Integrated Approach to Measuring Particulate Matter Emissions from Agricultural Operations

Presented by
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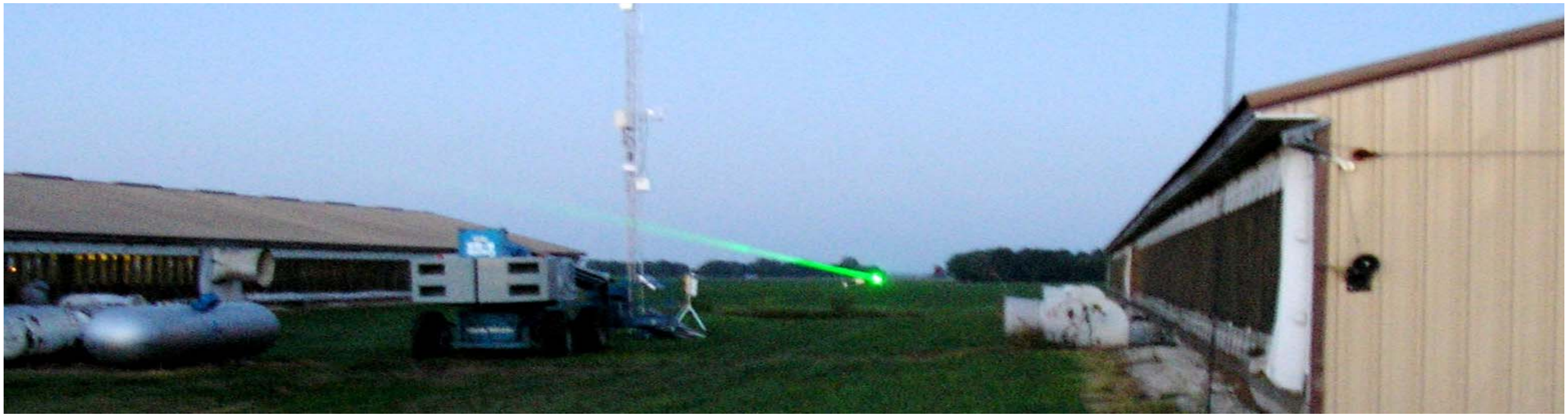
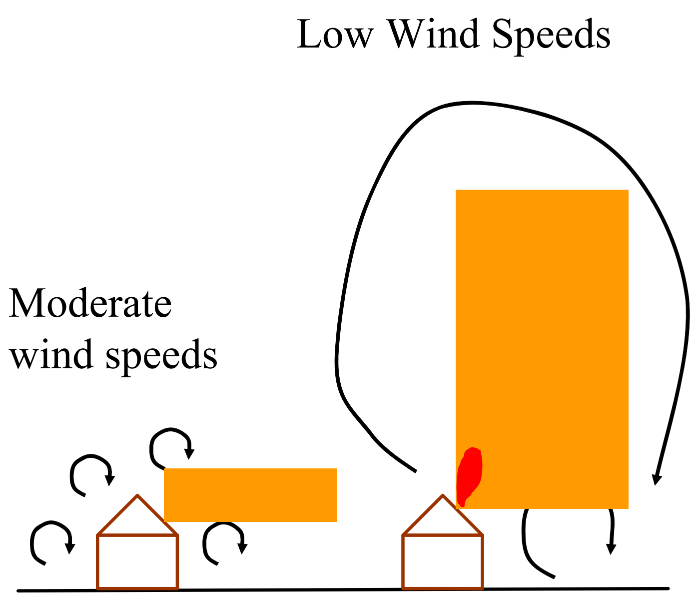


The Problem

- The movement of urban population into agricultural production areas, combined with the increasing size of these facilities to capture economies of scale and global food needs, has elevated the issue of facility emissions to national attention.
  - The development of data using conventional techniques is limited by the distributed and episodic nature of agricultural sources.
  - Point sampling methods designed for well mixed aerosols and gasses are challenged by the disrupted wind flow fields and varied surface temperatures of agricultural facilities.



Problem Phases

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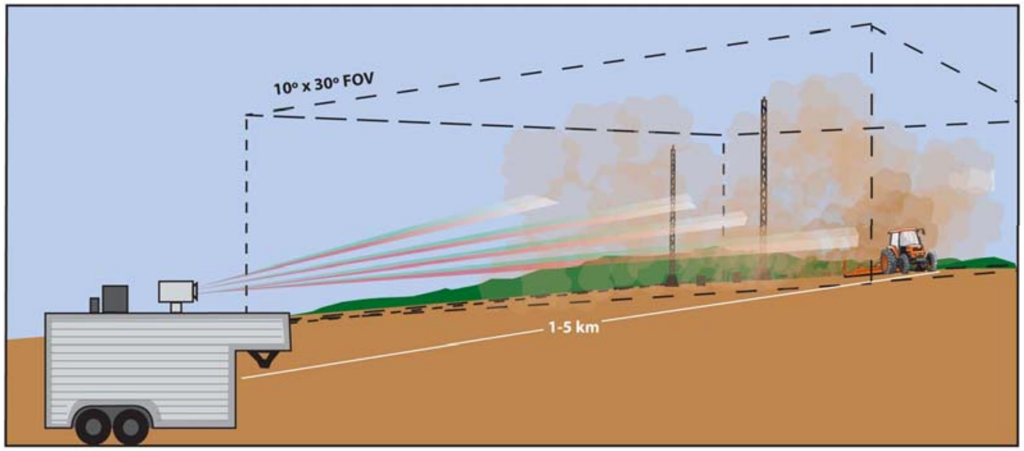
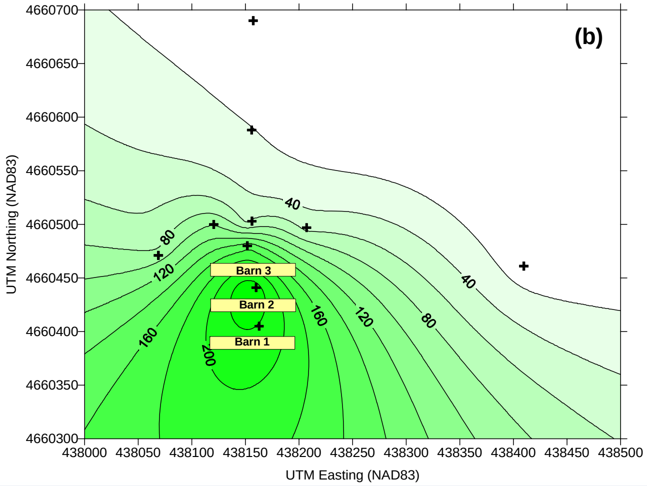
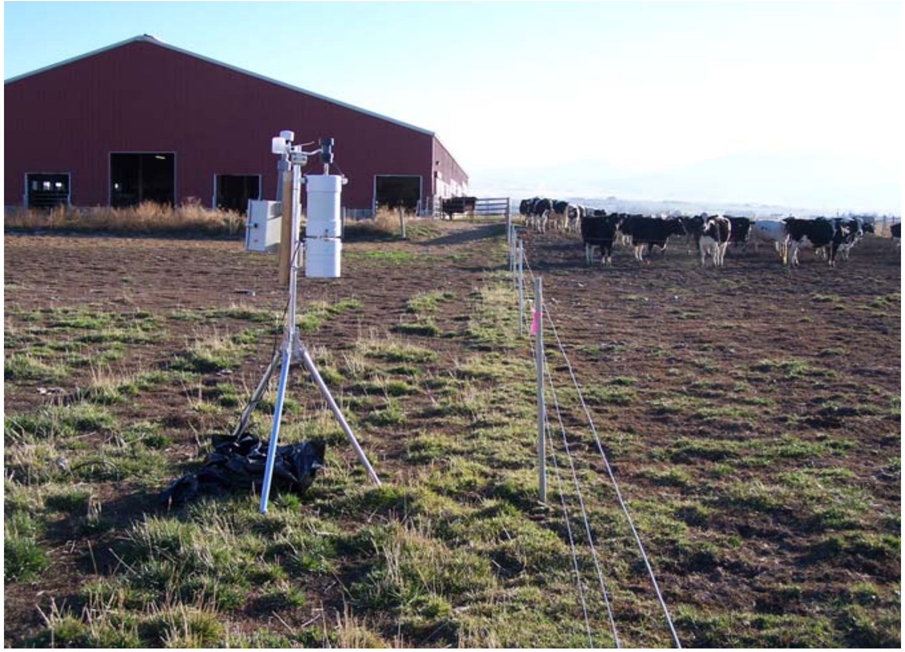
- Particulate research has two phases:
  - Research to develop and apply efficient best management practices
  - Operational emission rates for regional models
- Data collection for both phases is limited by the nature of the source and current instruments and procedures
  - Quantification of distributed and uncontained sources
  - Need for real time area emission data
  - Mixing of structured and open sources with variable thermal emissivity
  - Complex reactions that vary with environmental conditions



