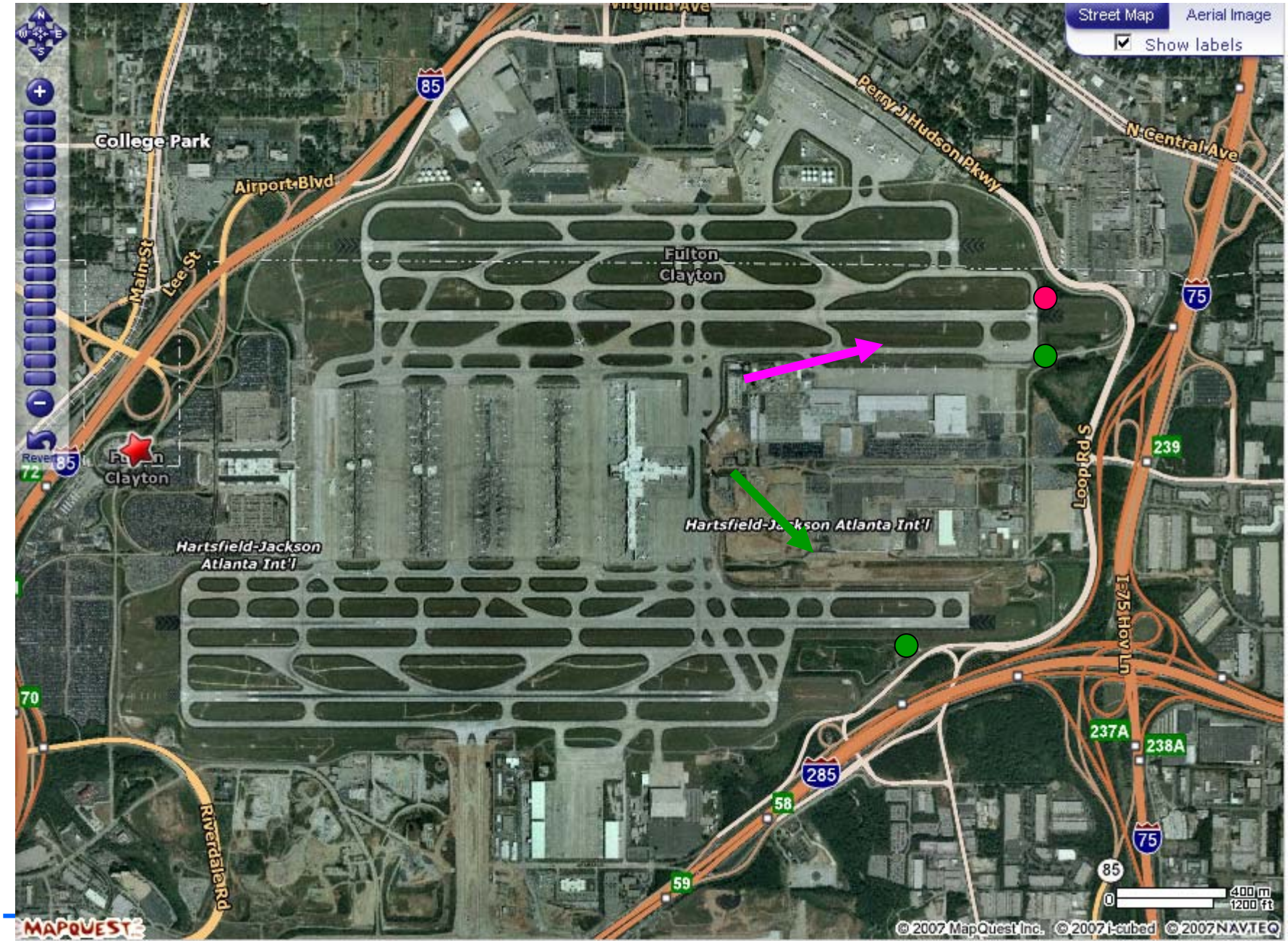
Aerodyne Research, Inc.

Remote Sensing (LIDAR)

University of Central Florida

the VOLPE center

NOAA


Street Map
Aerial Image
Show labels
College Park
Airport Blvd
Main St
Lee St
Fulton
Clayton
Perry J Hudson Pkwy
N Central Ave
Hartsfield-Jackson
Atlanta Int'l
Hartsfield-Jackson Atlanta Int'l
Loop Rd
I-75 Hov Ln
Riverdale Rd
85
75
239
285
58
59
70
72
237A
238A
400 m
1200 ft
MAPQUEST
© 2007 MapQuest Inc.
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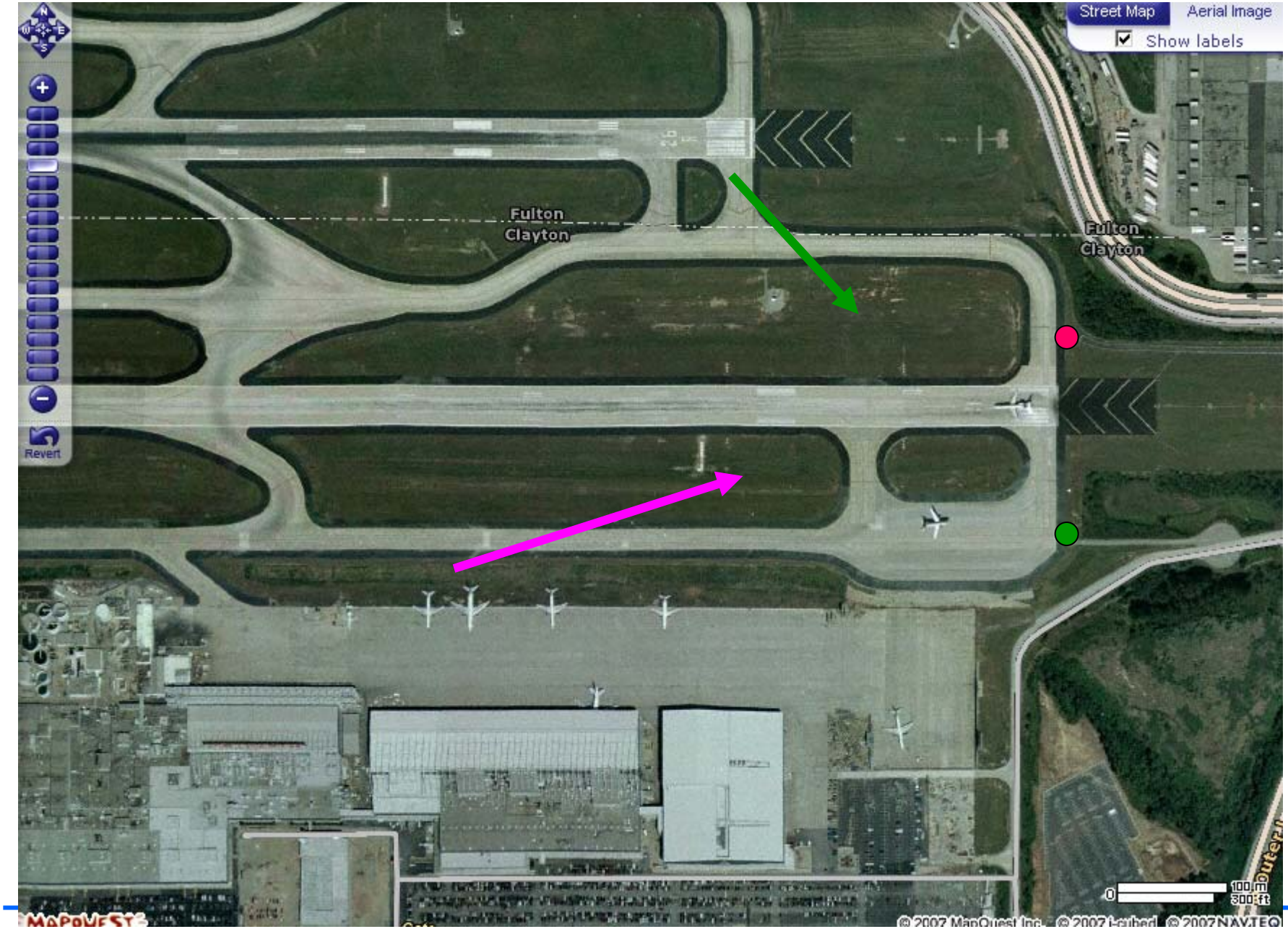
© 2007 NAVTEQ


Street Map
Aerial Image
Show labels
Fulton
Clayton
Fulton
Clayton
Revert
0
100 m
300 ft
MAPQUEST
© 2007 MapQuest Inc. © 2007 I-cubed © 2007 NAVTEQ

