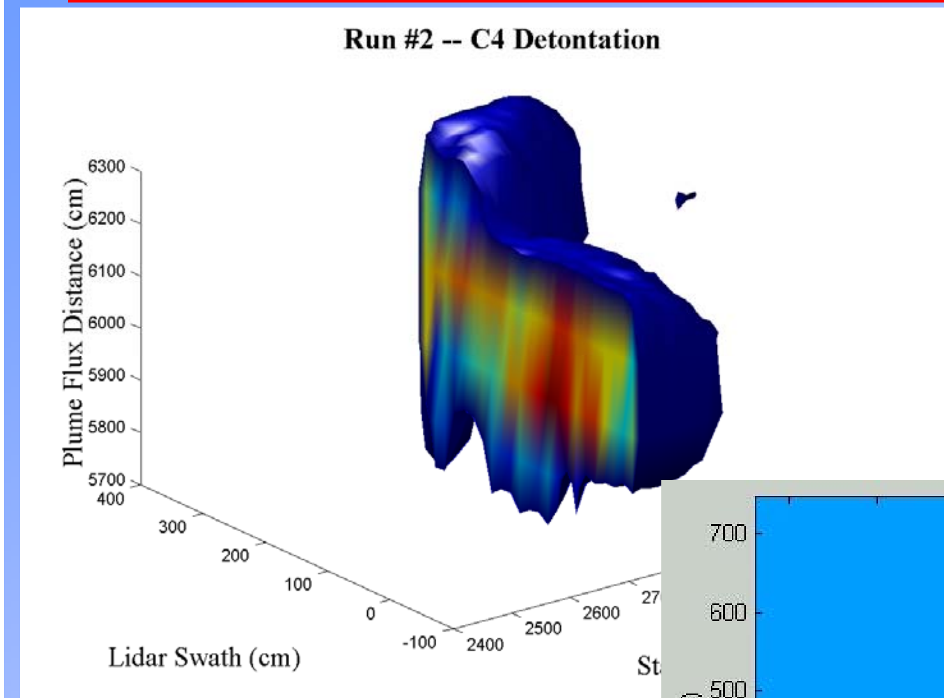
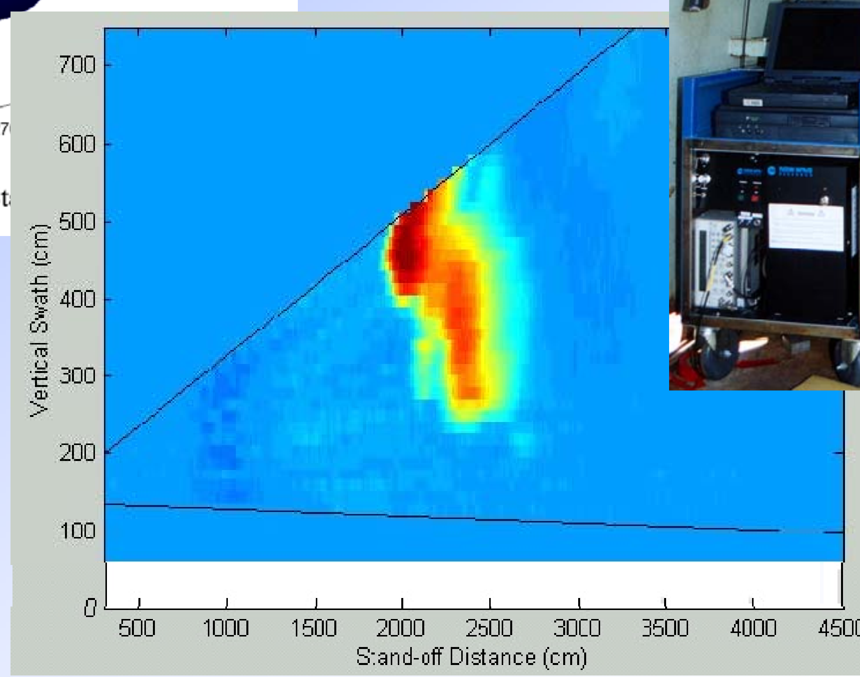
Plume Dimensioning and Volume Estimation Using Aerosol Lidar





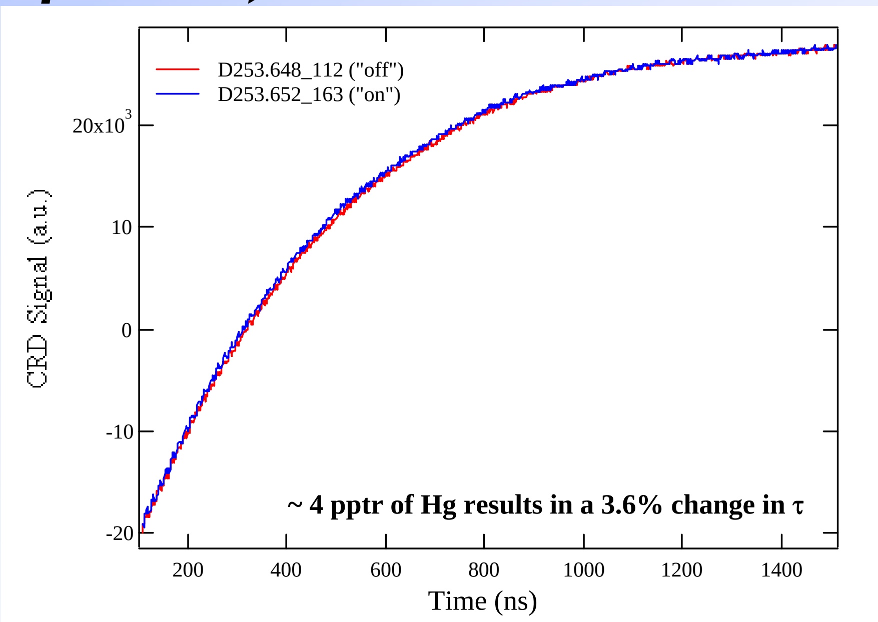
Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY

Other Activities

Mini-Raman Lidar System (MRLS) -DOE/NA and DOD

- ***short-range, non-contact detection/identification of chemical spills --*** *Rev. Sci. Instru. 2000; Trends in Appl. Spectros. (in press); US Patent -17 claims accepted (5/02)*
- ***UV Raman spectroscopy (in support of MRLS)***



UV - Cavity Ringdown Spectroscopy -

-- ambient pptr-level detection of Hg.

Project Team and Acknowledgements

Aberdeen Proving Grounds - 2001/12/21

Left to Right
???, Explosives expert, US Army Aberdeen Test Center
Jason Szabo, Photogrammetric Vol. Measurement, Vexcel
Art Sedlacek, LIDAR Vol. Measurement, BNL
Toni Wisbith, Battelle
Mike Holdren, Battelle
Bob Plastridge, Battelle
Jan Satola, Battelle
Chet Spicer, Battelle
Bill Bolt, Test Director, US Army Aberdeen Test Center
Dale, ???, US Army Aberdeen Test Center

"Behind the scenes":

Tamera Clark-Rush AEC
Dr. Randall Cramer - NSWC
Edward Baroody -- NSWC
Steven Rasmussen -- Hill AFB

TRI Emissions From Munitions Activities

Problem Statement

- *DoD Facilities are being required by Executive Order to report emissions of Toxic Release Inventory chemicals*
    - *More than 600 TRI chemicals*
    - *Numerous types of munitions with potential TRI emission*
- *Numerous DoD sites generate TRI emissions*
- *Field verification of emissions estimates needed under realistic conditions*

TRI Emissions From Munitions Activities

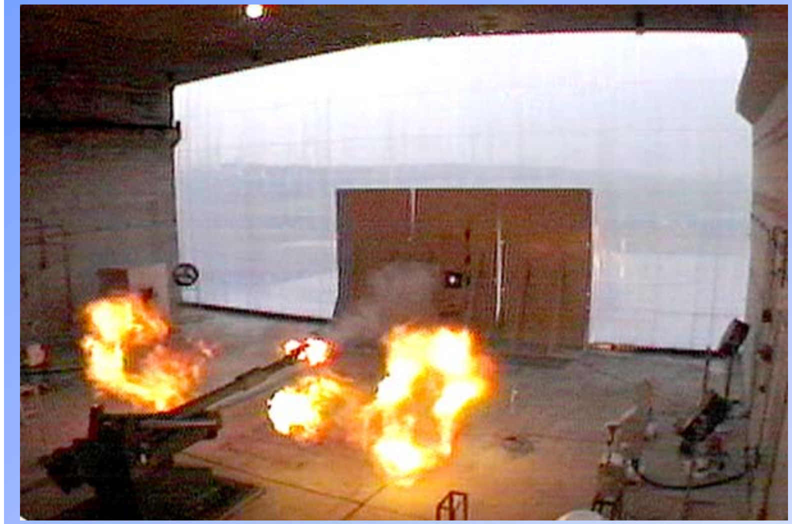
Technical Objective

- ***Develop a methodology and tools to determine emission factors from munitions activities at DoD facilities***
- ***Apply this approach to determine emission factors for TRI chemicals from selected munitions activities***
  - ***Point of Discharge***
  - ***Point of Impact***

TRI Emissions From Munitions Activities

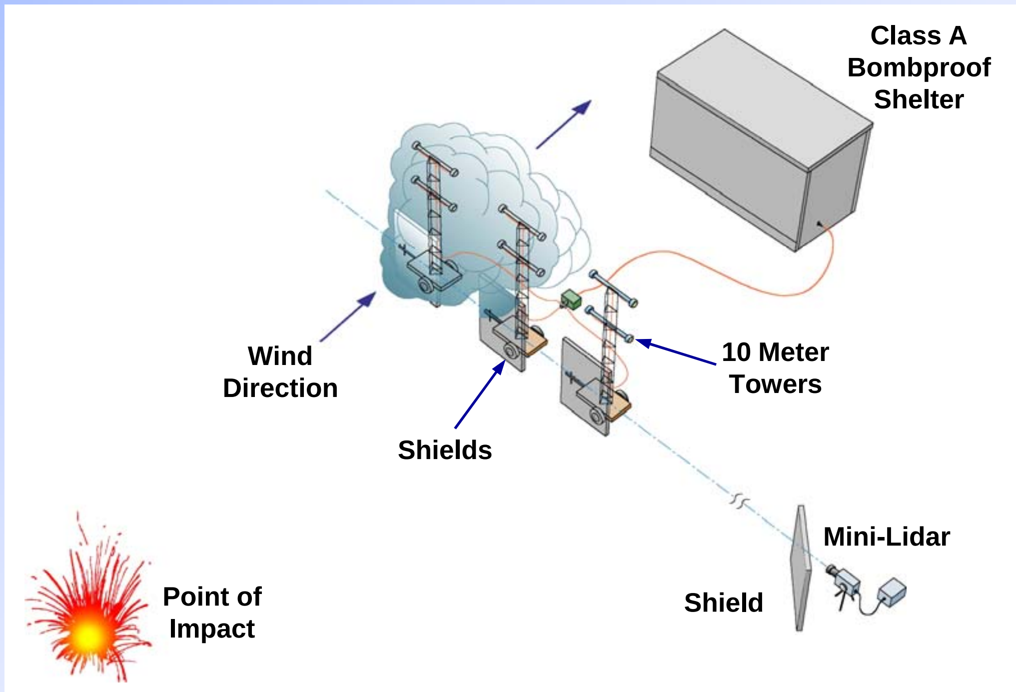
Technical Approach

Point of Discharge



- *Comparability with ATC standard measurement methods*

Point of Impact



Measurement Methods

Whole Air Sampling/GC-MS	
acetaldehyde	chlorobenzene
acrolein	chloromethane
acrylonitrile	chloroprene
benzene	ethylbenzene
1,3-butadiene	methyl tert-butyl ether
carbon tetrachloride	vinyl acetate
chloroform	bromoform
1,2-dibromoethane	o-xylene
1,2-dichloroethane	m-xylene
1,2-dichloropropane	p-xylene
1,1,2,2-tetrachloroethane	styrene
tetrachloroethylene	benzyl chloride
trichloroethylene	1,2-dichlorobenzene
vinyl chloride	1,4-dichlorobenzene
toluene	1,3-dichlorobenzene
allyl chloride	hexachloroethane
bromomethane	1,2,4-trichlorobenzene
carbon disulfide	carbonyl sulfide
acetonitrile	naphthalene