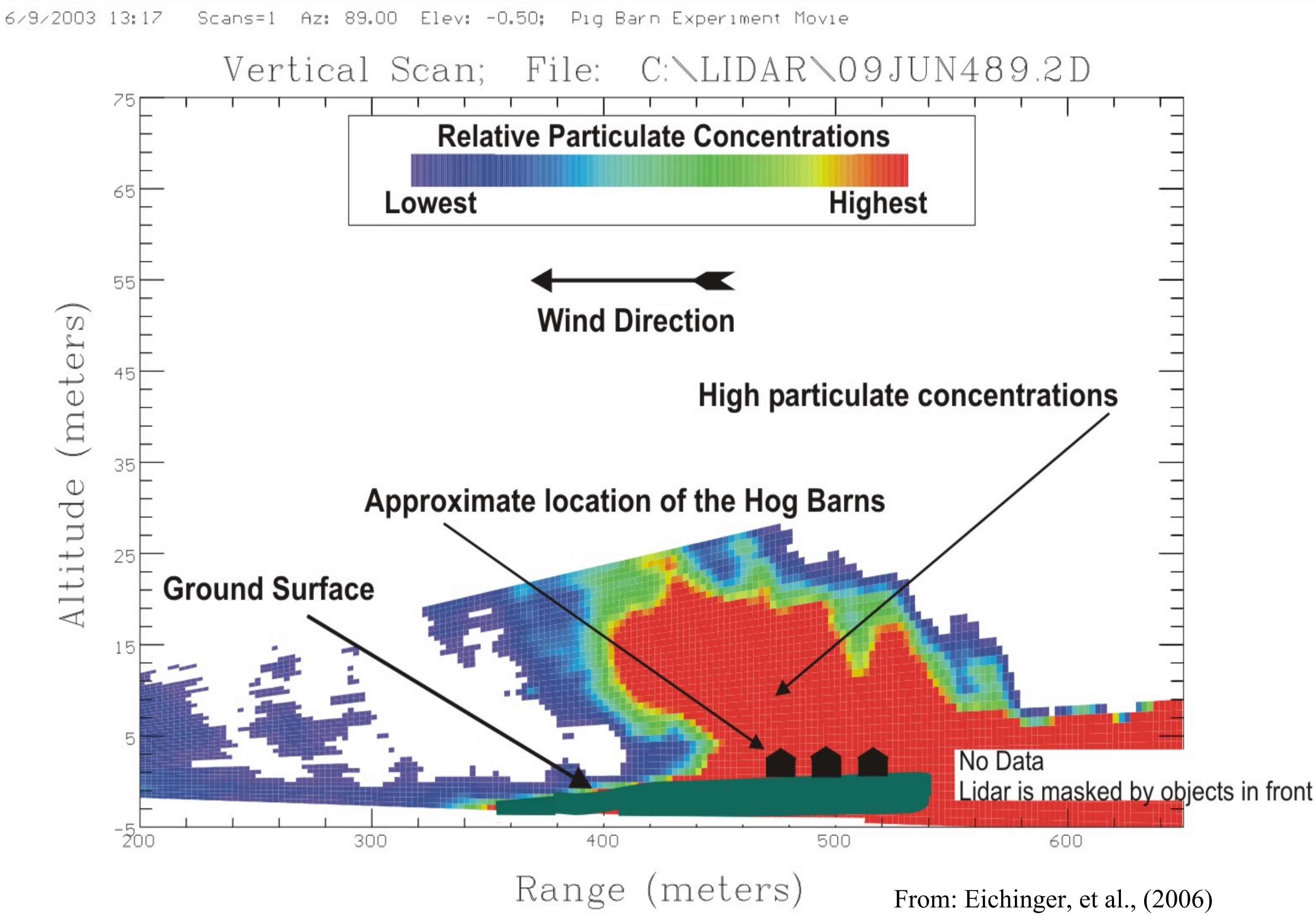


Limits on Good Data Collections



- Traditional monitoring methods were derived for stack and diffused regional pollutants – not the temporal and spatially variable agricultural sources.
- "Standard" instrumentation for gases and particles, deployed at "nose" level, combined with exiting source models, do not adequately describe source coupling into regional models.