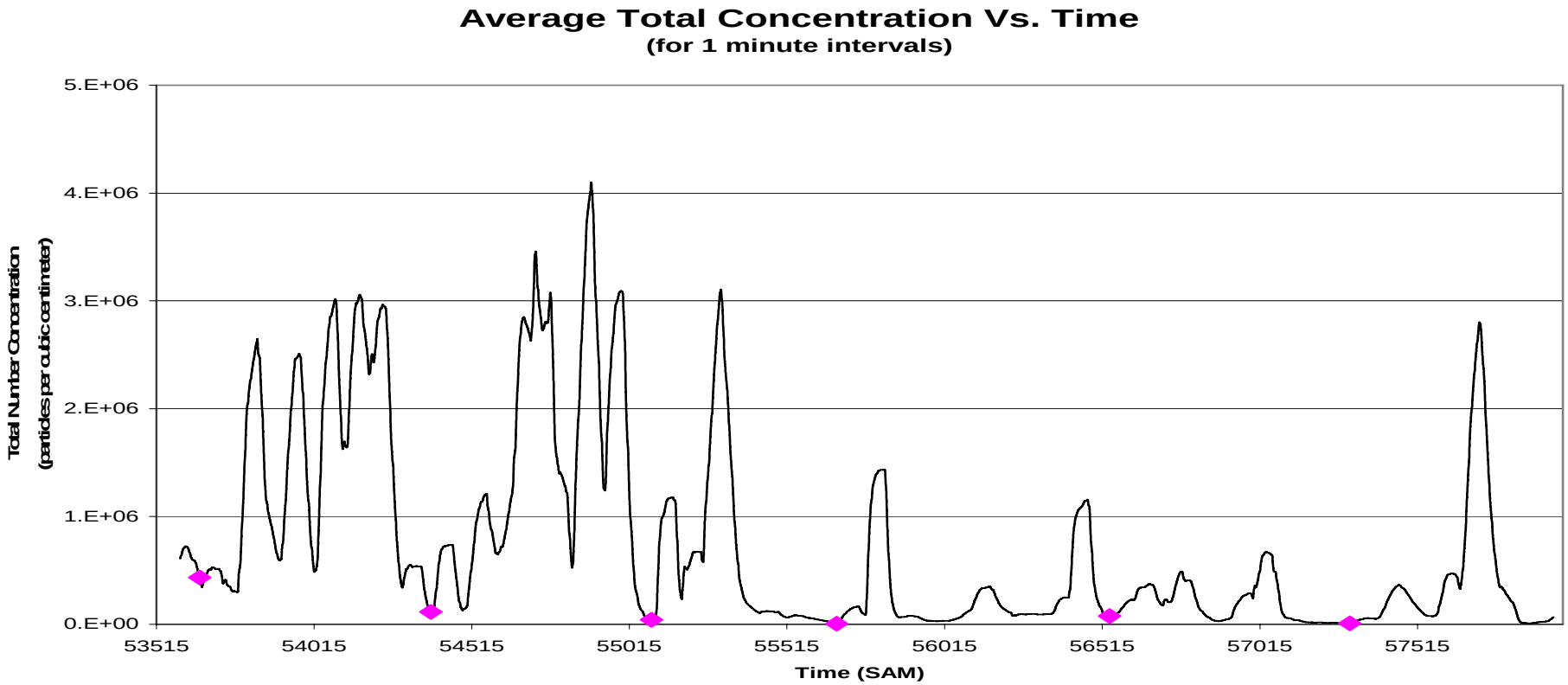

Street Map
Aerial Image
Show labels
Revert
Cargo Service Rd
Cargo Service Rd
Nlvr Se
Nlvr Se
Nlvr Se
S Inner Loop Rd
S Outer Loop Rd
285
100 m
300 ft
MAPQUEST
© 2007 MapQuest Inc. © 2007 i-cubed © 2007 NAVTEQ

Measurement Suite

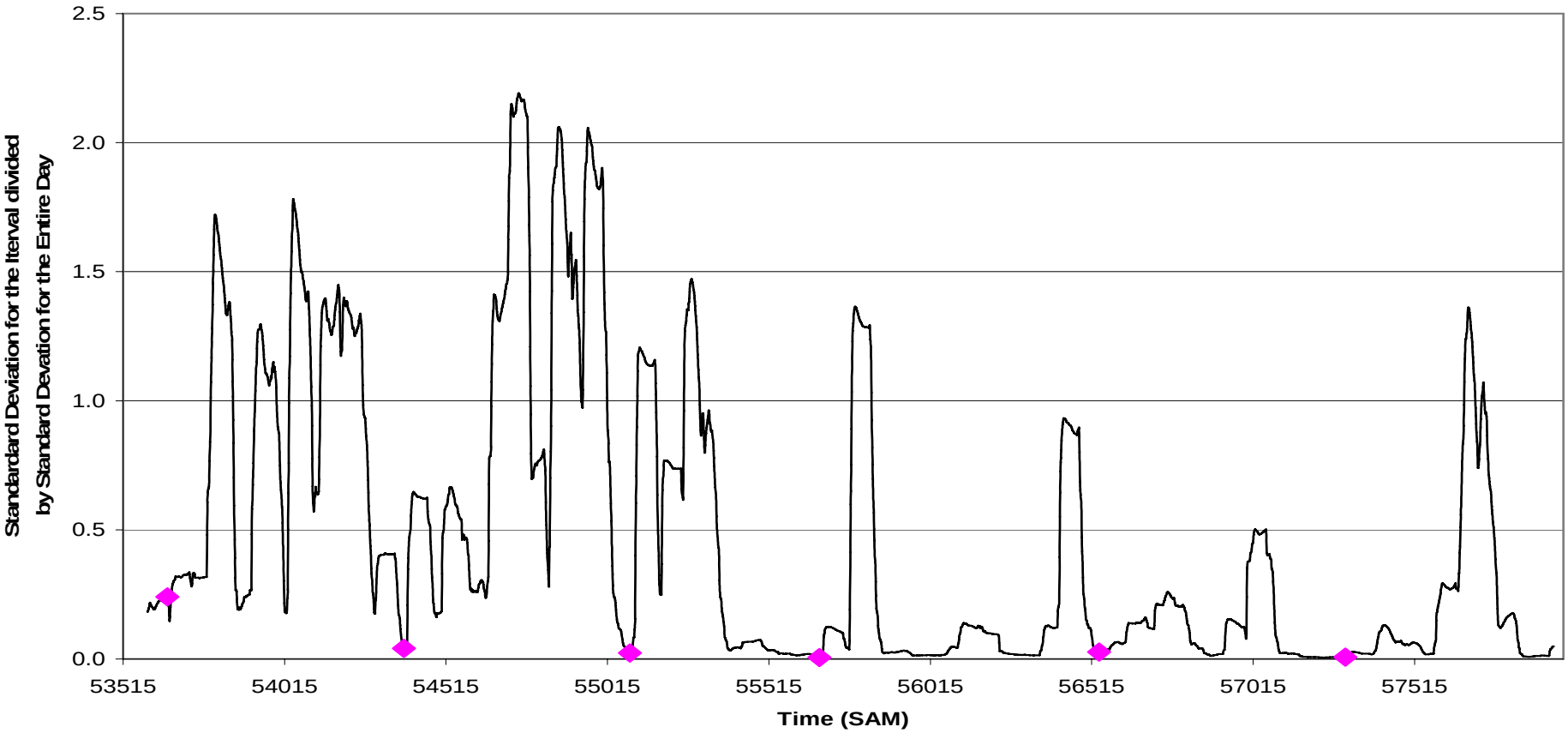
- Cambustion DMS500
- Scanning Mobility Particle Sizer (SMPS)
- Condensation Particle Counter
- Multi-Angle Absorption Photometer (MAAP)
- Aerosol Mass Spectrometer (AMS)
- Tunable Diode Laser Differential Absorption Spectrometer (TILDAS)
- Non-dispersive IR (Licor)
- LIDAR