- **Modified EPA Method TO14**
- **Detection Limit of 0.1 ppb**

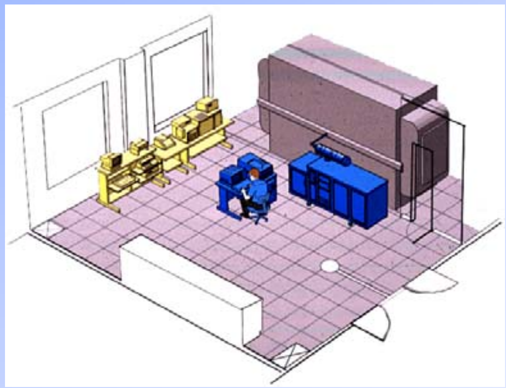
Proton Transfer Reaction-MS
anthracene
naphthalene
quinoline
nitrobenzene
o-dinitrobenzene
m-dinitrobenzene
p-dinitrobenzene
2,4-dinitrotoluene
2,6-dinitrotoluene
phenol
2-nitrophenol
4-nitrophenol
2,4-dinitrophenol
benzidine
biphenyl
dibenzofuran
4-aminobiphenyl

- **Relatively new technology**
- **Continuous real-time monitoring**
- **Detection limits of 0.05 ppb for many chemicals of interest**

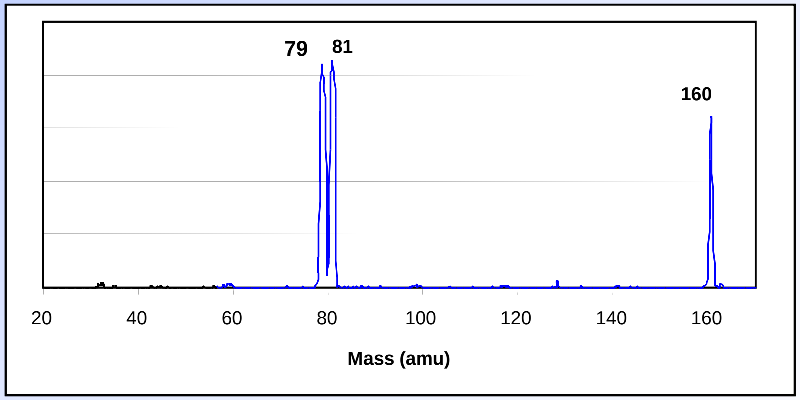
Measurement Methods

Measurement System Evaluation Example: APCI Tandem Mass Spectrometer

- Prepare test atmospheres of target chemicals in $17m^3$ environmental chamber



- Select parent/daughter ion pairs for specific monitoring
- Calibrate instrument with authentic compound
- Determine detection limits under field campaign settings
- Evaluate sample line losses
- Select 5-8 chemicals for monitoring



Atm. Pressure Chemical Ionization Tandem MS
nitroglycerine
formic acid
hydrogen cyanide
chlorine
o-dinitrobenzene
m-dinitrobenzene
p-dinitrobenzene
2,4-dinitrotoluene
2,6-dinitrotoluene
N-nitrosodiphenylamine
N-nitrosodimethylamine
N-nitrosodiethylamine
aniline
dimethylphthalate
diethylphthalate
dibutylphthalate
nitric acid
hydrogen chloride

TRI Emissions From Munitions Activities

Overview

- ***Develop list of target TRI chemicals***
- ***Select munitions/activities***
- ***Prepare Mini-Lidar for munitions applications***
- ***Demonstrate sampling and analysis approach***

→ ***Conduct plume dimensions field trial***

→ ***Conduct point-of-discharge field studies***

→ ***Conduct point-of-impact field studies***

Methods Tested for Plume Dimensioning

Chemical measurements:

- carbon balance
- Zeon trace gas concentration

LIDAR – plume volume measurements:

- Oscillating laser beam
- range to near and far edge of plume

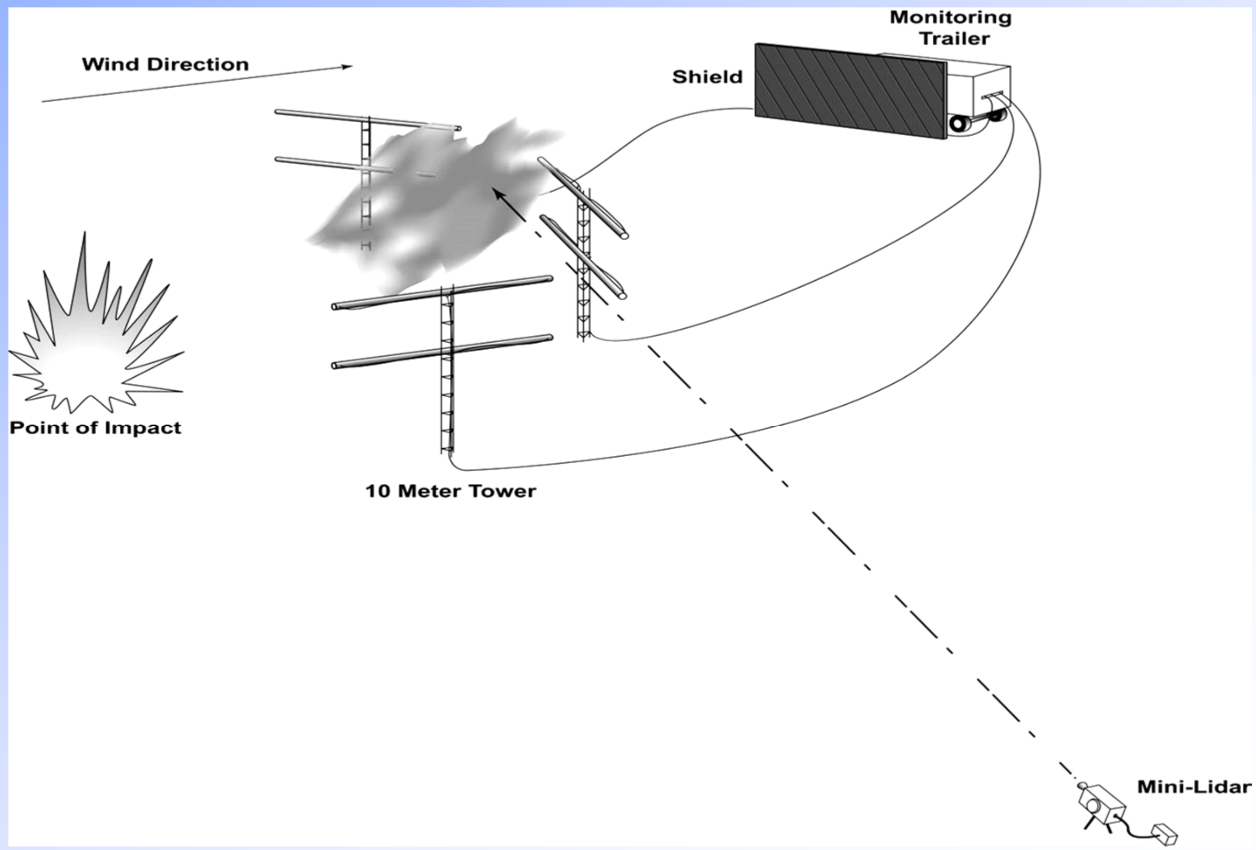
Photogrammetric plume volume measurements:

- 4 JVC digital video cameras (DVC)
- 4 simultaneous viewpoint
- approximately 90° to each other

TRI Emissions From Munitions Activities

Point of Impact Studies
Characterize Point of Impact Emissions Outdoors at the Aberdeen Test Center Test Range

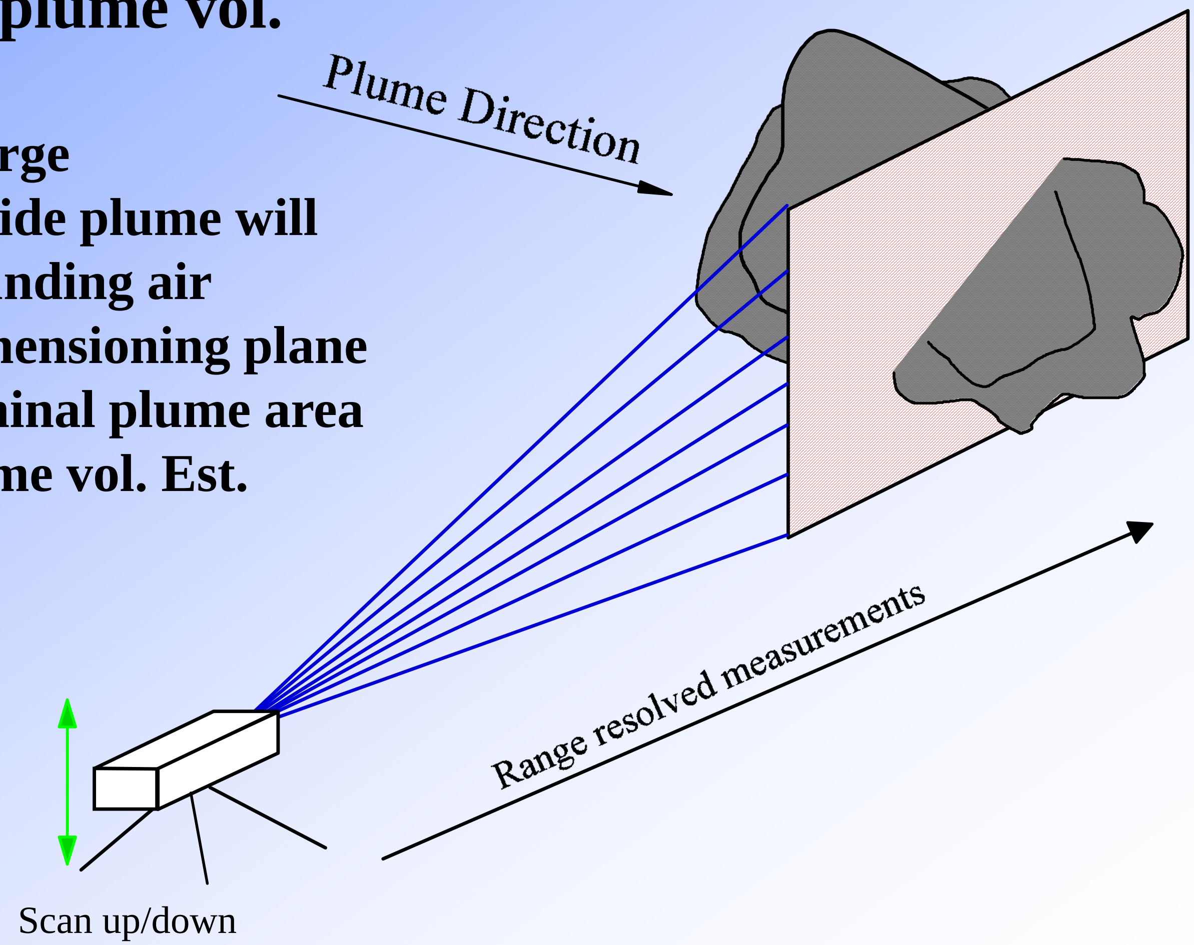
- ***Static detonation (air burst or buried)***
- ***Multiple towers to maximize chance of sampling emission cloud***
- ***Two field campaigns***