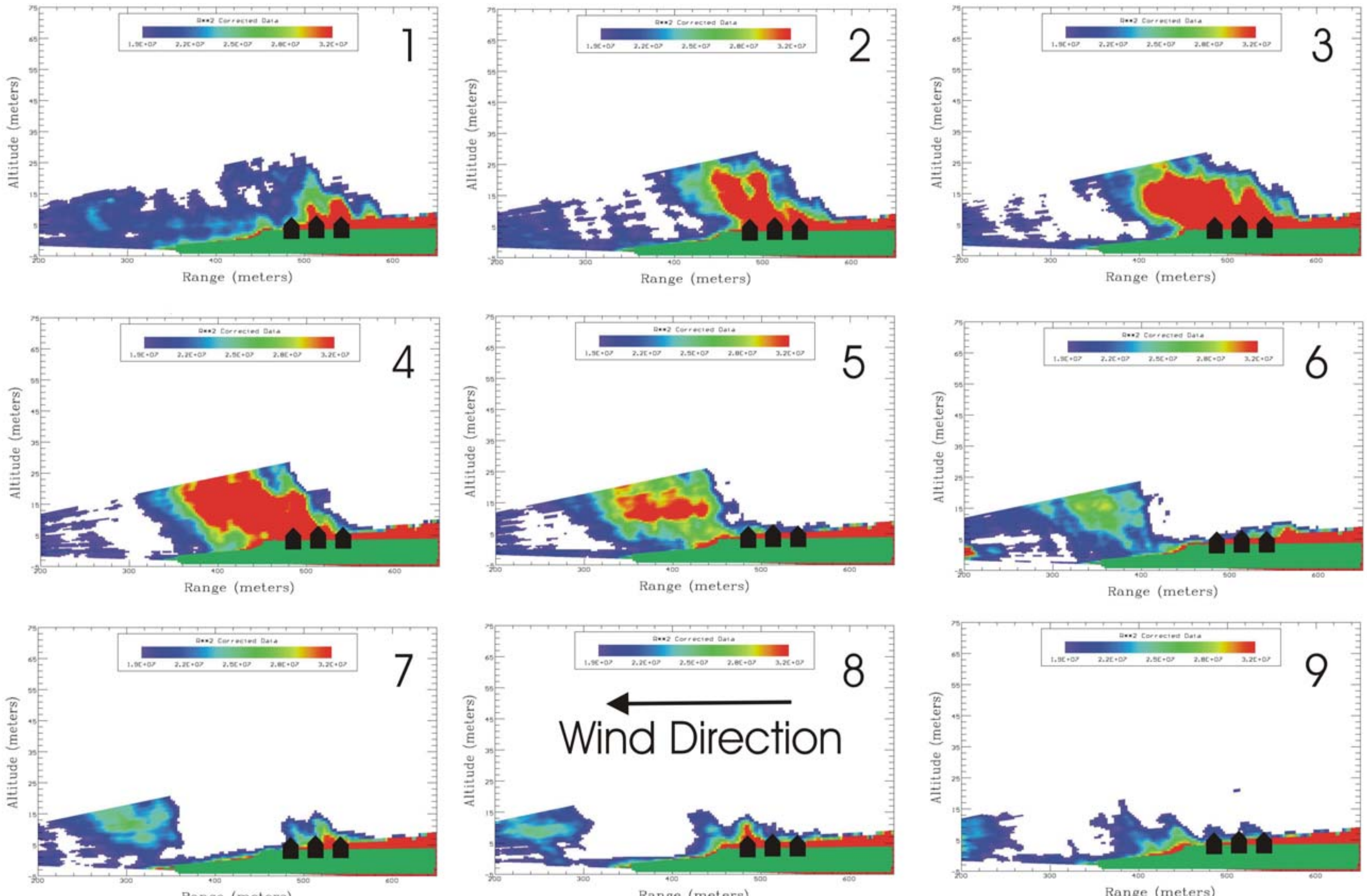
Example - Plume Dispersion



From: Eichinger, et al., (2006)

Plume Sequence Images

(13 second intervals)



From: Eichinger, et al., (2006)

Observations

- Dispersion of particulate plumes can be extremely rapid around facilities, especially under full sun and light winds.
- Profiles of particulates do not behave according to unlimited fetch assumptions in low wind cases.
- Conclusion: To accurately characterize the dispersion patterns and concentrations from a livestock facility will require new methods of being able to quantify the plume.

Models based on unlimited fetch do not adequately describe atmospheric coupling from many agricultural facilities.

Project Objectives

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- SDL has teamed with the ARS researchers to bring space technology remote sensing hardware and analysis to quantify sources and track emission transfer phenomenon.
- Our objectives are:
  - Investigate new sensors and protocols for operational monitoring and provide quantitative feedback to improve management practices
  - Develop a flux protocol that accurately describes whole facility coupling to the atmosphere
  - Support the integration of these new sensors and methods into operations
- First objective centers on particulate emissions and facility flux rates
- Future efforts will focus on improving trace gas monitoring

Our first objective is to develop new sensors and methods.

Aerosol Emission Visualization

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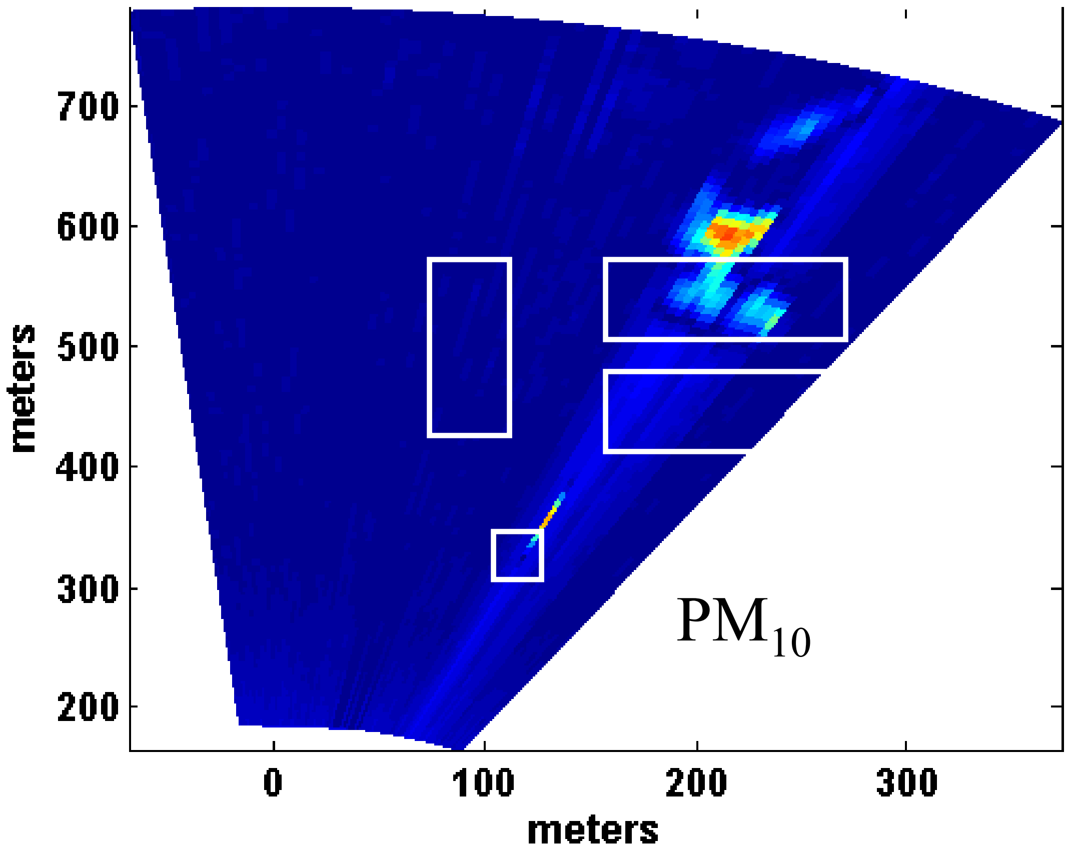
- We have developed a three-wavelength lidar and a method for real-time measurement of source processes and time averaged emissions.
- The lidar allows 3D visualization of aerosol concentrations entering and leaving a facility. Differencing these measurements provides the source flux term assuming only conservation of mass.
- The method is being validated against EPA standard point samplers to provide unambiguous measurement and characterization.
- We have demonstrated that the system can provide near real-time size fraction concentrations and facility emission rates.