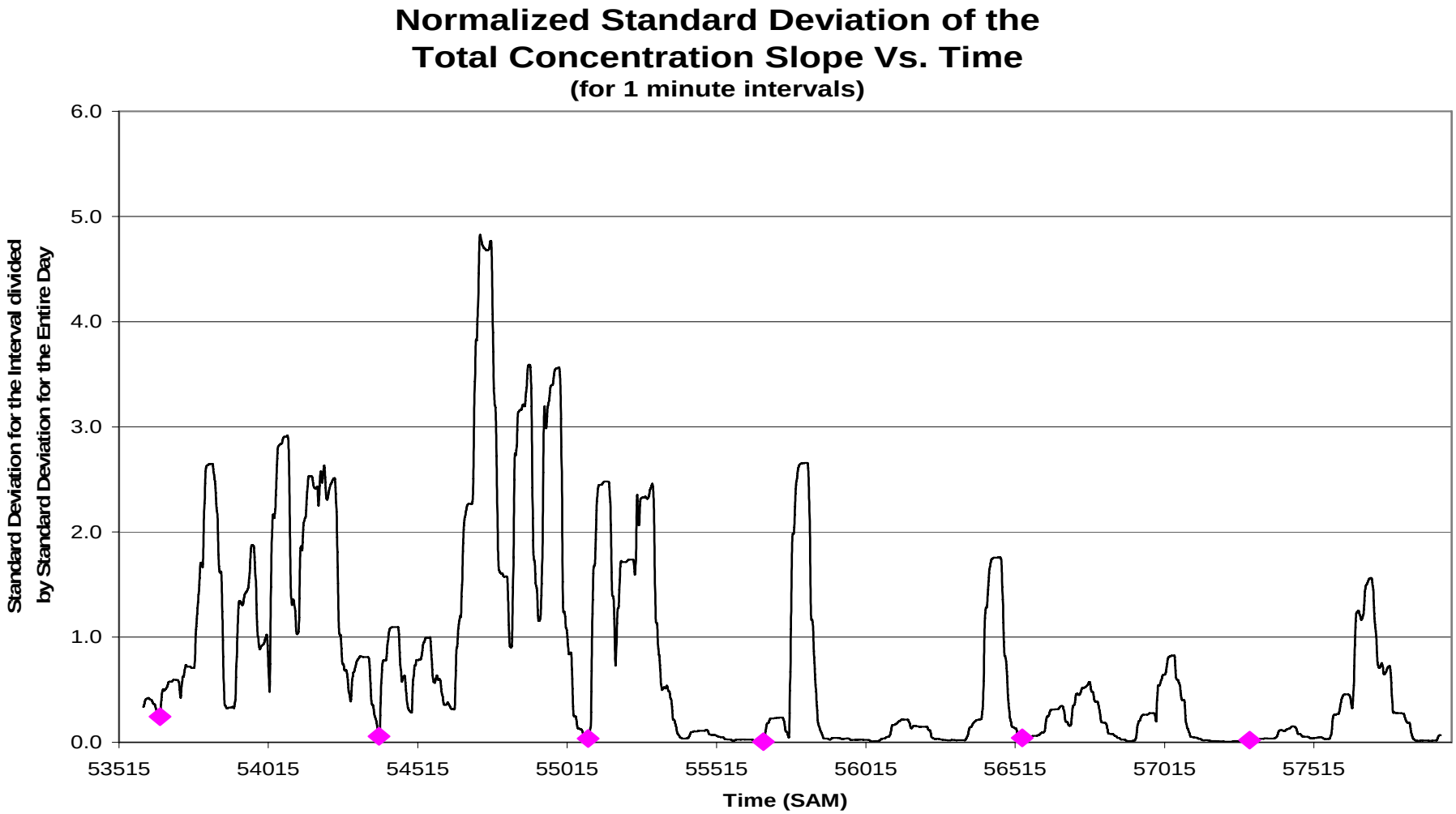
Data Presentation Plan

- Background
  - ✓ Want aircraft (esp. takeoff) emissions.
  - ✓ Other PM sources are active.
  - ✓ They are time dependent.
- Four specific take-off events
  - ✓ Several different airframe and engine types
  - ✓ Kinds of information that can be extracted
- Compilation of 289 take-off events
  - ✓ Six popular engine types
  - ✓ Three different days

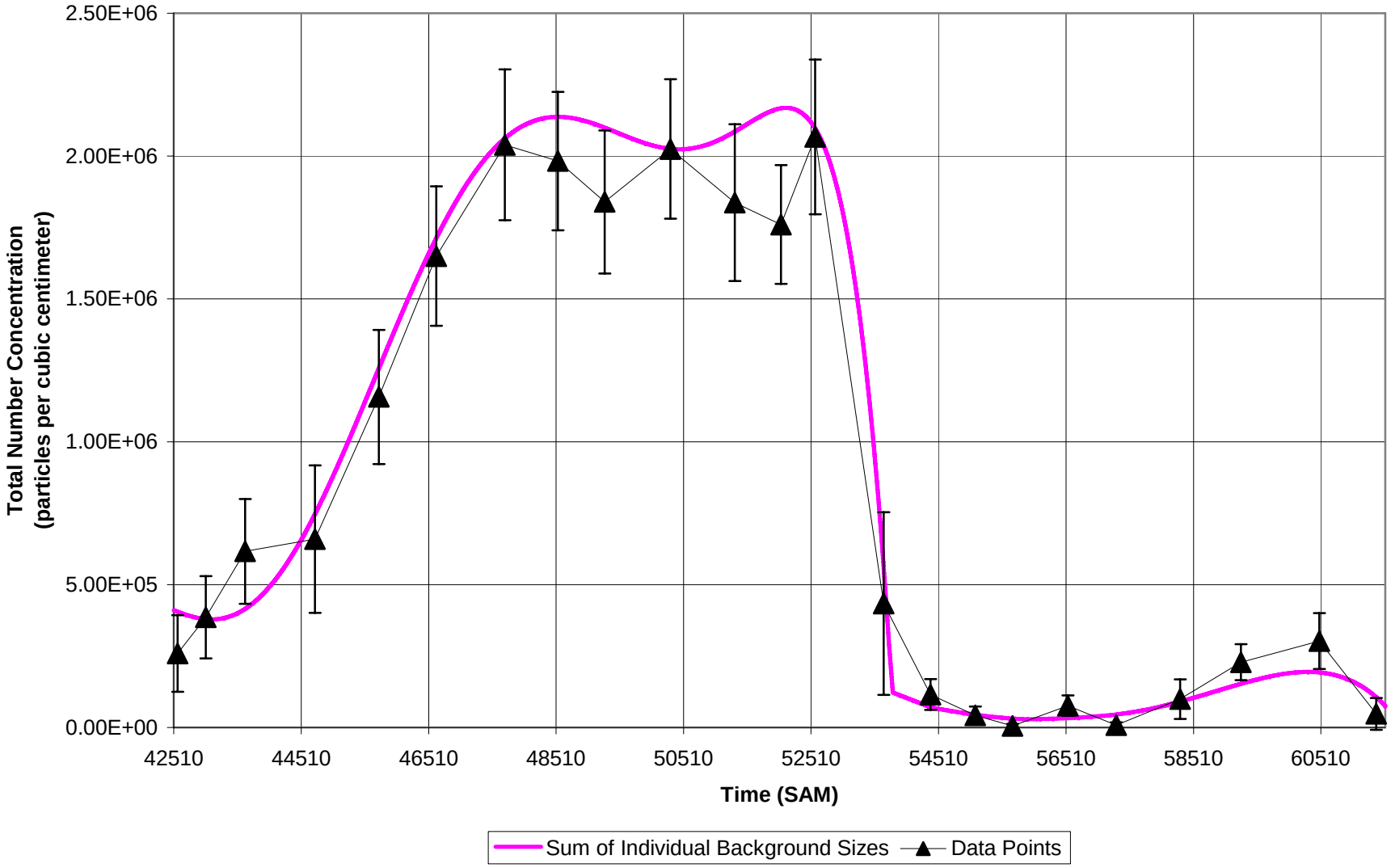

Average Total Concentration Vs. Time
(for 1 minute intervals)
Total Number Concentration
(particles per cubic centimeter)
5.E+06
4.E+06
3.E+06
2.E+06
1.E+06
0.E+00
53515
54015
54515
55015
55515
56015
56515
57015
57515
Time (SAM)

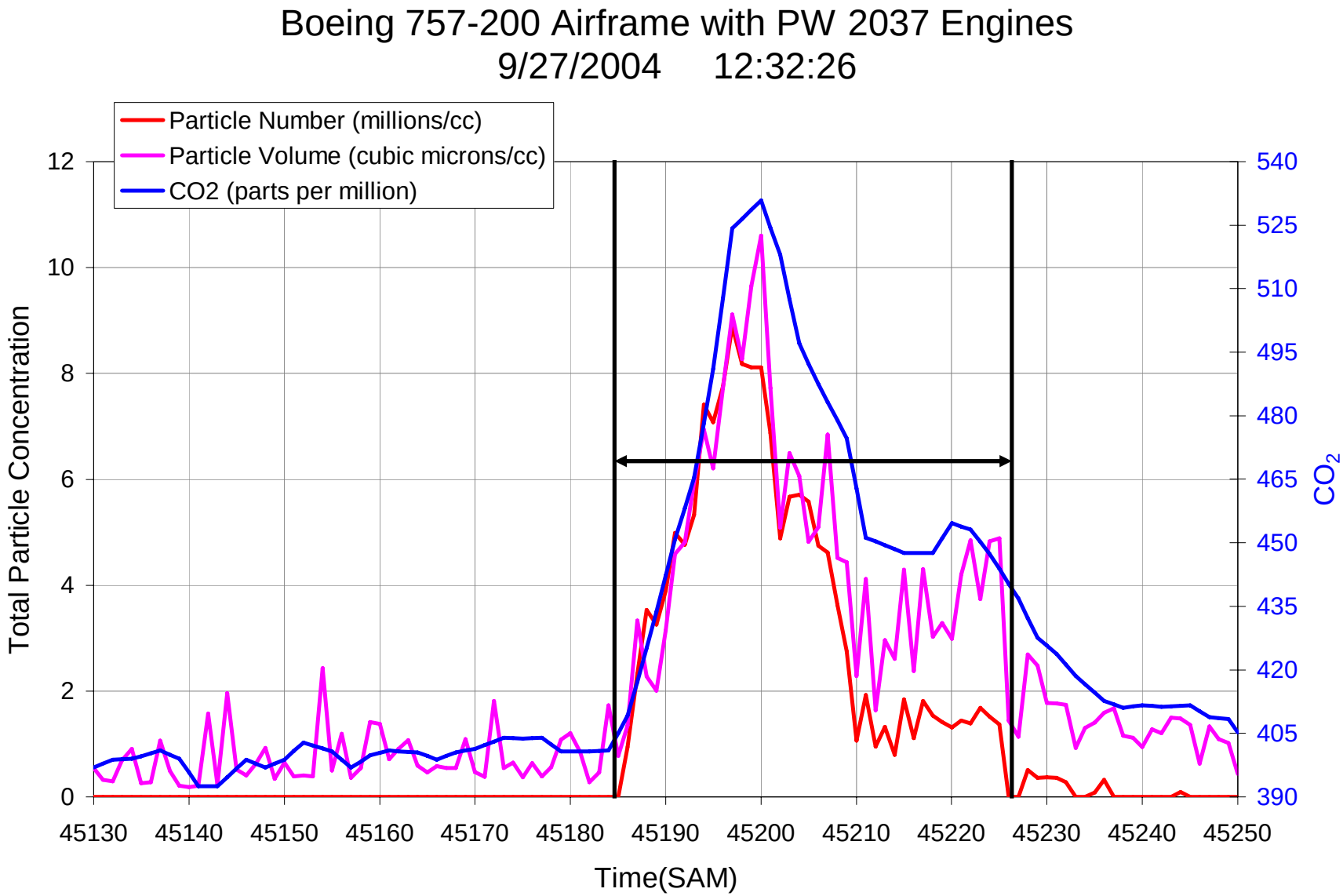
Normalized Standard Deviation of the Total Concentration V. Time
(for 1 minute intervals)