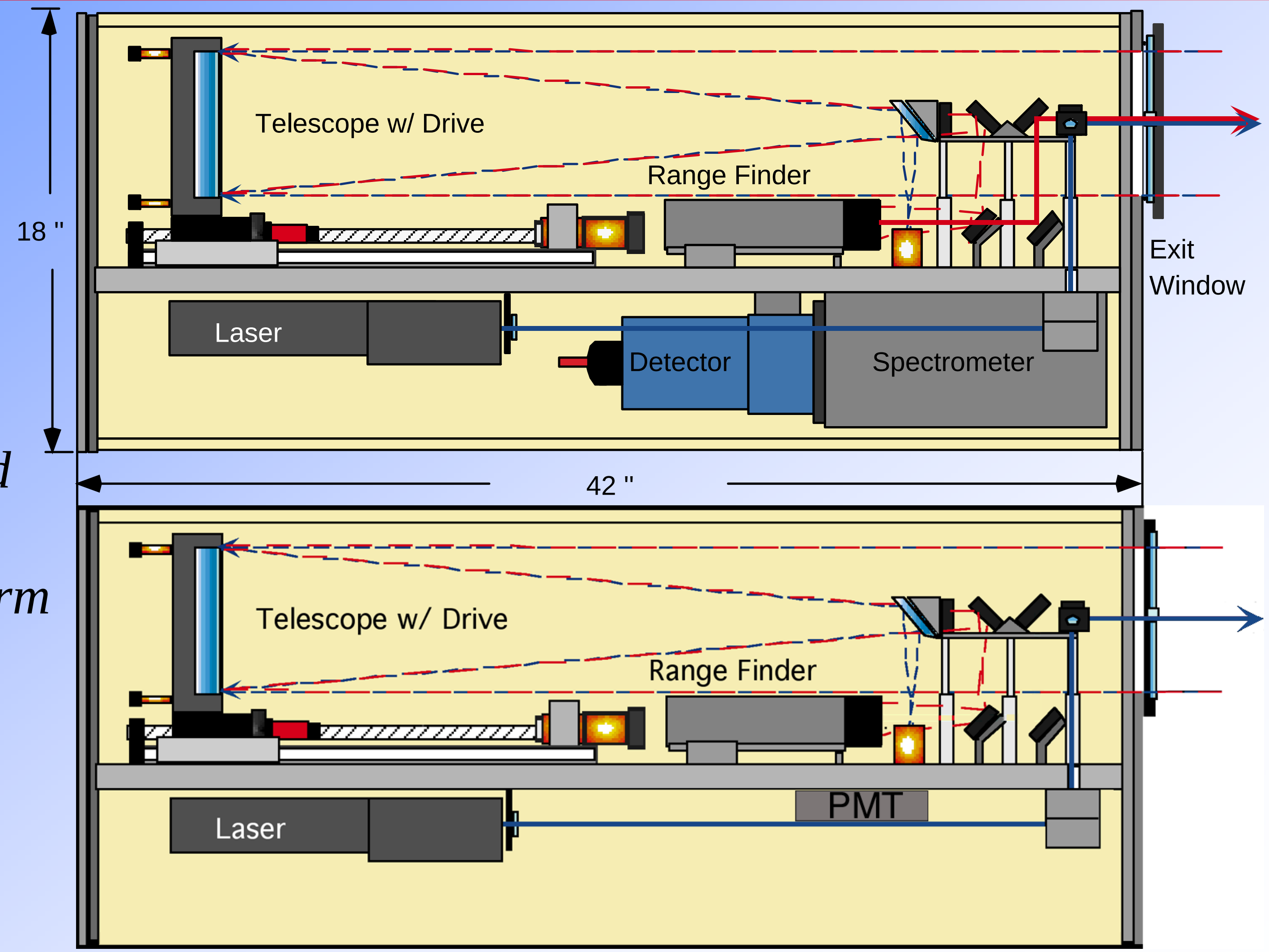
Use of Elastic Lidar for Plume Dimensioning

Exploit Mie Scattering to define plume boundary & est. plume vol.

> X-sections are quite large
> Particulate density inside plume will be different from surrounding air
> Creation of a lidar dimensioning plane
> Direct measure of nominal plume area
> Wind vector gives plume vol. Est.

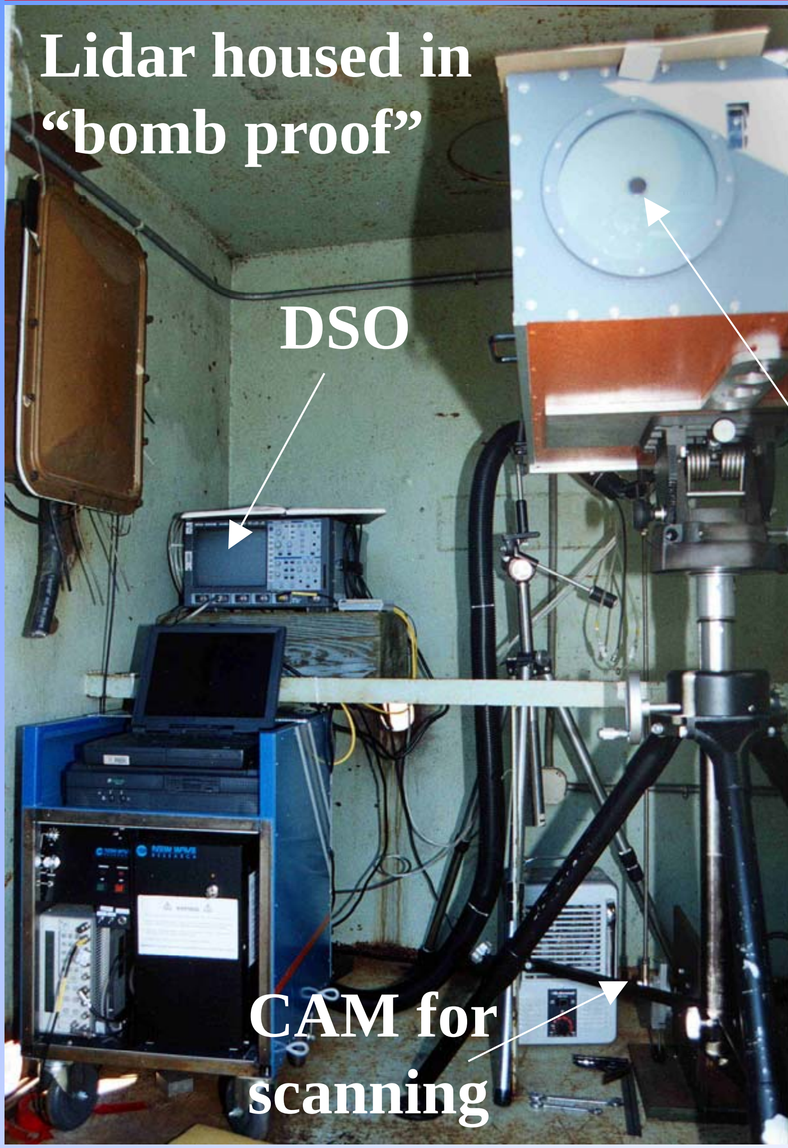


Reconfigured the MRLS to a Mie Lidar System

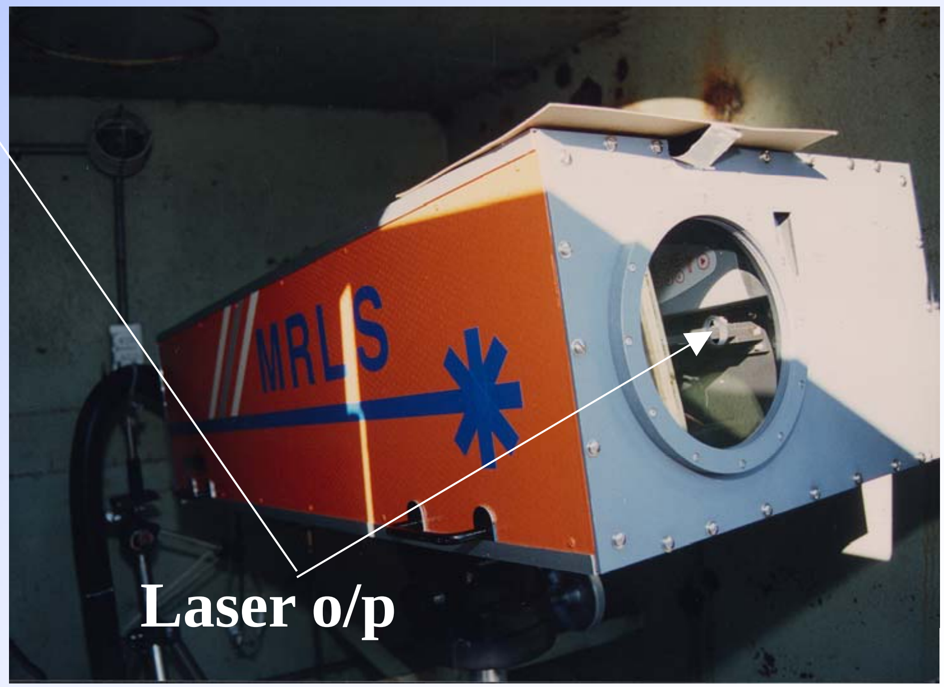


Mie Lidar platform can be reconfigured back to original Raman lidar platform

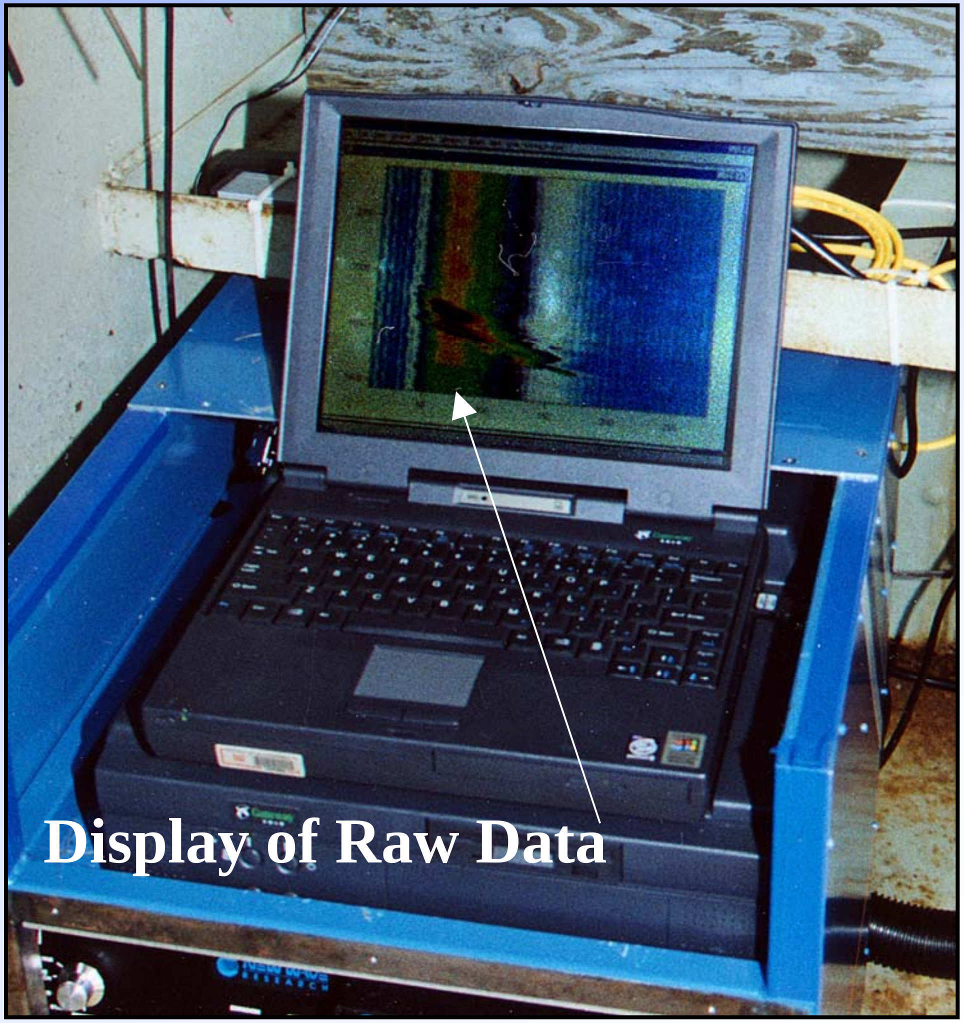
Reconfigured the MRLS to a Mie Lidar System