The three-wavelength lidar allows near real-time visualization of aerosol size distribution, location and facility source strength.

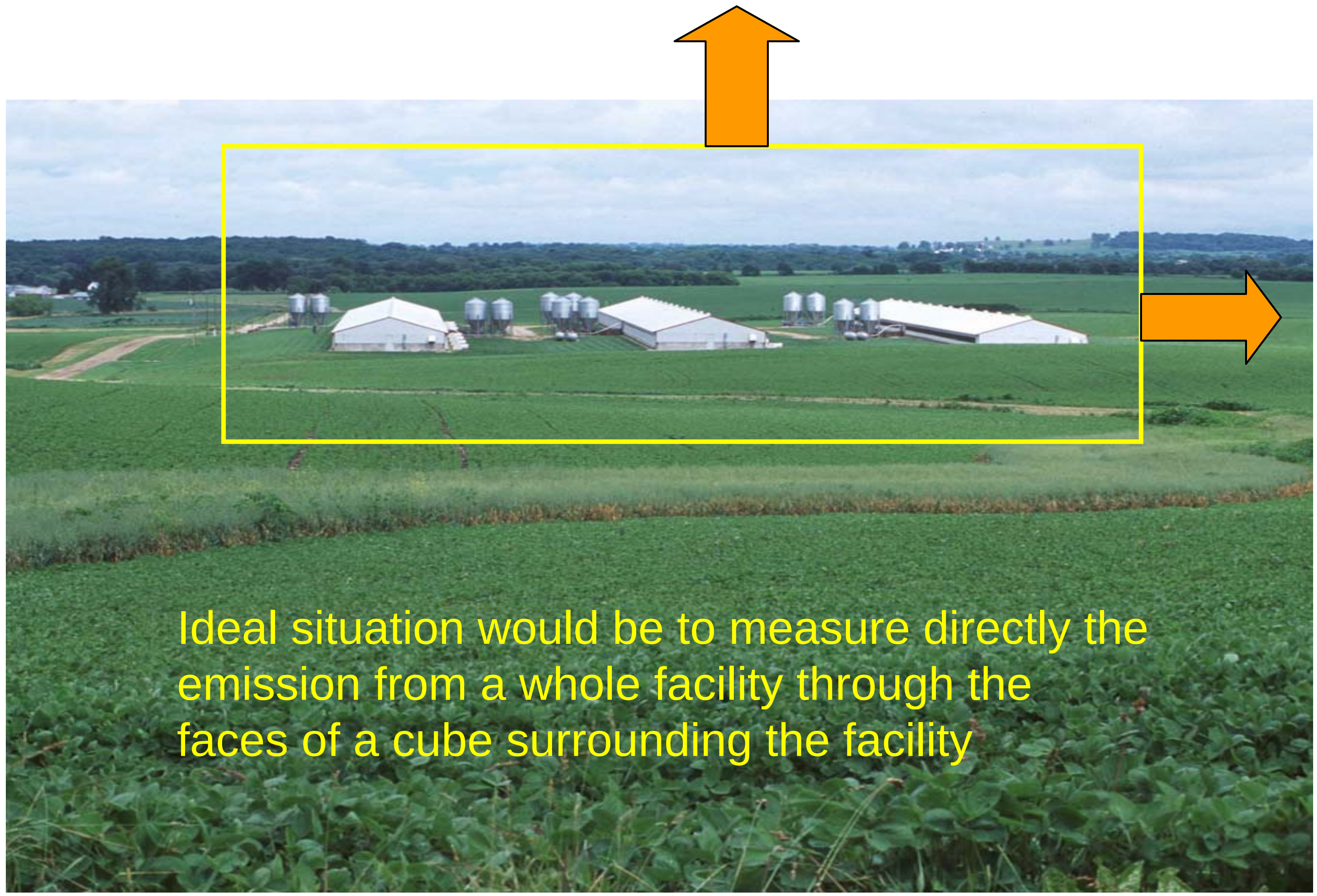
Management Practice Investigations (1)

Lidar Horizontal Scan PM_{10} (11/22/05 5:01 PM)