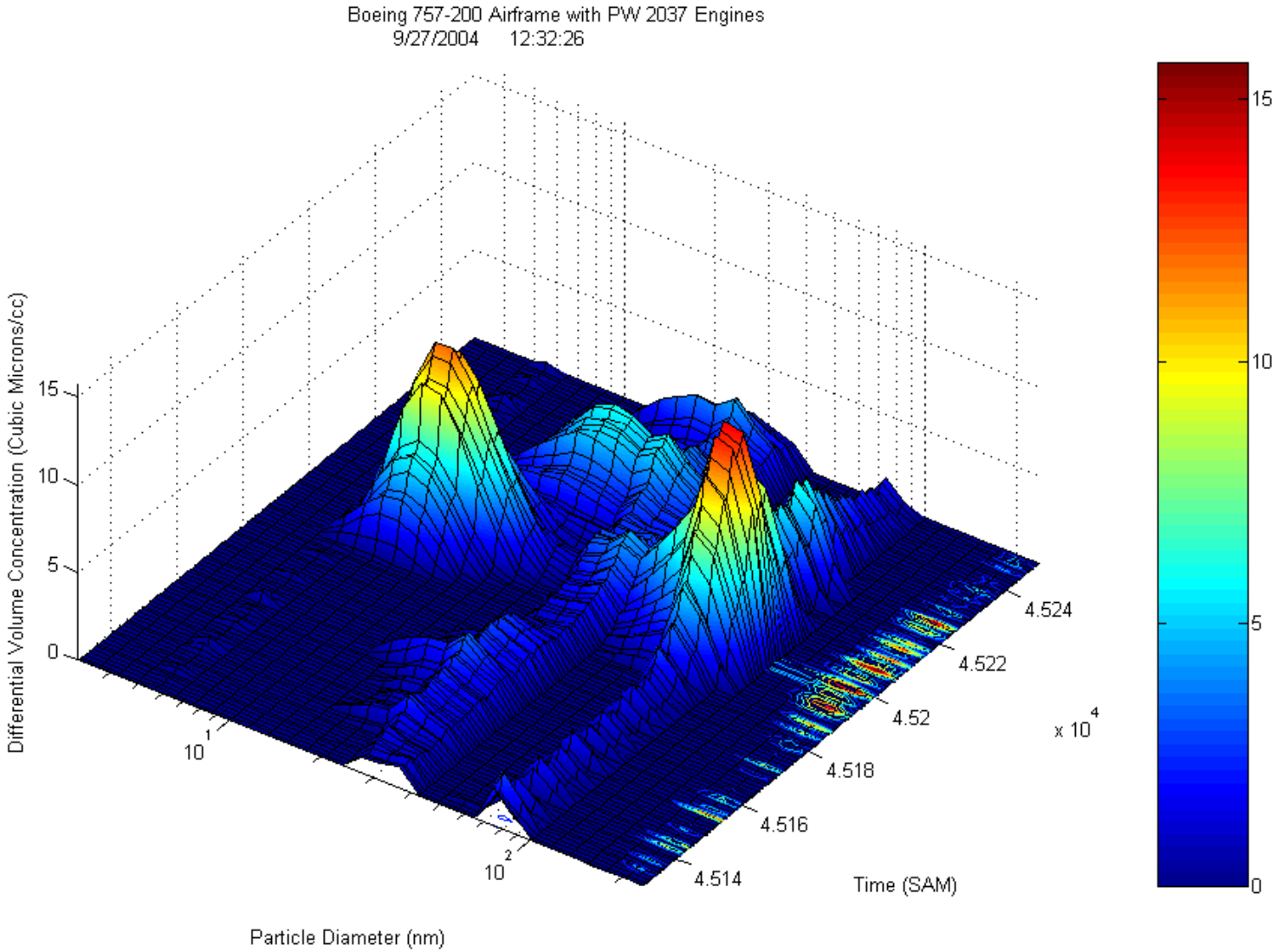


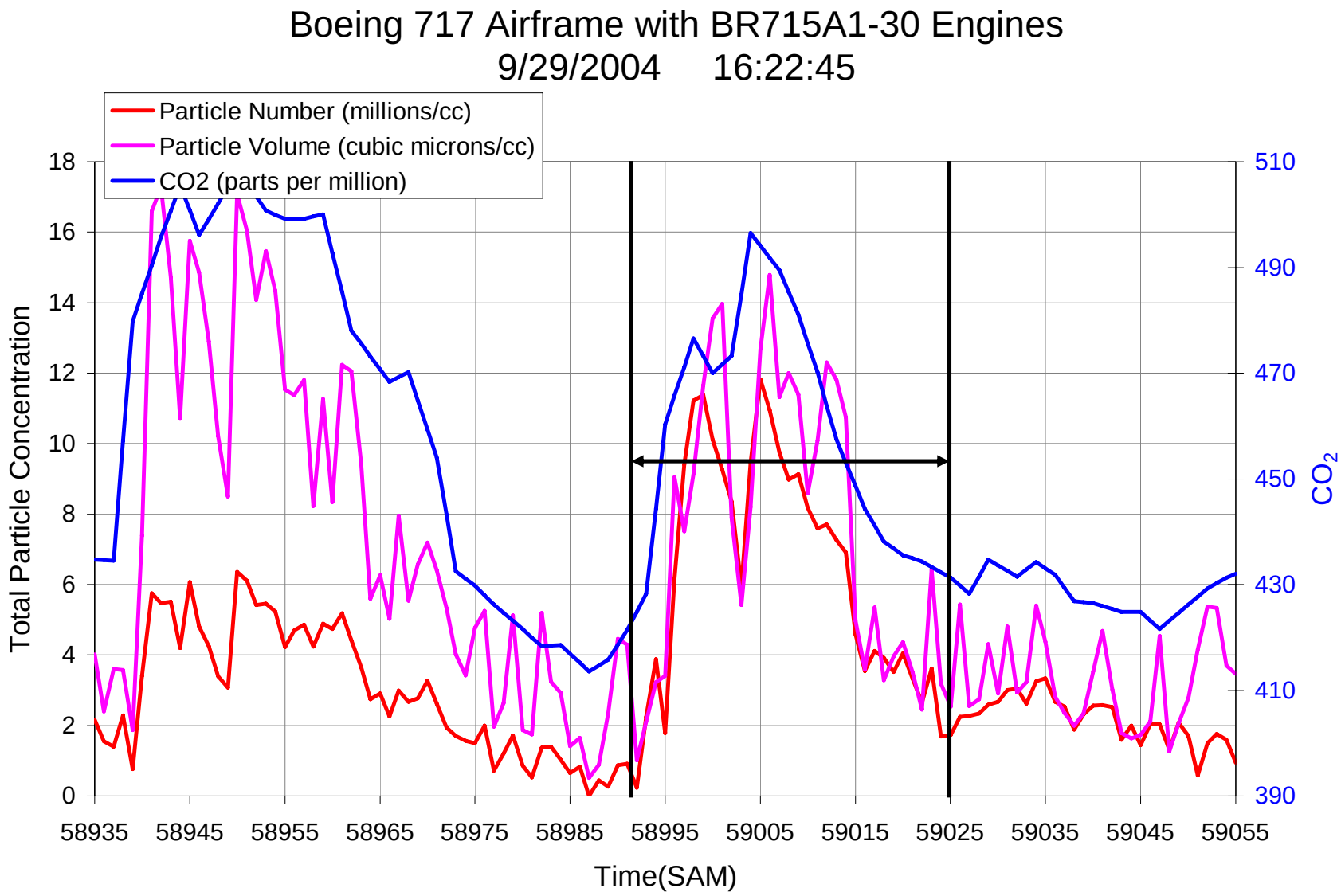

Normalized Standard Deviation of the
Total Concentration Slope Vs. Time
(for 1 minute intervals)
Standard Deviation for the Interval divided by Standard Deviation for the Entire Day
6.0
5.0
4.0
3.0
2.0
1.0
0.0
53515
54015
54515
55015
55515
56015
56515
57015
57515
Time (SAM)