Laser: 266 nm YAG (5 mJ/pulse) 20 Hz
Detector: Solar-blind PMT
ADC: LeCroy 9354 DSO (500 MHz)
Computer: GateWay Solo (P-II)

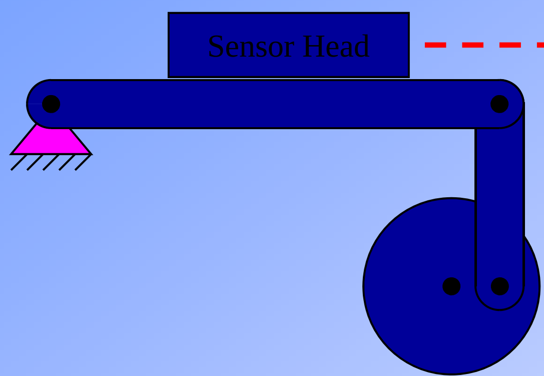


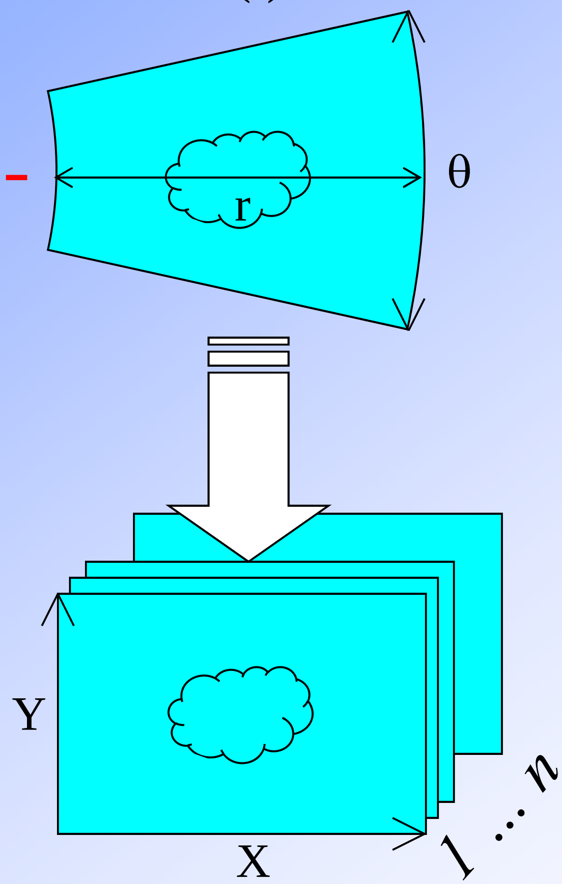
Mini-Mie Lidar System



Mechanics of Measuring Plumes with Scanning Lidar

Mie Lidar detect clouds over a range of distances (r)





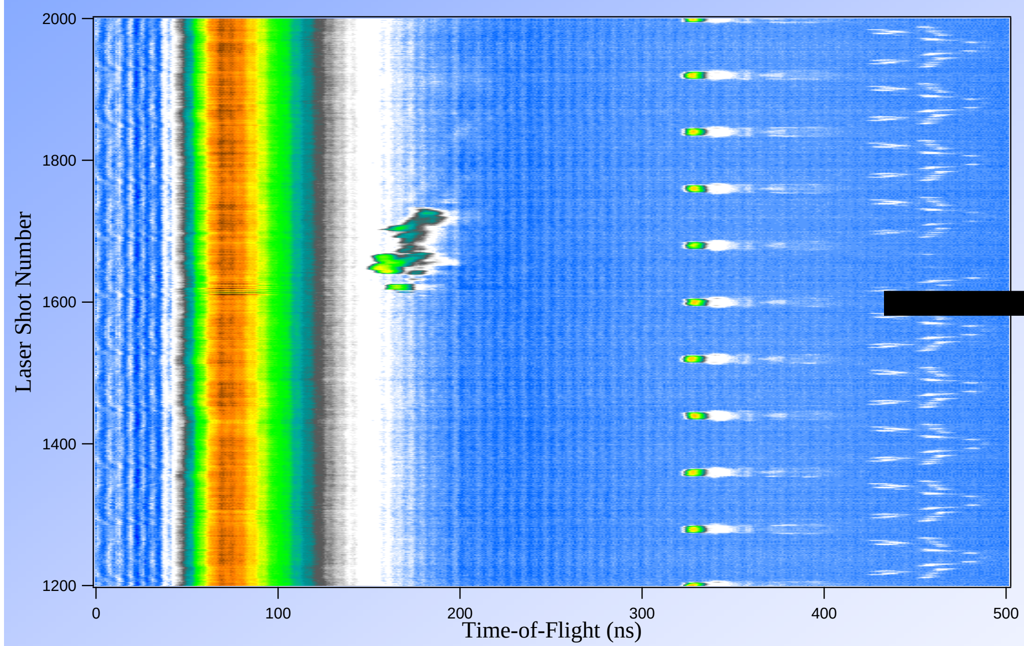
An oscillating mechanism sweeps the laser beam up and down (θ) to sample plumes (cross section)

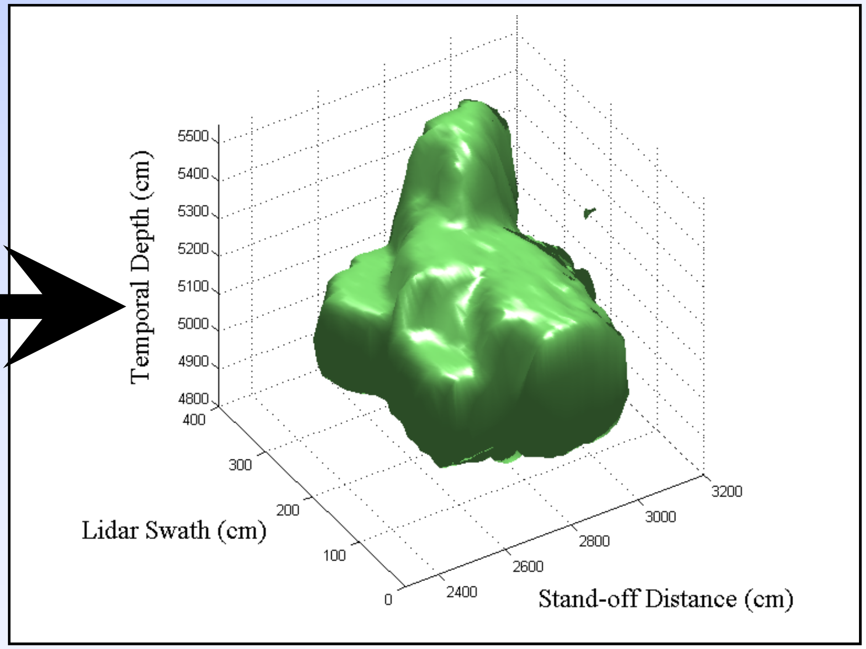
The goal is to measure plume area & With knowledge of wind vector the plume volume

Data Acquisition methodology results in a "data-cube" which contains lidar images as a function of time

Data Reduction Approach

- *Acquired images are distorted (polar scan coordinates)*
- *Alternate images are reversed (bi-directional scanning)*
- *Measure plume area and sum over all frames (i.e., data cube)*
- *Background interference (background removal)*
- *Detect plumes and separate from background (segmentation).*