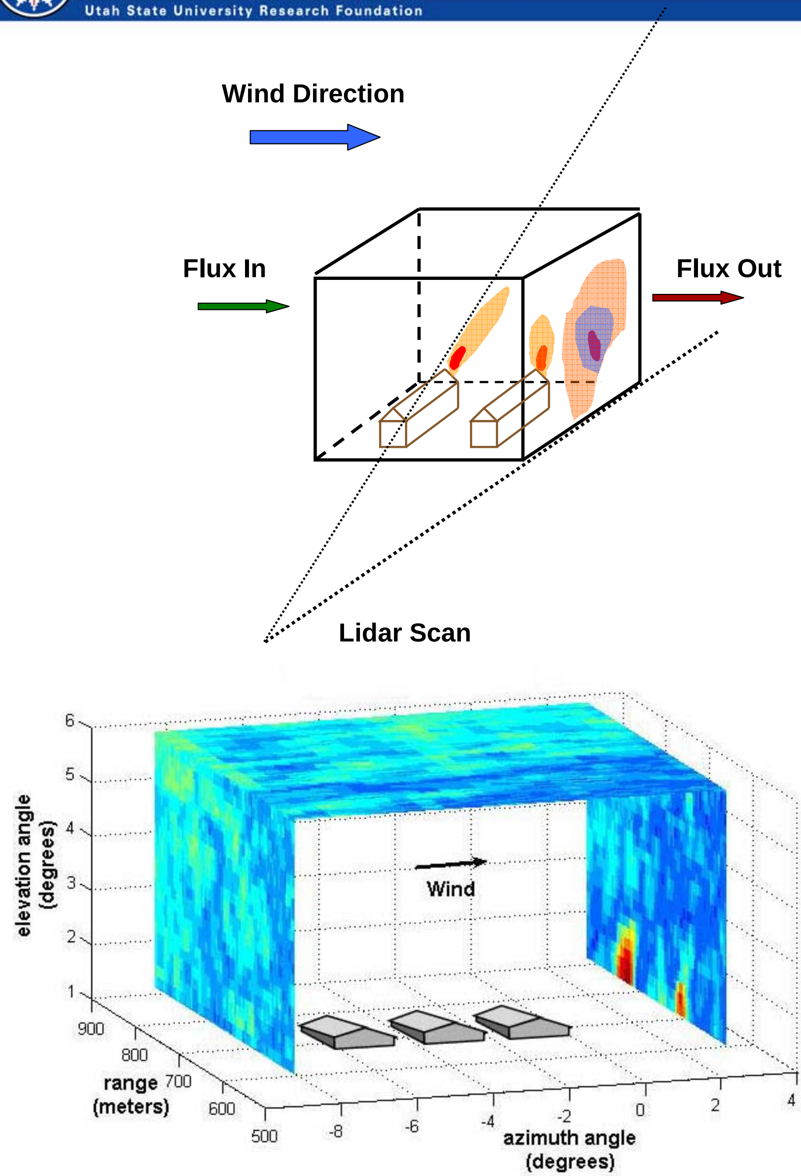


A scan over a dairy facility pinpoints emission sources and their characteristics.

Dispersion Estimates



Facility Emission Approach



- We have designed a system to characterize emissions from the complex structures and temporally dependent agricultural sources.
- This approach combines state of the art standoff measurement techniques with standard point source monitoring equipment.
- The combination provides the calibrated, high spatial and temporal frequency data required to validate models and management practices.

The lidar allows differencing of aerosols entering and leaving a production area.

Aglite Lidar System

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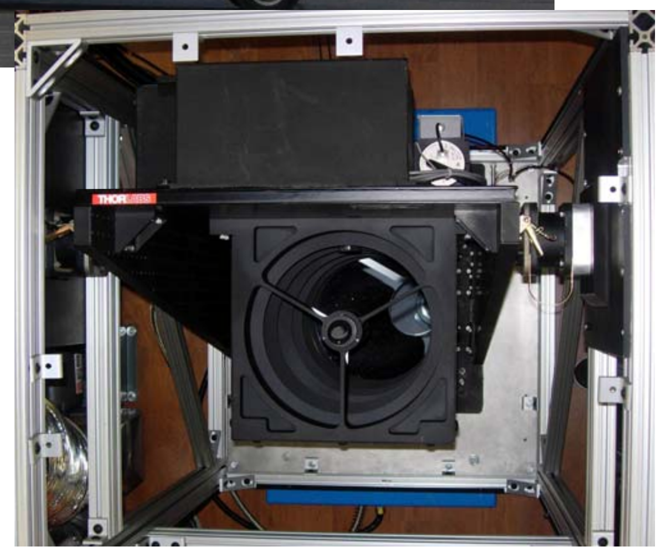
- The multi-wavelength lidar maps and tracks particle emissions.
- The lidar uses a 10 KHz micropulsed NdYAG laser radiating at 355 (uv), 532 (vis) and 1064 nm (near IR).
- The system is being used with a wide range of sources to build experience.
- Aglite is easily mobile, generator-powered, and remotely controllable.
- Adjustable power allows eye safe operation from 500 m to 15 km.
- A remoteable visible camera provides real-time safety monitoring.
- An analysis software package allows quick look analysis in near real-time.

The Aglite hardware and software are nearing operational status.

Lidar System is Mobile

The lidar system can be transported as modules for distant operation.



The vertical 12” telescope is the heart of the lidar receiver.

In Operation

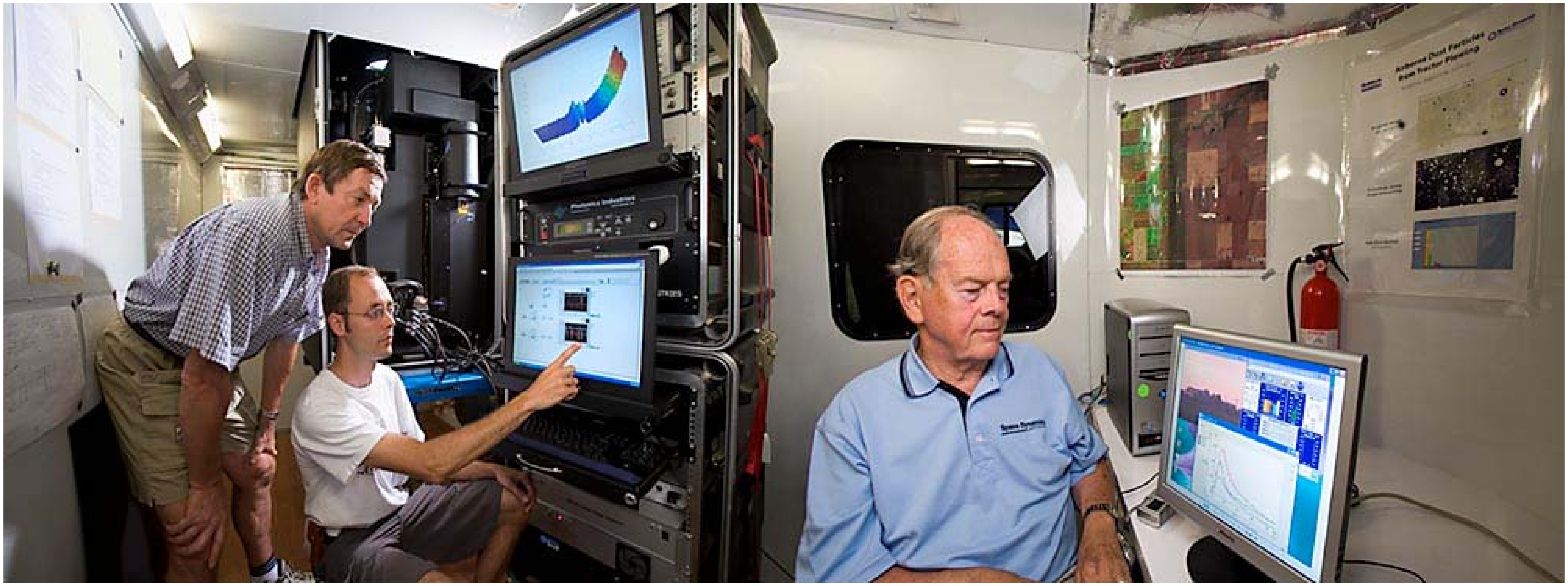
In the field, a screen tent is necessary to keep the "bugs" out of the laser as the UV beam attracts insects!

A WIFI link allows the system to be monitored and controlled from a central location.

The WIFI also provides full lidar data transfer.