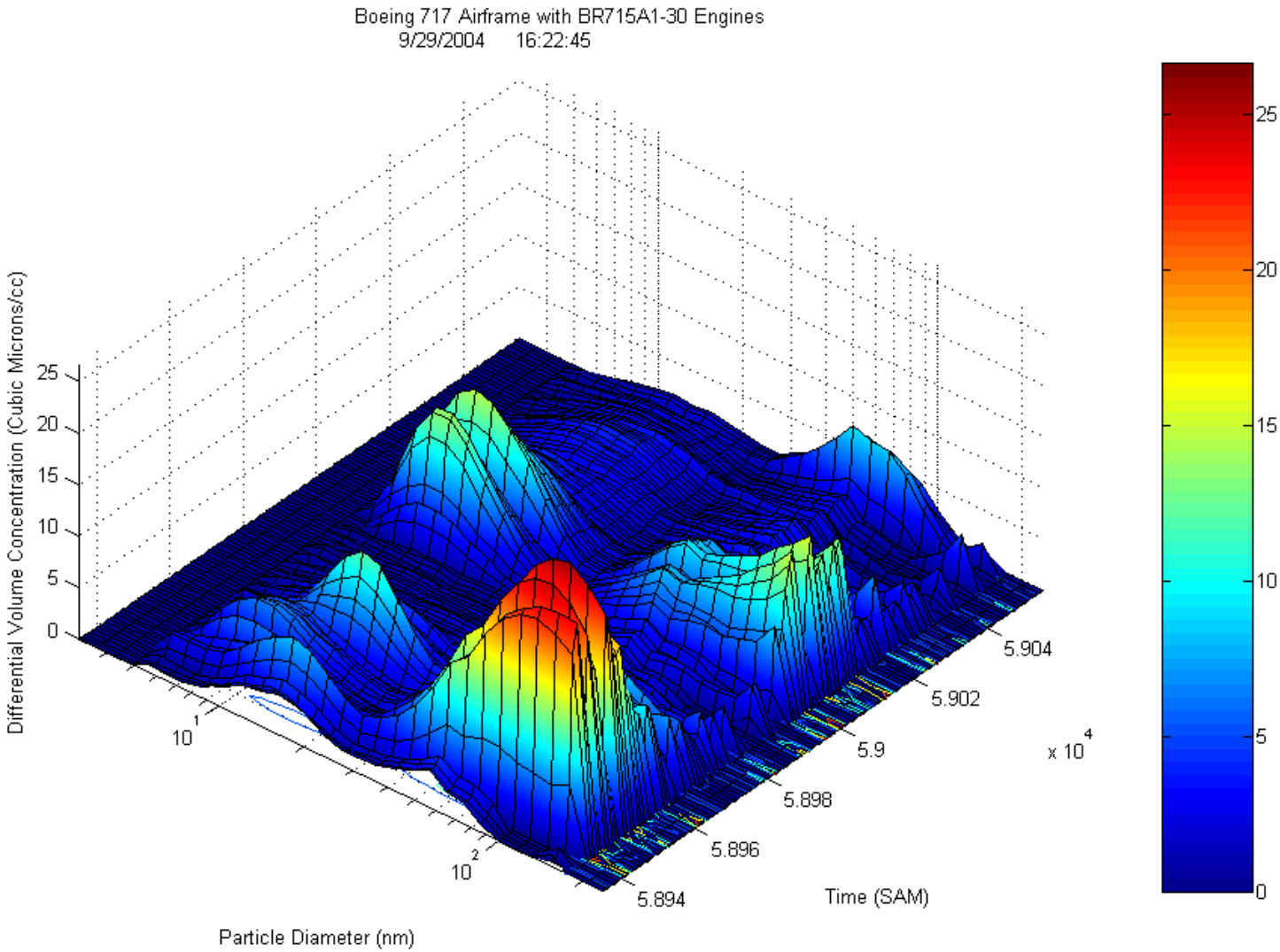
Background Total Concentration vs. Time

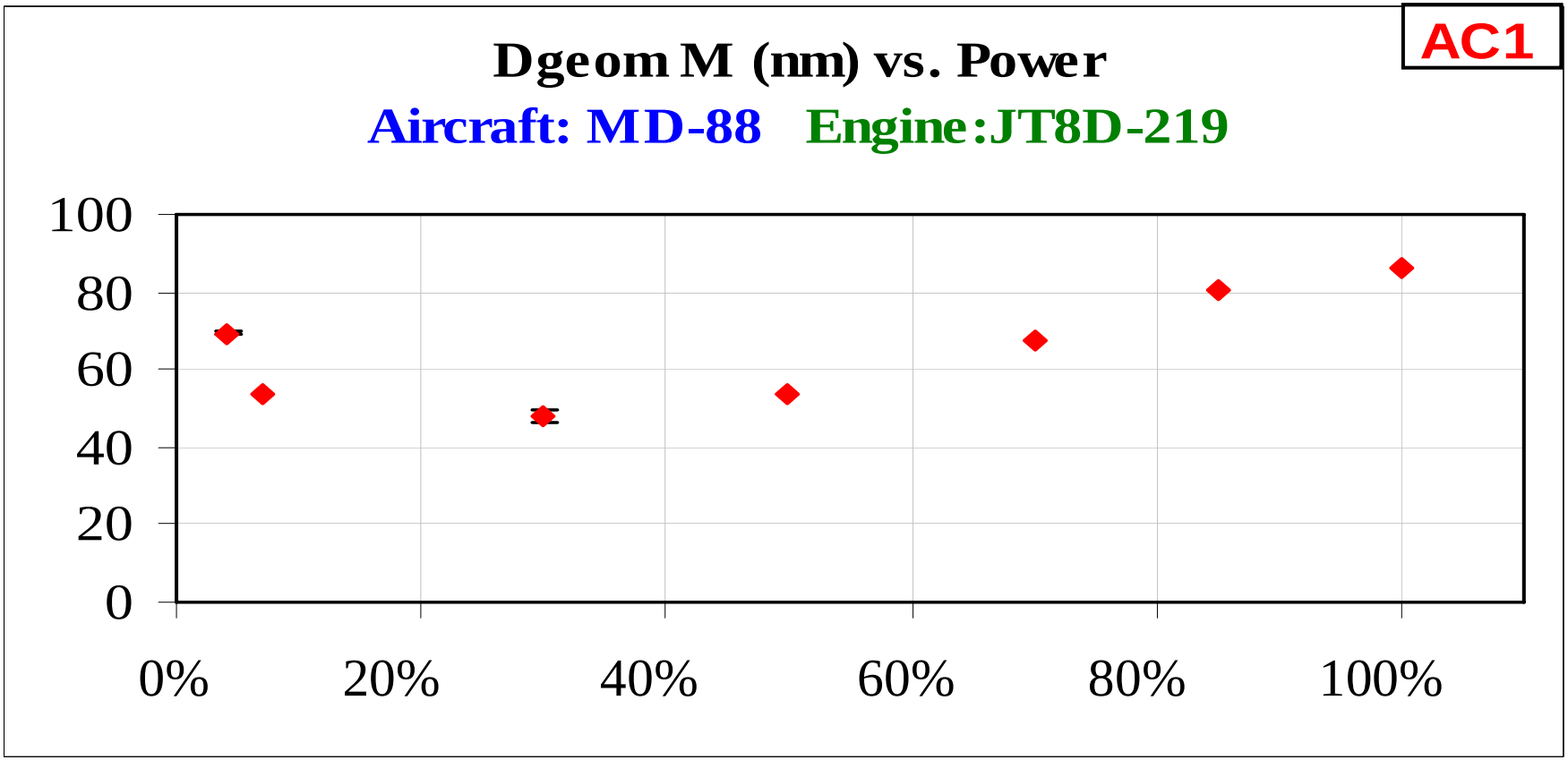


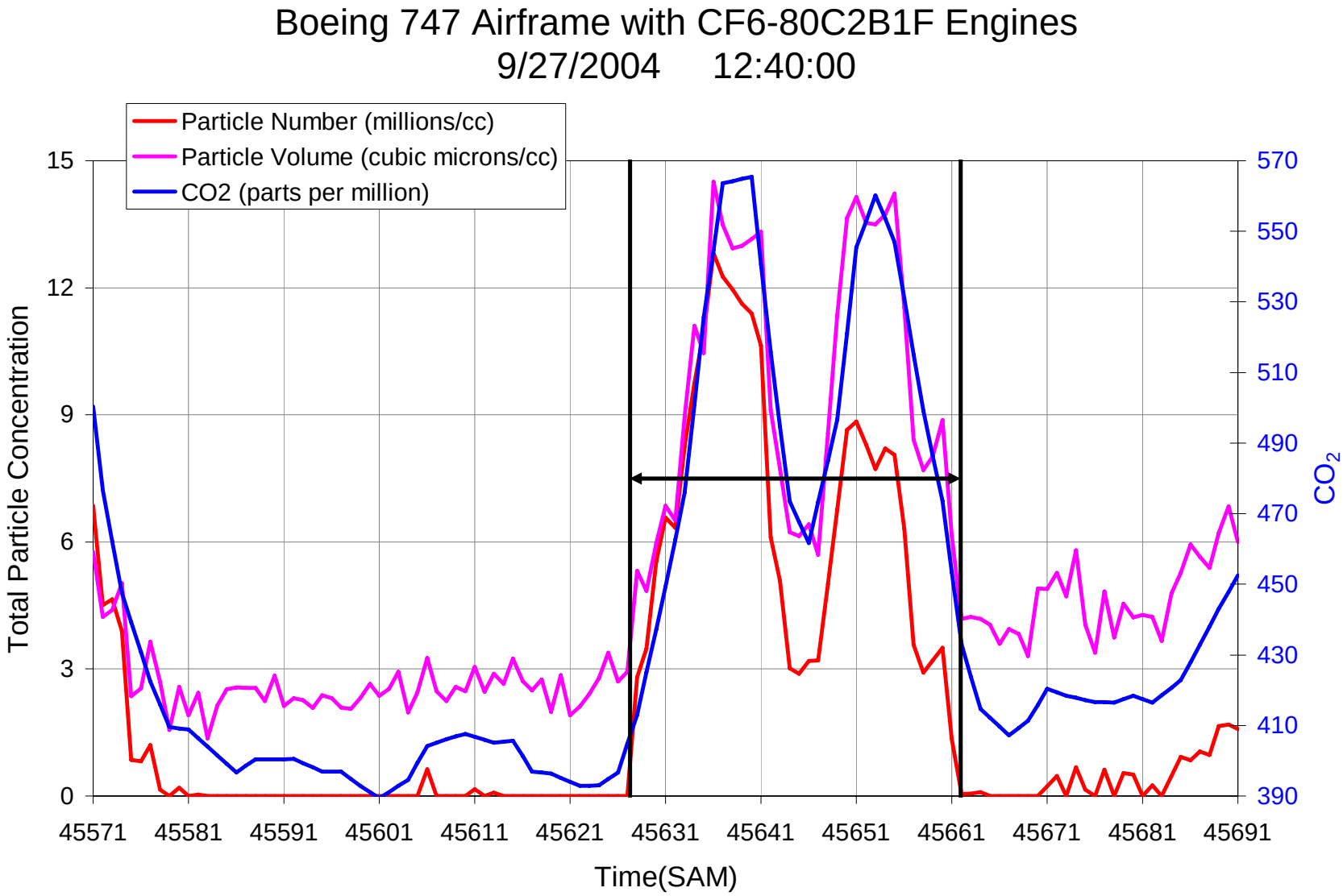

Boeing 757-200 Airframe with PW 2037 Engines
9/27/2004 12:32:26
Particle Number (millions/cc)
Particle Volume (cubic microns/cc)
CO2 (parts per million)
Total Particle Concentration
CO_2
Time(SAM)
0
2
4
6
8
10
12
390
405
420
435
450
465
480
495
510
525
540
45130
45140
45150
45160
45170
45180
45190
45200
45210
45220
45230
45240
45250