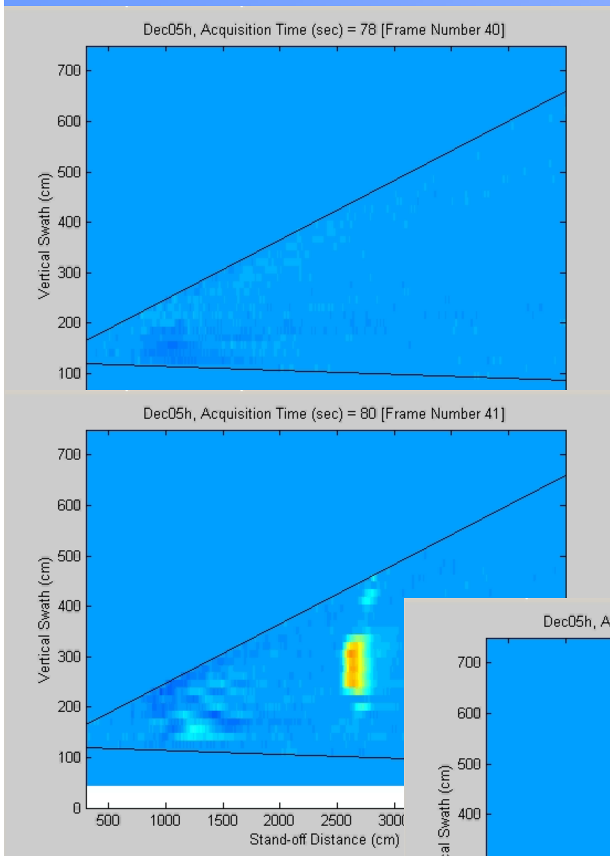


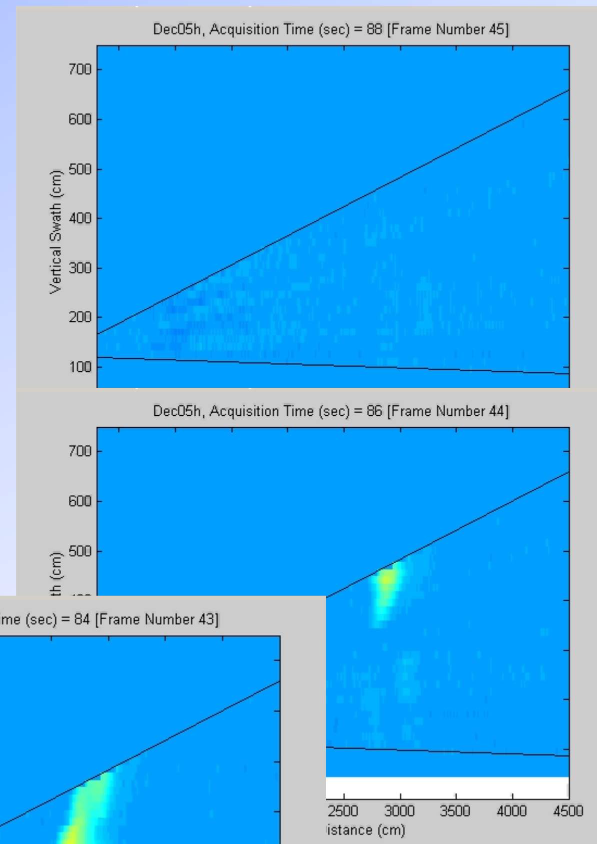
MatLab To the Rescue

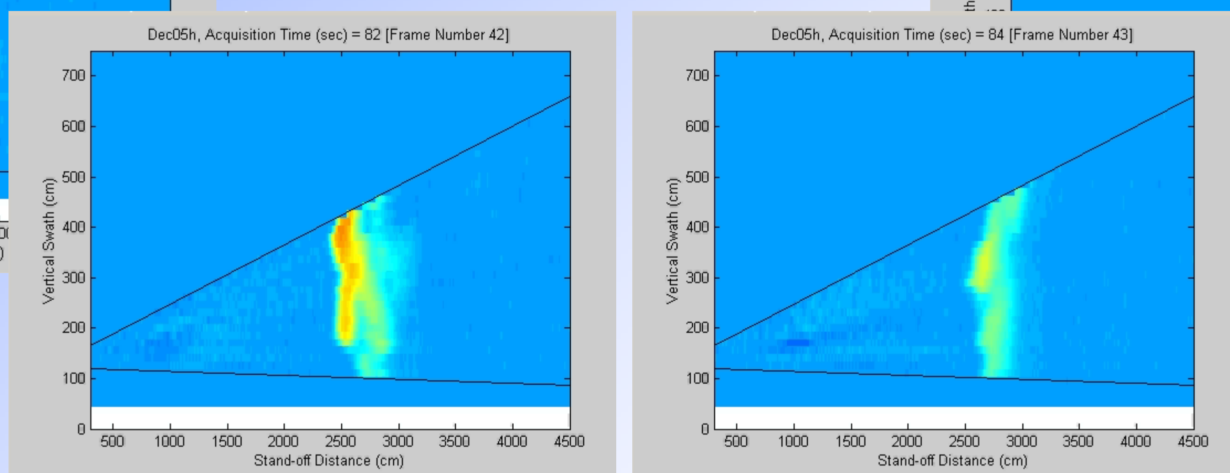
1. *Reverse alternate images (index & reshape matrices)*
2. *Background interference – **characterize** with ensemble median average, **remove** by template image subtraction*
3. *Image distortion – **model** scanning system, develop **spatial transform**, synthesize test image to **validate** the algorithm, then **use** the transform on real images*
4. *Detect clouds – **characterize** intensity distribution, establish a robust **threshold** level using image statistics and use threshold to **segment** clouds (white) from background (black).*
5. *Measure cloud area (feature extraction) – count pixels and multiply by pixel area, then repeat over stack of images (batch processing) to get total area over all frames.*

Example of the Entire Data Reduction Process: Dec_03c

Each image represents a 2-second time slice.

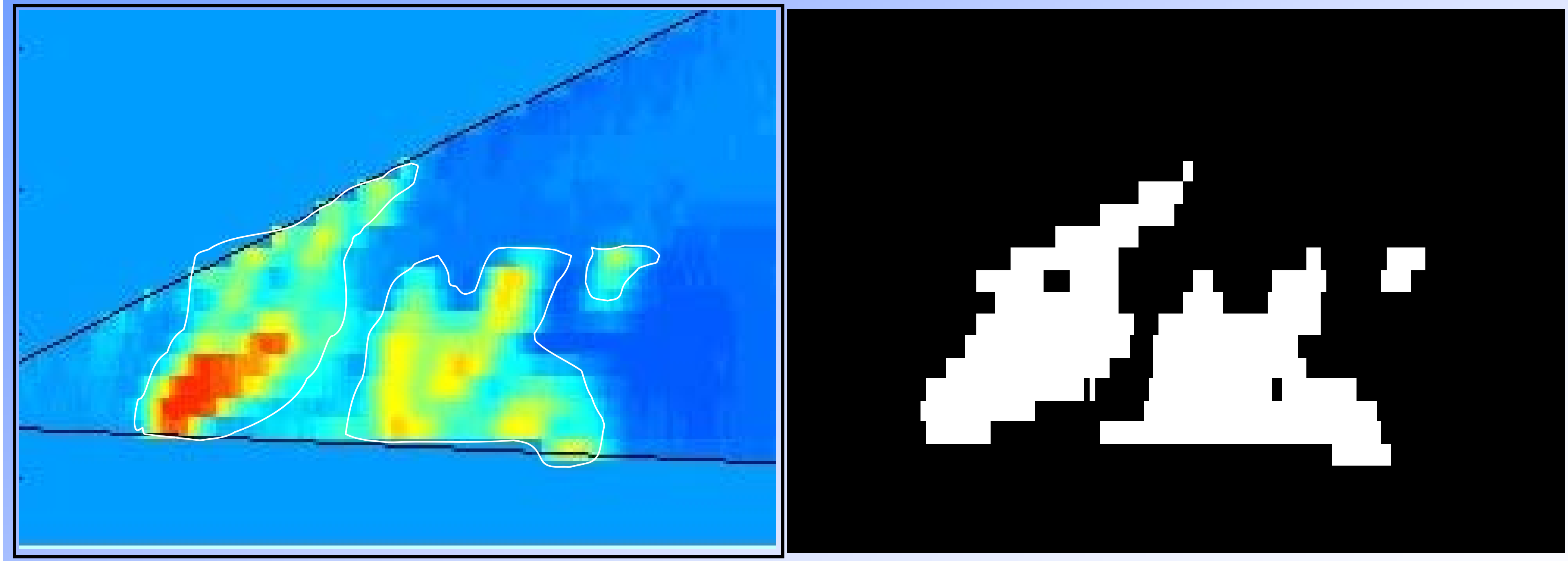






Detection of Plumes Against Background

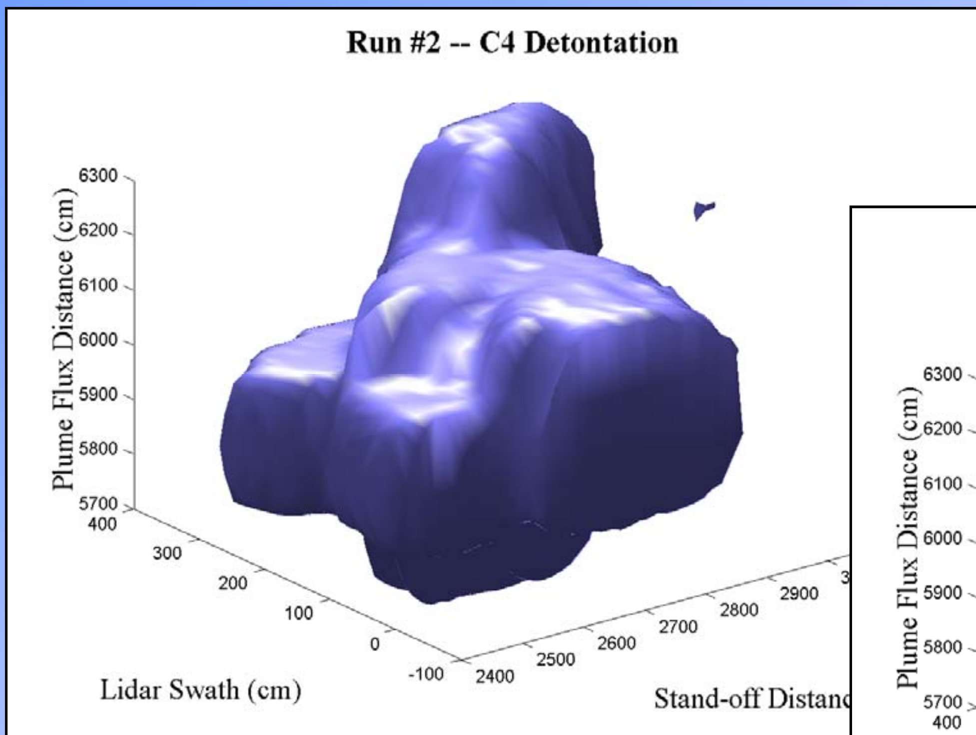
Lidar provides information on internal structure of plume

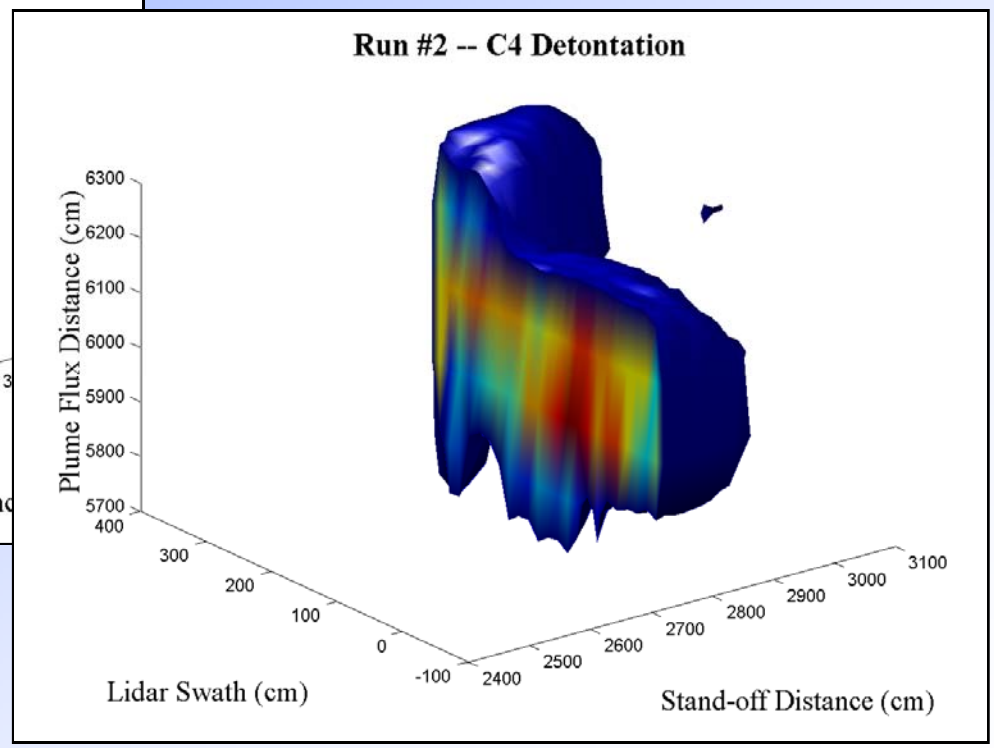


Automatic plume detection by setting detection threshold to 3σ above mean background

Lidar Provides Plume Boundary (Volume) Estimates as well as Estimates of Internal Structure of the Plume:

Dec_03c (run #3)





Two Types of Experiments: C4 Detonation and Smoke Grenade Release

C4:

1/4, 1/2 and 1# quantities
"Duration" of experiment: 5-30 seconds (depending on wind)
Concerns: Instrumentation durability (30 m from discharge)
Scan rate: 0.25 & 0.5 Hz

Smoke Grenade Release:

"Duration of obscurant release (60-90 seconds)
Green color
Scan rate: 0.25 Hz

Smoke Grenade Release

Run: #14
Smoke Grenade
Start time: 3:36:01 pm

Digital video: Vexcel

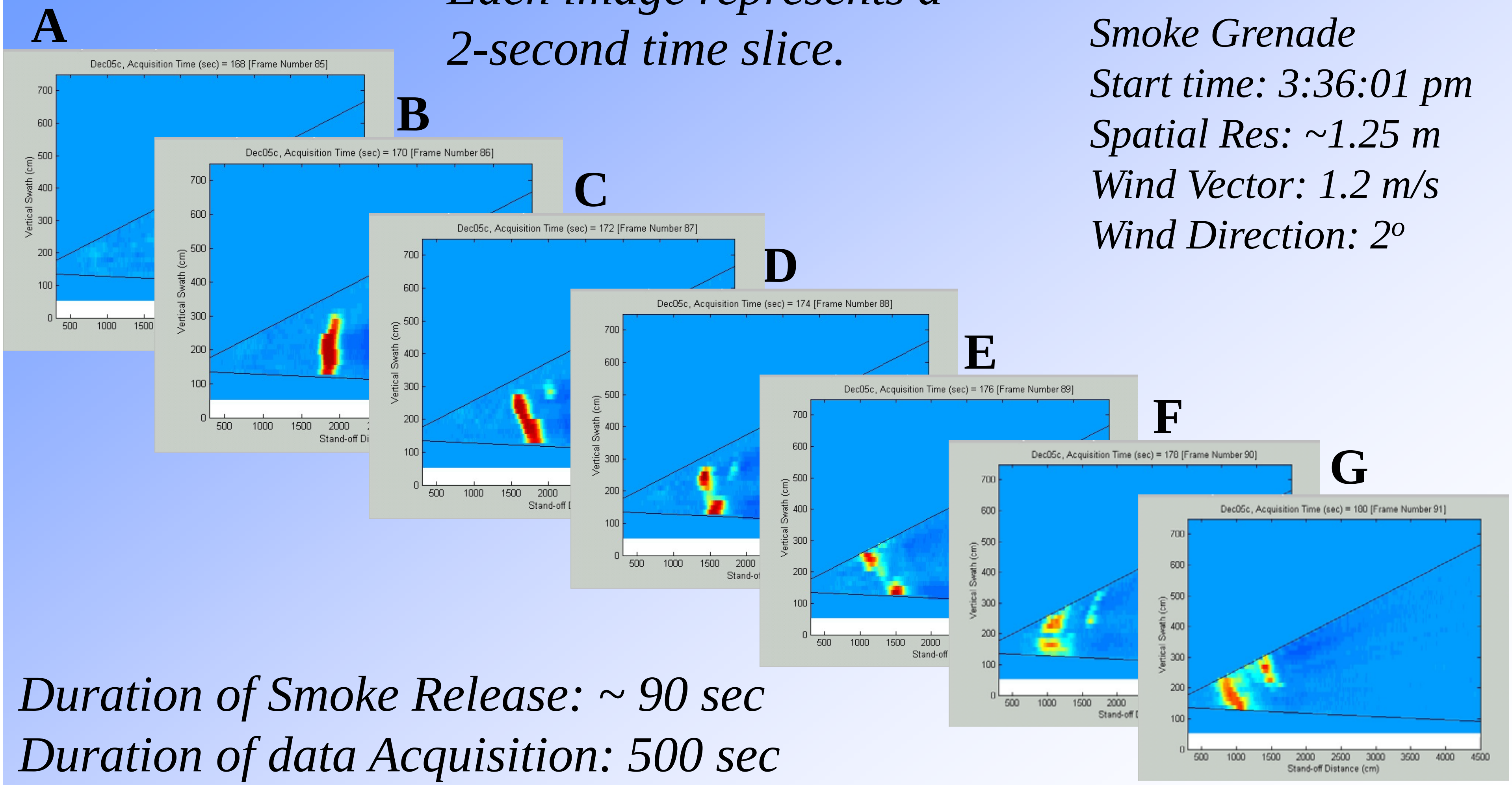
Measuring Cloud's Temporal Behavior with Scanning Lidar Smoke Grenade Release, 0.25 Hz Scan Rate

Measuring Cloud's Temporal Behavior with Scanning Lidar

Smoke Grenade Release – 0.25 Hz Scan Rate

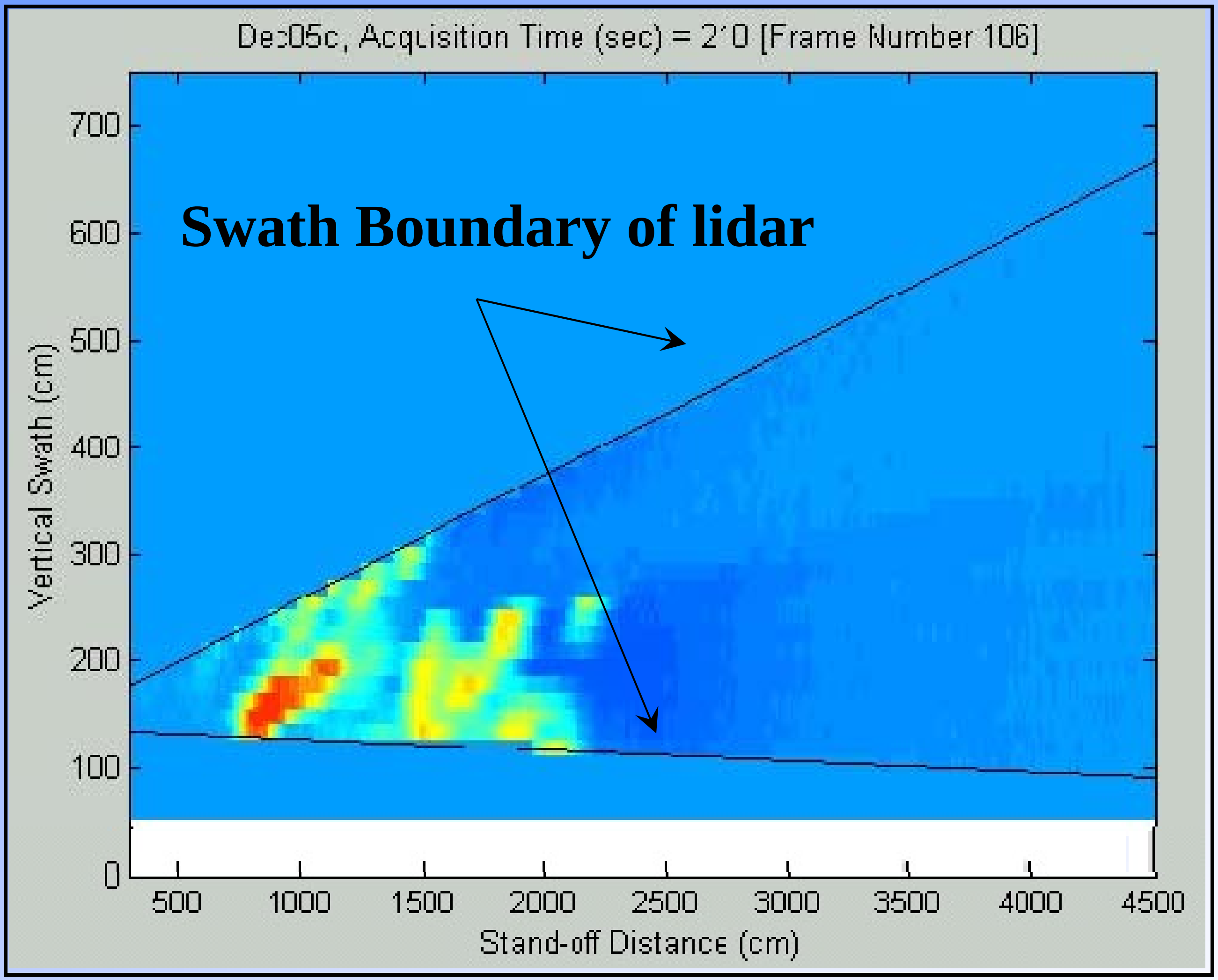
Each image represents a 2-second time slice.

Run: #12
Smoke Grenade
Start time: 3:36:01 pm
Spatial Res: ~1.25 m
Wind Vector: 1.2 m/s
Wind Direction: 2º



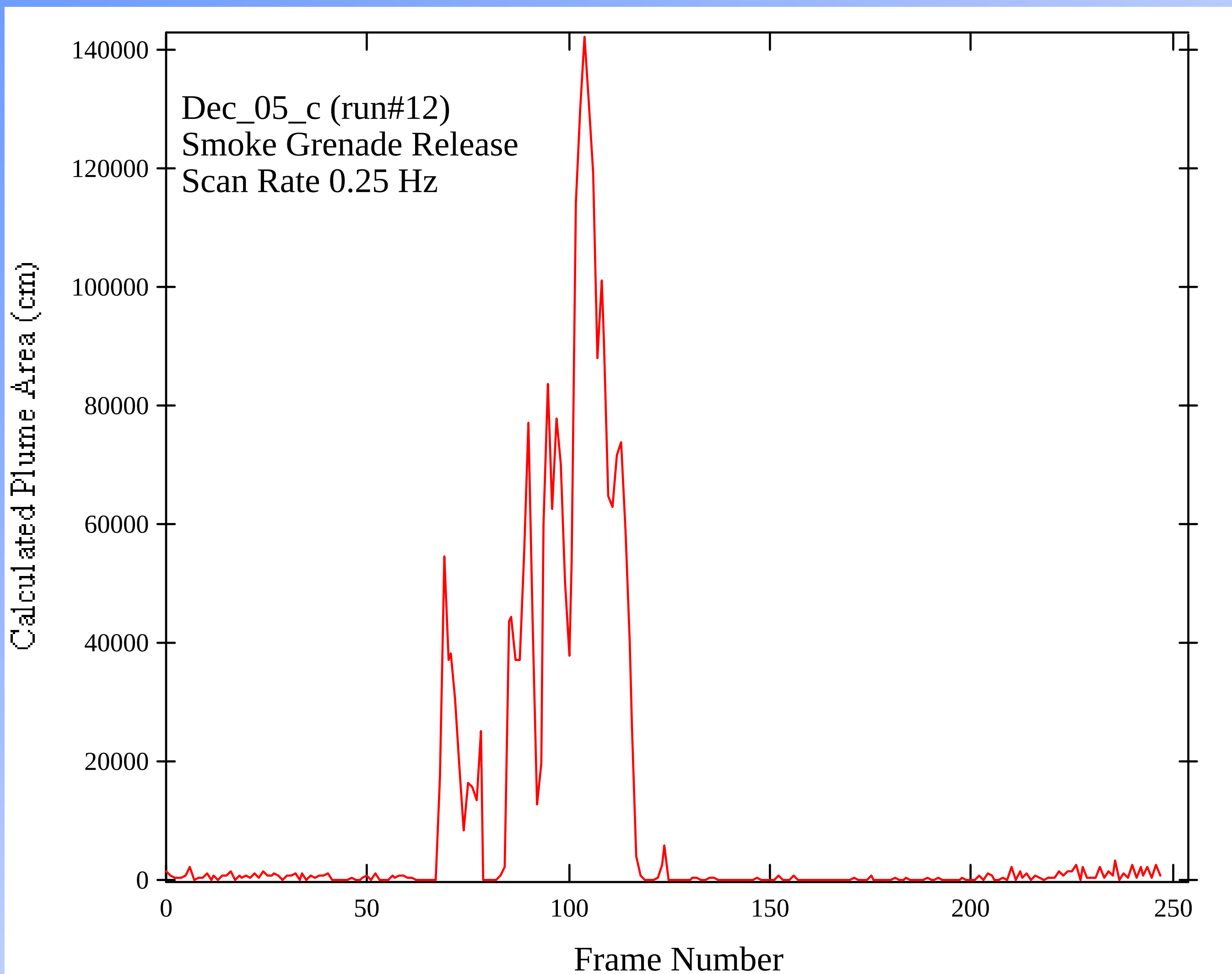
Duration of Smoke Release: ~ 90 sec
Duration of data Acquisition: 500 sec