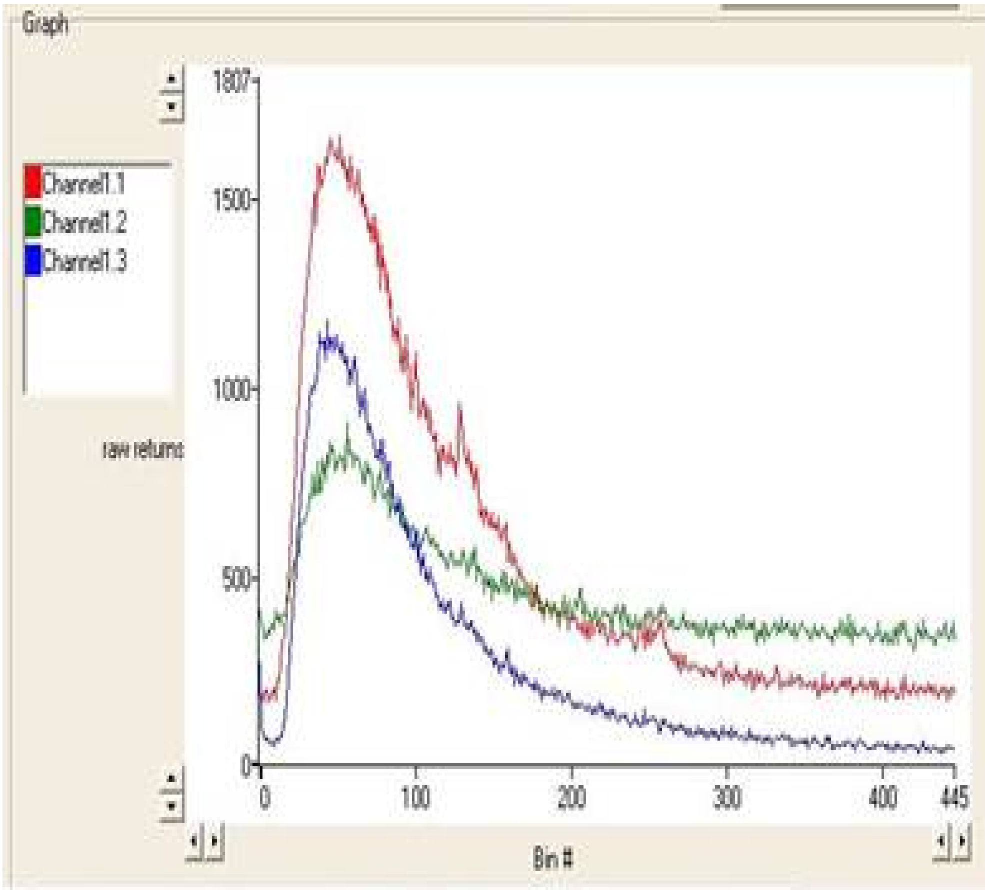
Aglite's turret allows 270° azimuth and -10° to + 45° in elevation.

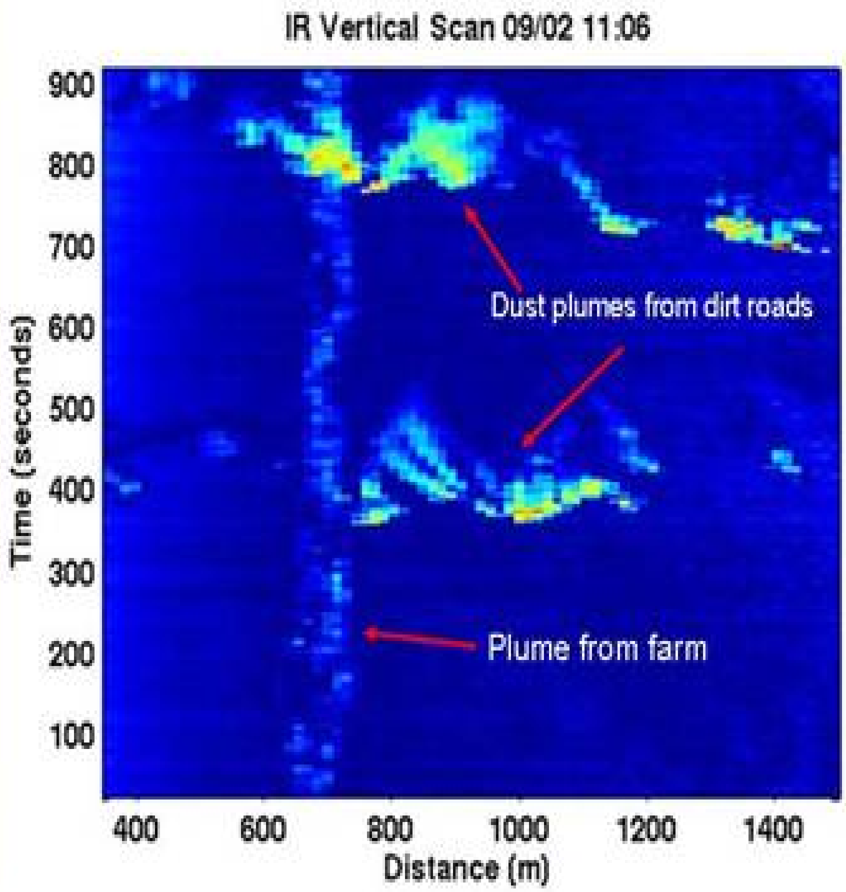
Inside Aglite



A key Aglite resource is our technical engineering and scientific staff.

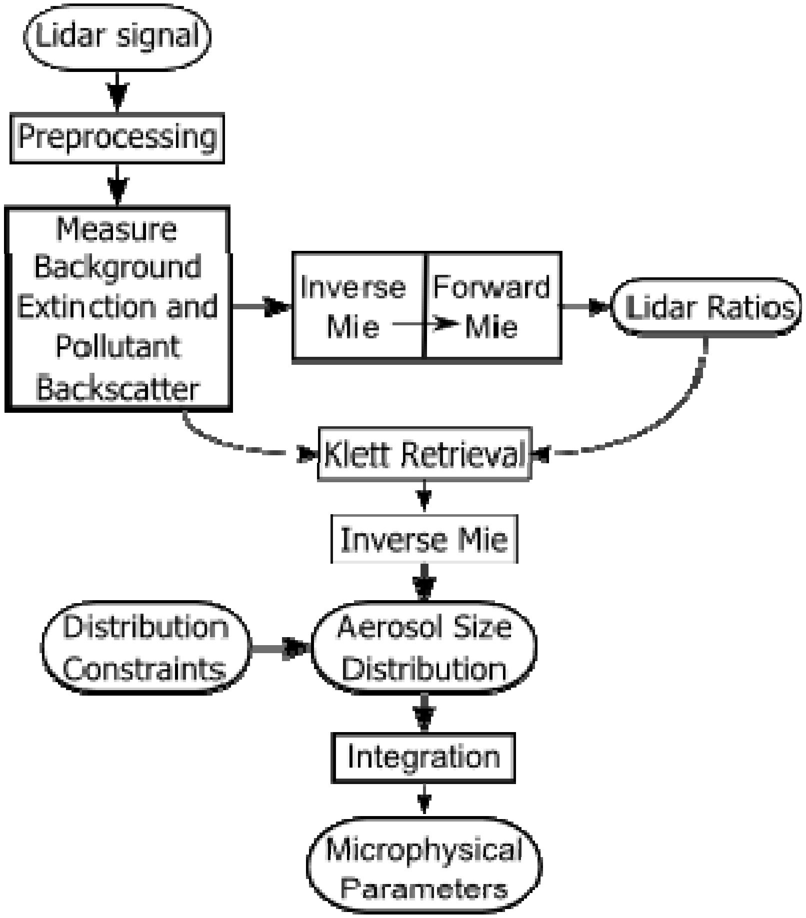
The Power of Lidar





Aglite's quick-look algorithm converts raw returns to range corrected IR intensity and PM_{10}.