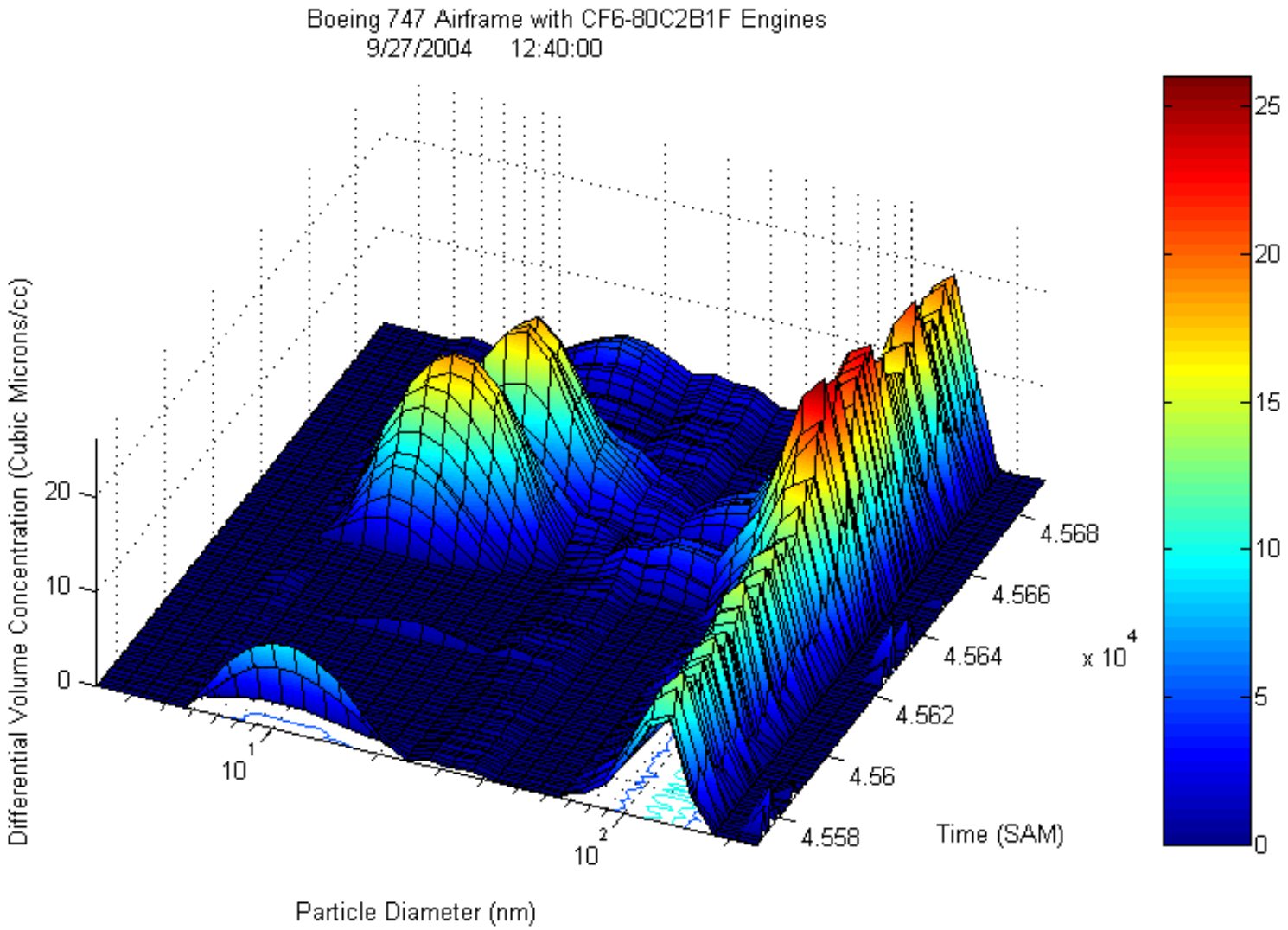

Boeing 757-200 Airframe with PW 2037 Engines
9/27/2004 12:32:26
Differential Volume Concentration (Cubic Microns/cc)
15
10
5
0
10^1
10^2
Particle Diameter (nm)
4.514
4.516
4.518
4.52
4.522
4.524
x 10^4
Time (SAM)
15
10
5
0


Boeing 717 Airframe with BR715A1-30 Engines
9/29/2004 16:22:45
Particle Number (millions/cc)
Particle Volume (cubic microns/cc)
CO2 (parts per million)
Total Particle Concentration
CO_2
Time(SAM)
0
2
4
6
8
10
12
14
16
18
390
410
430
450
470
490
510
58935
58945
58955
58965
58975
58985
58995
59005
59015
59025
59035
59045
59055

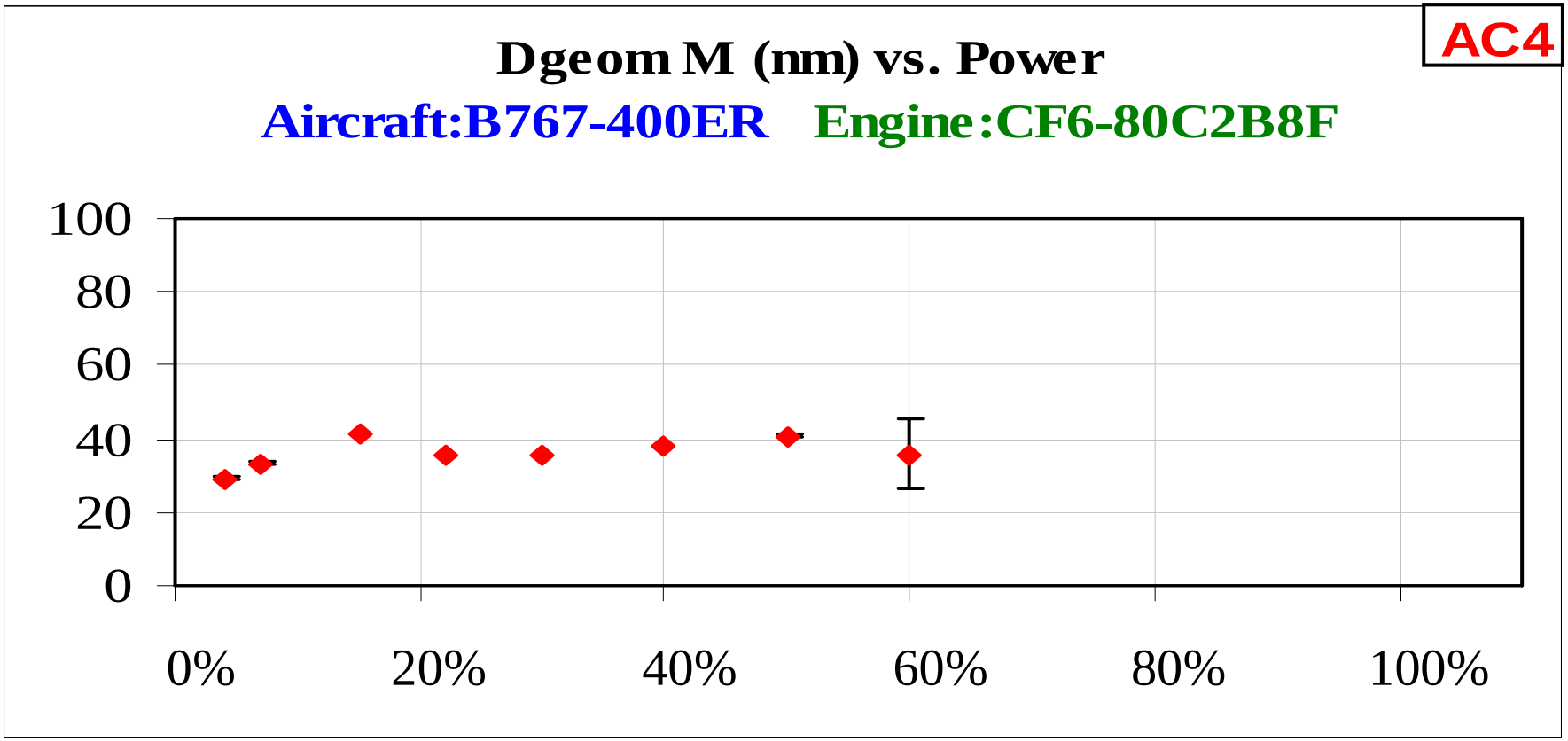

Boeing 717 Airframe with BR715A1-30 Engines
9/29/2004 16:22:45
Differential Volume Concentration (Cubic Microns/cc)
25
20
15
10
5
0
10^1
10^2
Particle Diameter (nm)
5.894
5.896
5.898
5.9
5.902
5.904
x 10^4
Time (SAM)
25
20
15
10
5
0