Measuring Clouds with Scanning Lidar - Smoke Grenade Release



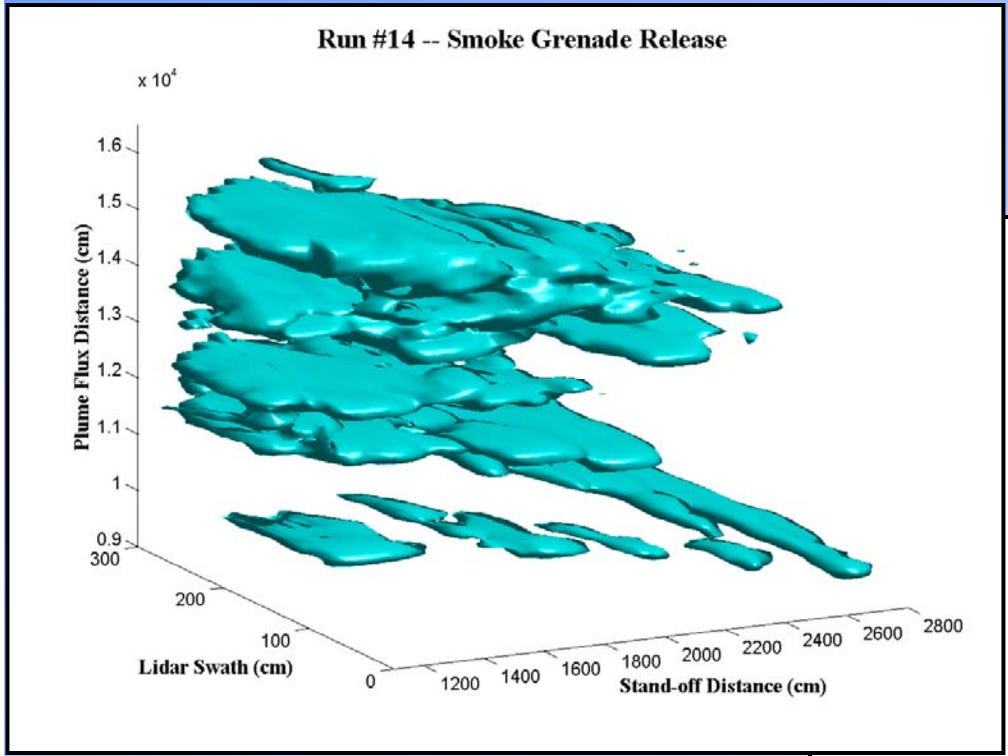
Run: #12
Smoke Grenade
Start time: 3:36:01 pm
Spatial Res: ~1.25 m
Wind Vector: 1.2 m/s
Wind Direction: 2º

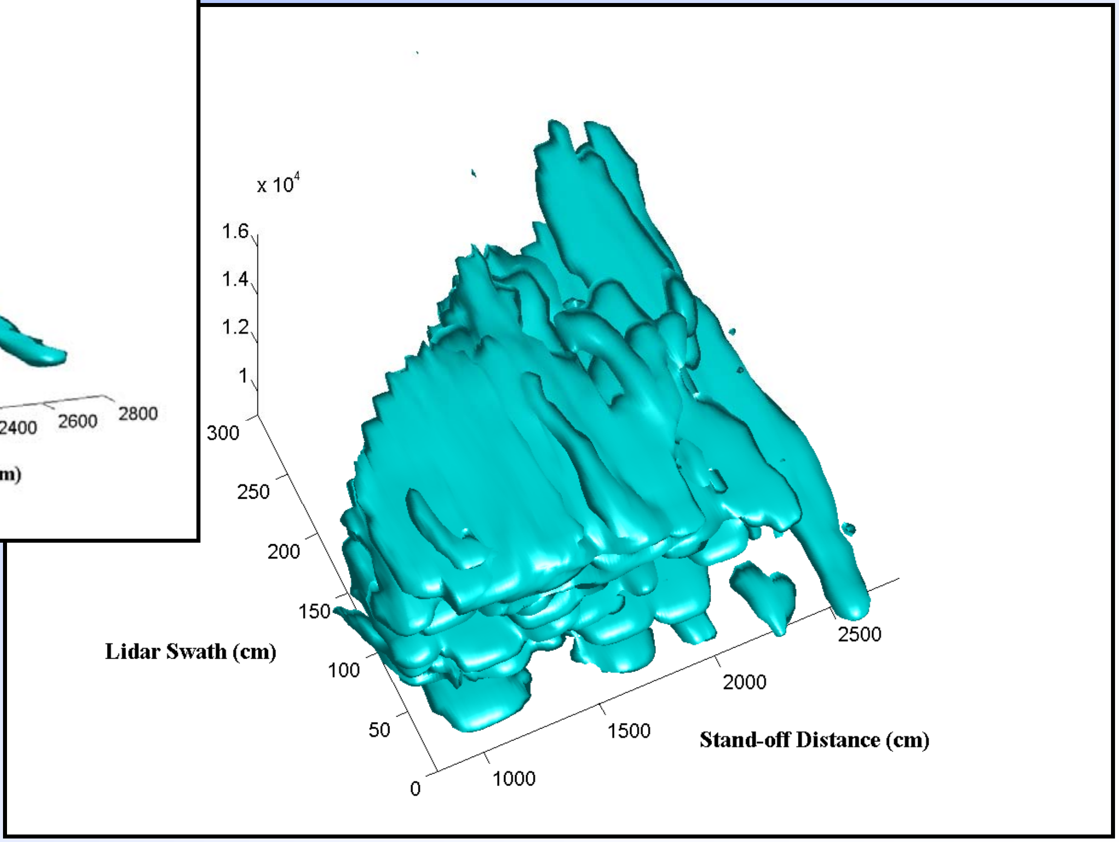
Measuring Cloud's Temporal Behavior with Scanning Lidar Smoke Grenade Release



Est. Total Volume : 612,306,000 cm^3 (37,365,204 in^3)

Measuring Cloud's Temporal Behavior with Scanning Lidar Smoke Grenade Release





C4 Detonation

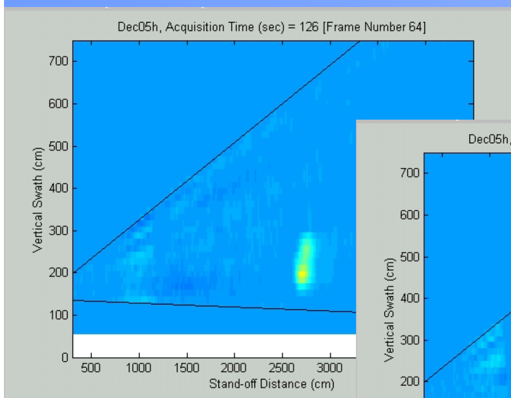
Run #17
0.5 # C4
Start time: 3:58:59

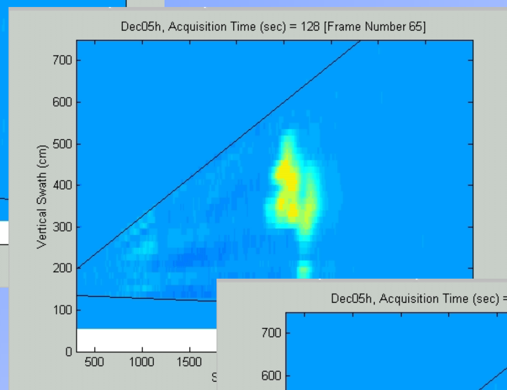
Digital video: Vexcel

Measuring Cloud's Temporal Behavior with Scanning Lidar C4 Release, 0.25 Hz Scan Rate

Run: #16
1/2 lbs C4
Start time: 3:36:01 pm
Wind Vector: 1.82 m/s
Wind Direction: 23^{o}

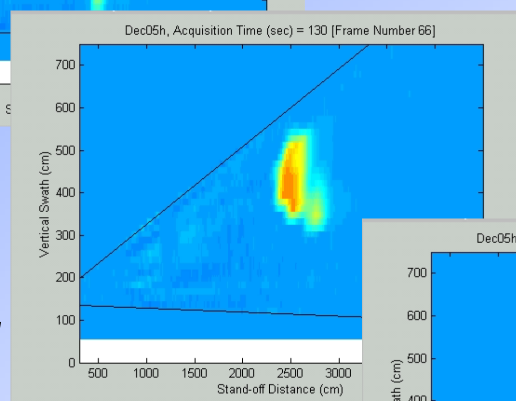
Measuring Plume's Temporal Behavior with Scanning Lidar - C4 Detonation

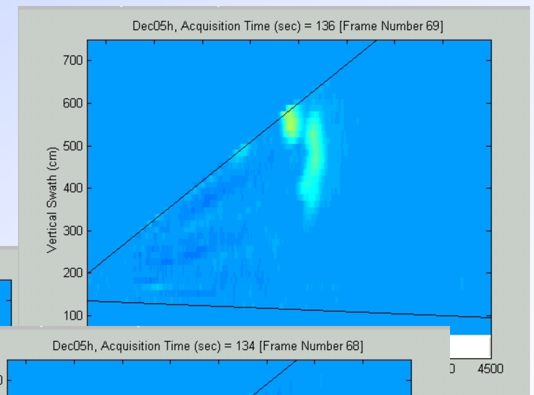




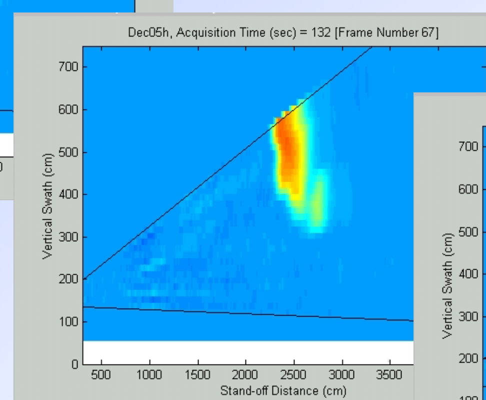
Each image is made-up of 1 laser shot at 40 different angles with 500 data pts per laser shot.