Retrieval algorithm flow chart



Retrieval steps:

1. Pre-processing (geometrical form factor and background)
2. Reference backscatter value and the lidar ratios of the background and the pollutant aerosols
3. Backscatter coefficients for entire data set using Klett's solution
4. Parameters of particle size distribution using inverse Mie solution – adjusted by OPC data
5. PM mass concentration of particles (PM_{10}, $PM_{2.5}$, PM_{10}-$PM_{2.5}$, PM_1)

Lidar theory provides a good base for determining particulate mass and size distribution, but accurate solutions must be tied to observed sample data collected in parallel. More variables are required than are provided by the lidar.

The Diagnostic System

An array of standard particulate samplers (optical and filter based) and a mobile particulate diagnostic laboratory are used in parallel with the lidar.

- The diagnostic trailer houses the more sophisticated particulate and trace gas characterization equipment.
- Gas and particulate-phase inorganic acids, NH_3, and $PM_{2.5}$–
  - Ionic composition analysis finished at USU/UWR
- Basic meteorology
- Impactor-based (mass) particle size distribution
- 3-hr averaged elemental & organic carbon mass ($PM_{2.5}$) fractions
- Same instruments as field array
- Gaseous ozone (O_3)
- Oxides of nitrogen (NO & NO_2) to examine oxidation potential and other potential influences
- Real-time particle (PM_1) mass spectrometry (composition and distribution)
- It also collects data from the distributed sampling array via WIFI.

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The Reference Measurement System

10 field arrays

Ten distributed sample collection array stations include WIFI linked optical and filter samplers

Field arrays (horizontal and vertical):
- Filter-based, daily-averaged $PM_{2.5}$ and PM_{10} and/or TSP samplers
- Real-time particle size distributions (optical particle counters)
- passive gas-phase NH_3

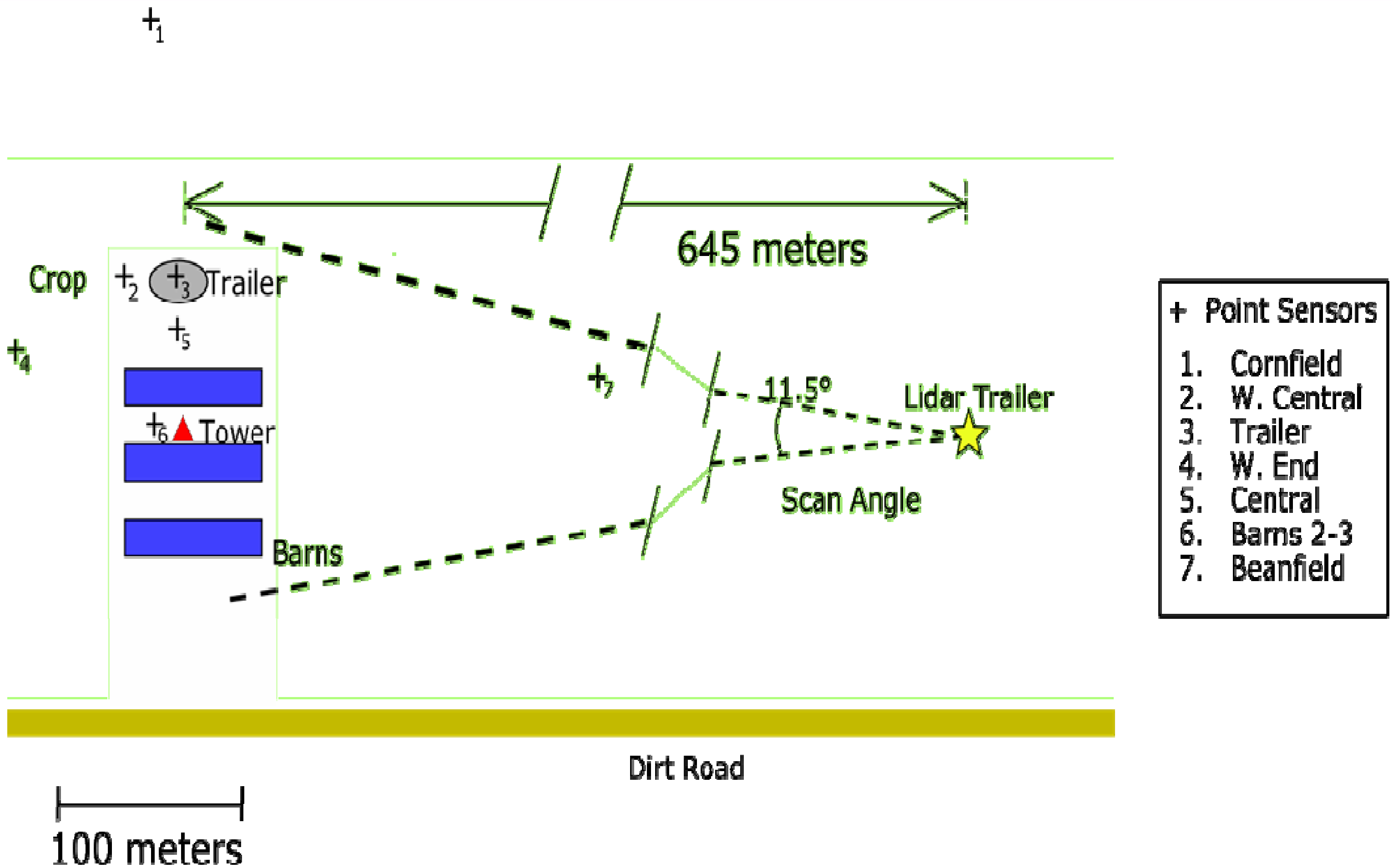
Inside the diagnostic laboratory

A particle mass spectrometer and carbon and gas analyzers are included in the diagnostic trailer.