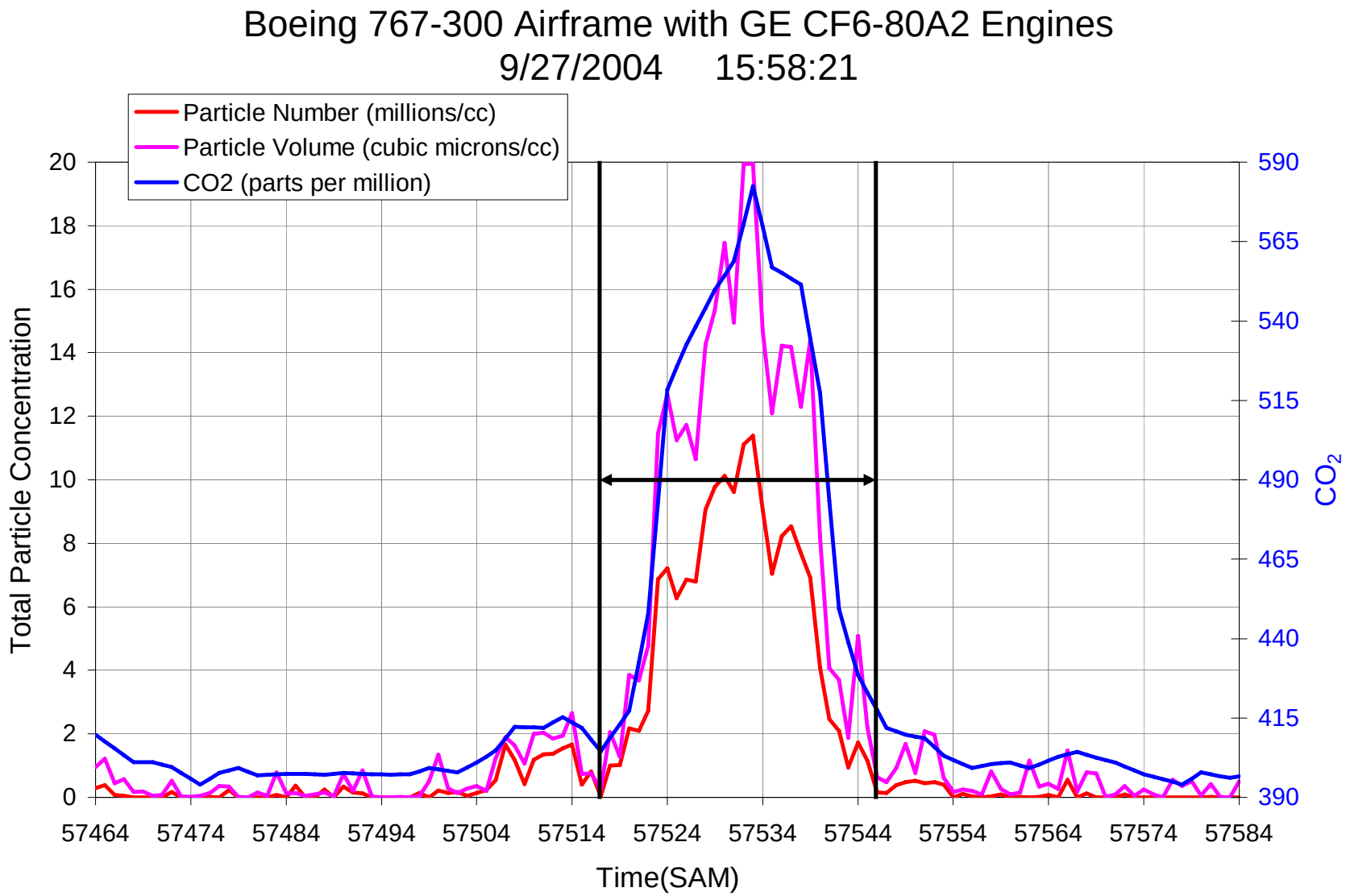

AC1
Dgeom M (nm) vs. Power
Aircraft: MD-88 Engine:JT8D-219
100
80
60
40
20
0
0%
20%
40%
60%
80%
100%


Boeing 747 Airframe with CF6-80C2B1F Engines
9/27/2004 12:40:00
Particle Number (millions/cc)
Particle Volume (cubic microns/cc)
CO2 (parts per million)
Total Particle Concentration
CO_2
Time(SAM)
0
3
6
9
12
15
390
410
430
450
470
490
510
530
550
570
45571
45581
45591
45601
45611
45621
45631
45641
45651
45661
45671
45681
45691

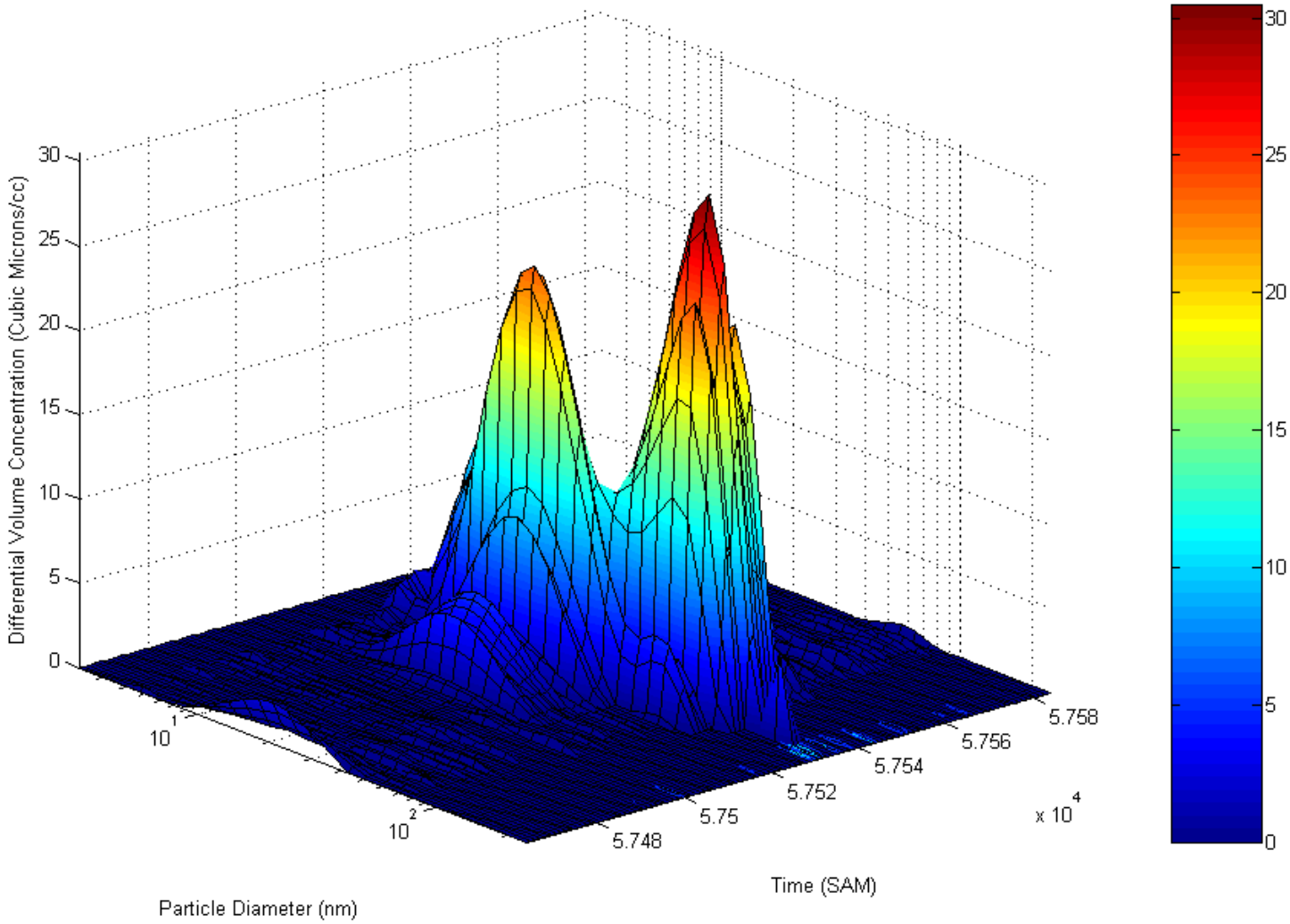

Boeing 747 Airframe with CF6-80C2B1F Engines
9/27/2004 12:40:00
Differential Volume Concentration (Cubic Microns/cc)
20
10
0
10^1
10^2
Particle Diameter (nm)
4.568
4.566
4.564
4.562
4.56
4.558
x 10^4
Time (SAM)
25
20
15
10
5
0

AC4


Dgeom M (nm) vs. Power
Aircraft:B767-400ER Engine:CF6-80C2B8F
100
80
60
40
20
0
0%
20%
40%
60%
80%
100%