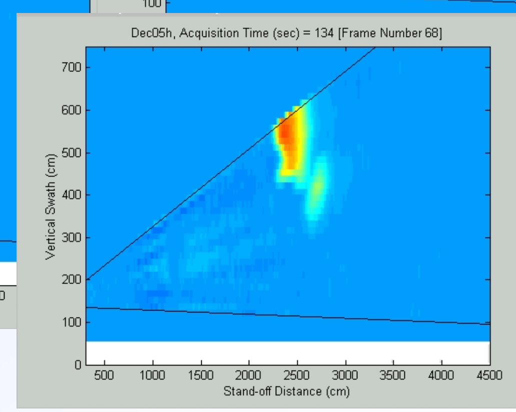
∴ 12-seconds = 200,000pts



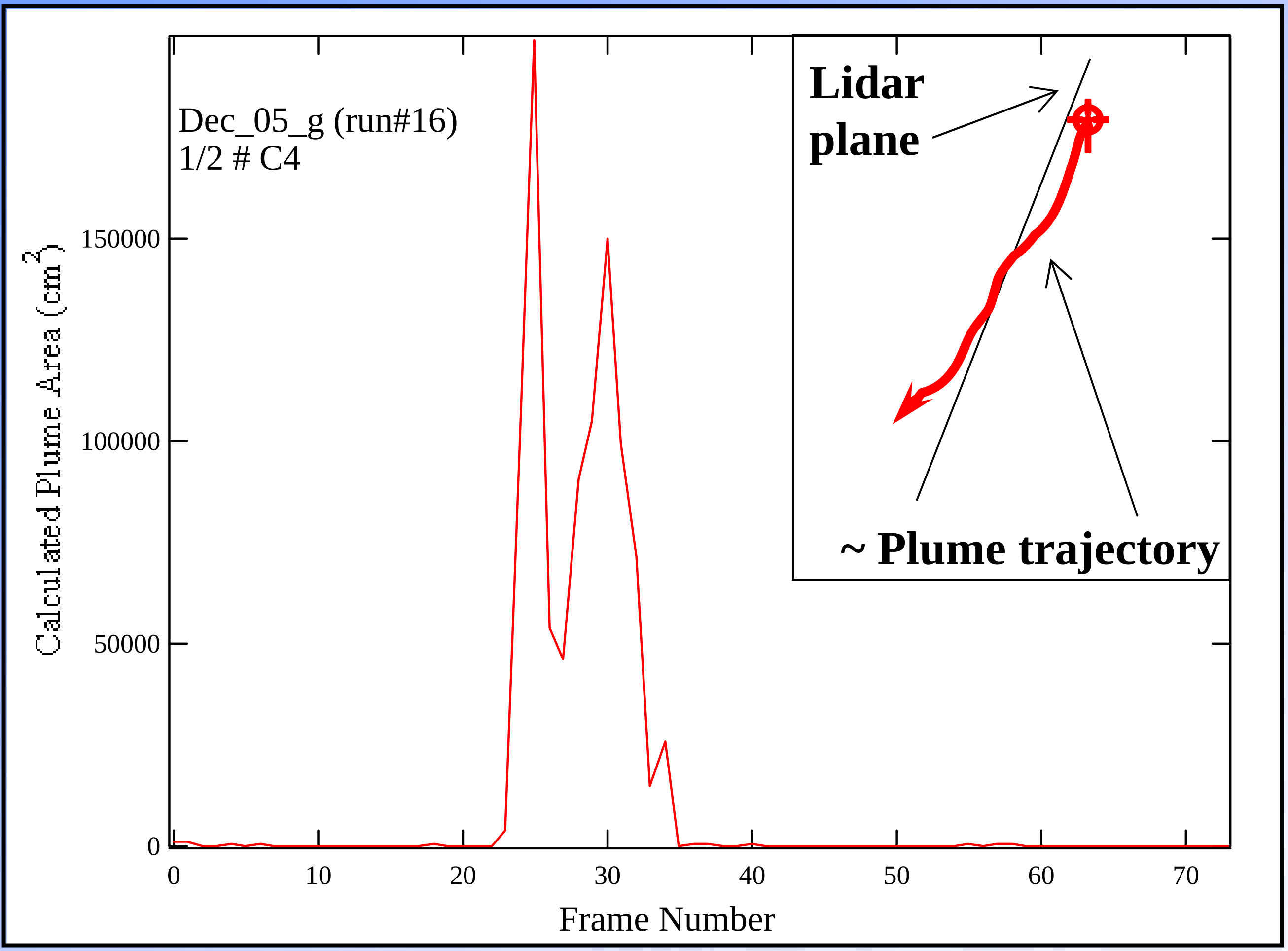


Each image represents a 2-sec time slice





Plume Area and Volume Estimates



Run: #16
1/2 lbs C4
Start time: 3:36:01 pm
Wind Vector: 1.82 m/s
Wind Direction: 23°

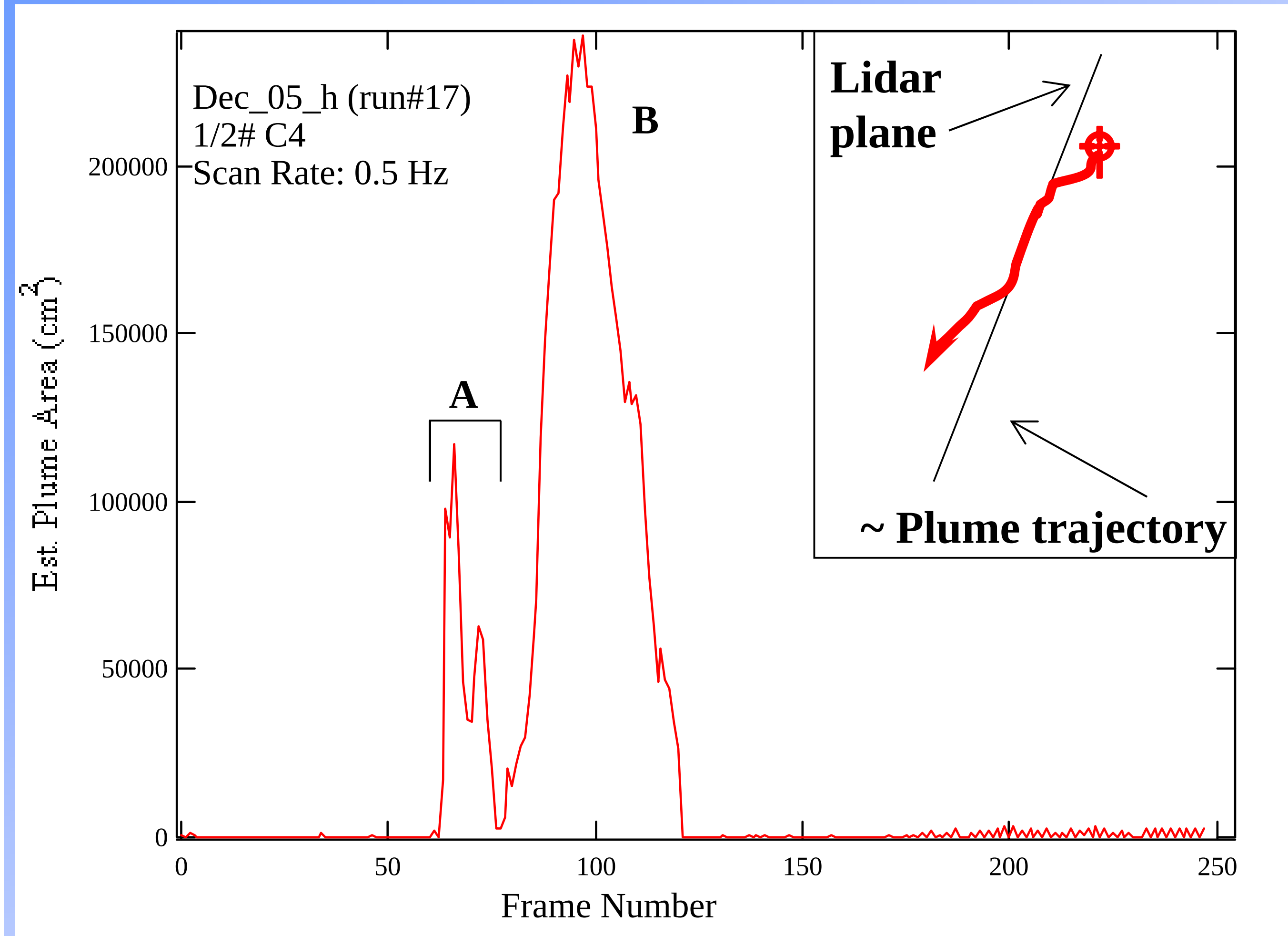
Total Plume area:
973800 cm^2

Plume Volume:
354,463,000 cm^3

Measuring Cloud's Temporal Behavior with Scanning Lidar C4 Release, 0.5 Hz Scan Rate

Run: #17
1/2 lbs C4
Start time: 3:58:59 pm
Wind Vector: ~1.25 m/s
Wind Direction: 62^{o}

Detection of C4 Detonation - Faster Scan Rate



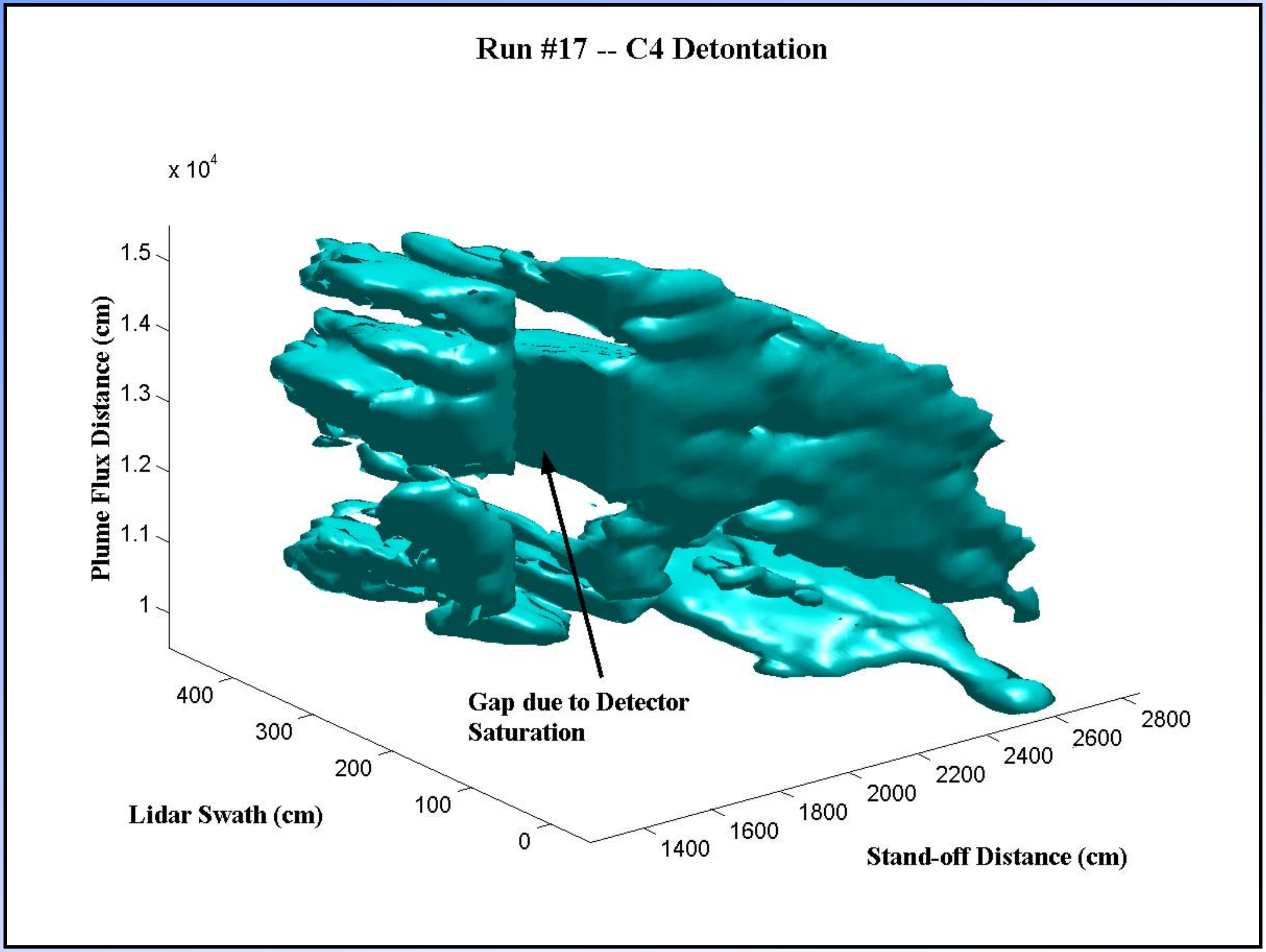
Run: #17: 1/2# C4
Start time: 3:58:59 pm
Spatial Res: ~1.25 m
Wind Vector:
B: ~ 1.25 m/s
Wind Direction: 62º

Calculated Plumes:
A area: 749,400 cm^2
B area: 5,365,100 cm^2

Plume Volume:
A: 59,952,000 cm^3
B: 670,637,500 cm^3

Lower spatial resolution compensated by higher temporal resolution

Detection of C4 Detonation - Faster Scan Rate



Upcoming Field Campaign and Areas for Improvement

Initial Plume dimensioning and inter-comparison underway

Next series of tests slated for fall of ‘02

larger quantities of C4 (up to ~6 of lbs)

Detonations involving “frag”

Move lidar back ~ 300 meters

should enable capture of entire plume

safer distance [for both operator and instrument]   :-)

enable 0.5 Hz scan rate

Better Determination of Plume Velocity

Edner and co-workers (Appl. Phys. 1998) demonstrated a cross-correlation technique using an ordinary video camera