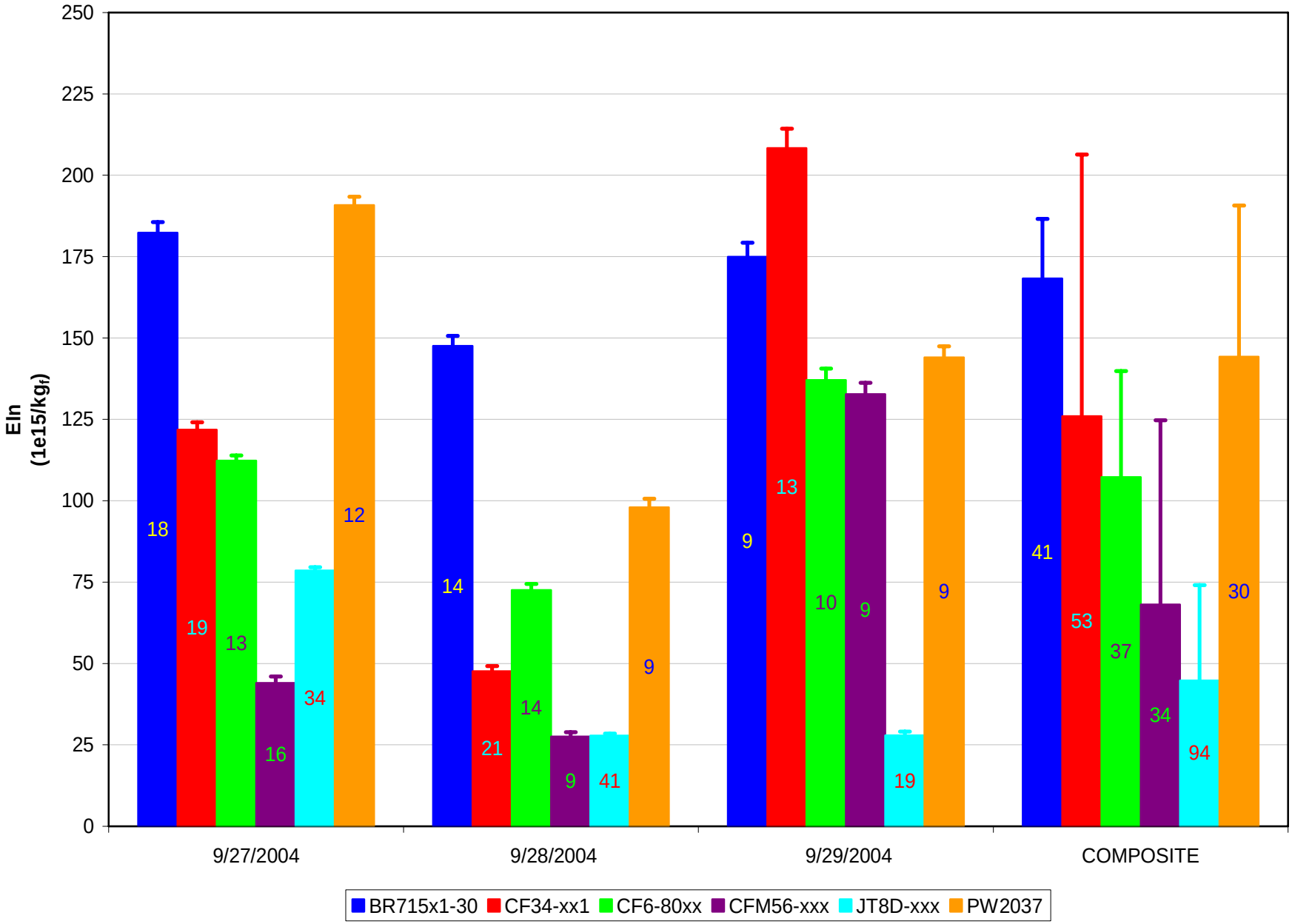

Boeing 767-300 Airframe with GE CF6-80A2 Engines
9/27/2004 15:58:21
Particle Number (millions/cc)
Particle Volume (cubic microns/cc)
CO2 (parts per million)
Total Particle Concentration
0
2
4
6
8
10
12
14
16
18
20
390
415
440
465
490
515
540
565
590
CO2
57464
57474
57484
57494
57504
57514
57524
57534
57544
57554
57564
57574
57584
Time(SAM)

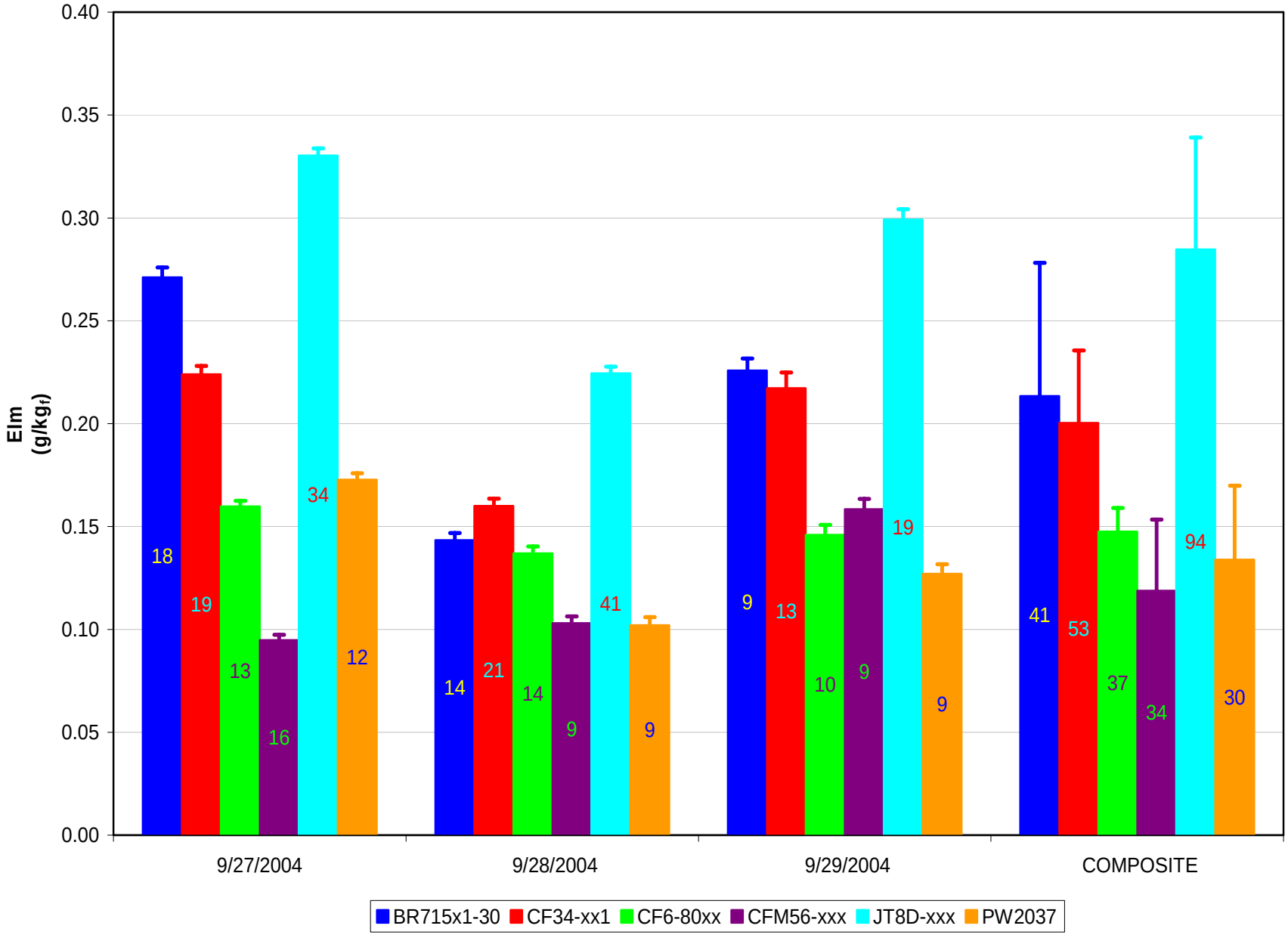
B767-300 with GE CF6-80A2



Compilation of 289 take-off events

- Six popular engine types
  - ✓BR715 B717 (Air Tran)
  - ✓CF34 Bombadier, Embraer, ACAC RJ's
  - ✓CFM56 DC8, B737, A319, A320, A340
  - ✓CF6-80 B747, B767, MD11, DC10, A300, A310, A330
  - ✓JT8D B727, B737, DC9
  - ✓PW2037 B757


250
225
200
175
150
125
100
75
50
25
0
EIn
(1e15/kgf)
18
19
13
16
34
12
14
21
14
9
41
9
9
13
10
9
19
9
41
53
37
34
94
30
9/27/2004
9/28/2004
9/29/2004
COMPOSITE
BR715x1-30
CF34-xx1
CF6-80xx
CFM56-xxx
JT8D-xxx
PW2037


0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
EIm (g/kgf)
18
19
13
16
34
12
14
21
14
9
41
9
9
13
10
9
19
9
41
53
37
34
94
30
9/27/2004
9/28/2004
9/29/2004
COMPOSITE
BR715x1-30
CF34-xx1
CF6-80xx
CFM56-xxx
JT8D-xxx
PW2037

Conclusions

- Demonstrated capabilities and techniques for measuring aircraft specific emissions from in-service aircraft on a non-interference basis with normal airport operations.
- Implemented at a major airport during routine operations without interference with airline activities.
- Acquired take-off data for over 500 departures
- Requires fast instrumentation, ~ 1 Hz.

Conclusions

- Particle emissions evolve as they disperse and show distinct features associated with engine technology.
- Data analysis requires integrating results from multiple PM and gas phase instrumentation.

Acknowledgements

Partnership for AiR

Transportation Noise
and Emission Reduction

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