Some filter processing can be accomplished in the field to provide quick look data

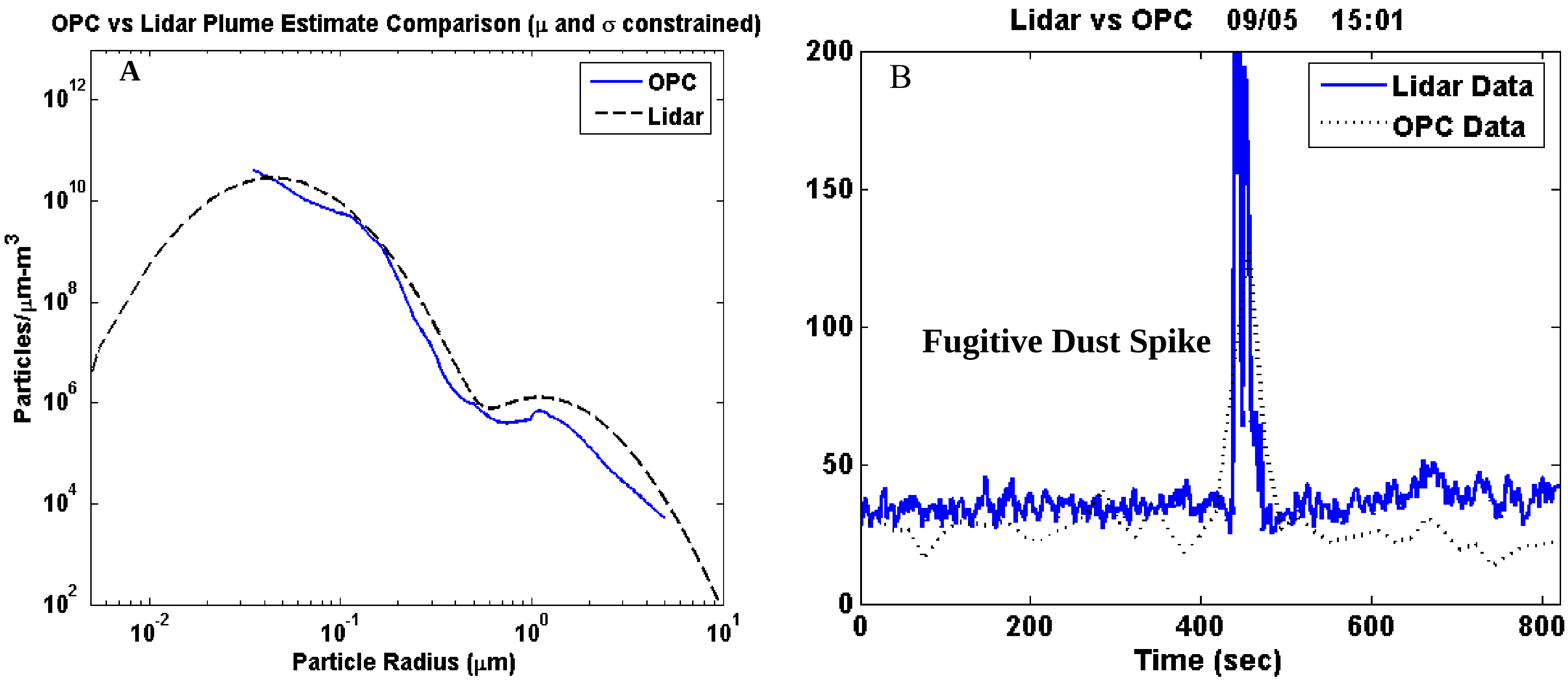
Most samples are refrigerated and returned to the laboratory for processing and analysis

Iowa Experimental Setup



The following data were collected at a deep pit swine finishing facility near Ames, Iowa in August and September, 2005.

Lidar Particulate Calibration



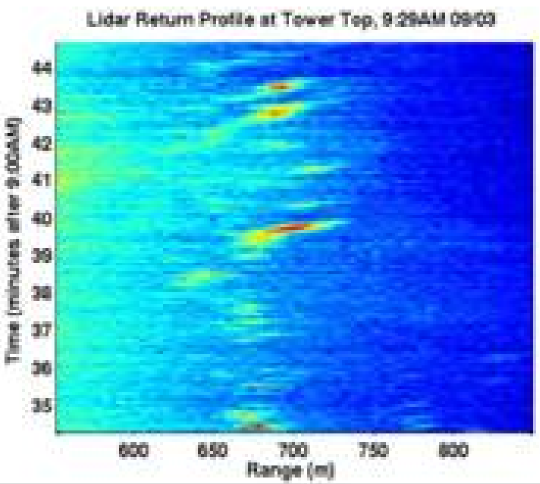
A: Algorithm uses measured values to determine particulate concentrations and size distribution – which may vary between sources.

B: The algorithm is tuned to match the observed relationship between the retrieved size distributions of the lidar and OPC data.

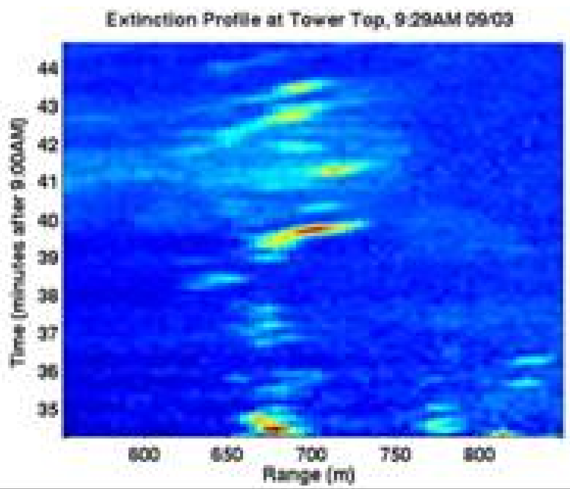
Aerosol characterization algorithm is grounded by point observed data.

Particulate Processing

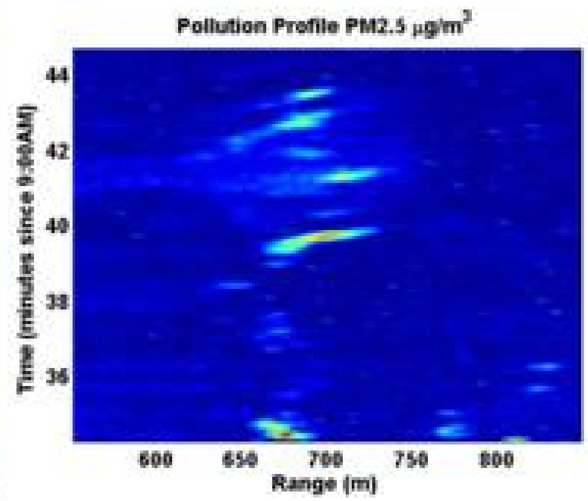
Range corrected return



Particulate extinction



$PM_{2.5}$ time series ($\mu g/m^3$)



- Through the use of the three colors, both particle size and mass fraction can also be retrieved from the returns.
- This data is from a 10-minute period with the beam steady near the top of the tower, showing the raw return, the extinction coefficient, and the $PM_{2.5}$ ($\mu g/m^{3)}$ mass fraction time series.

Lidar calibration is verified by staring at a point array for minutes.

High Frequency Plume Characterization

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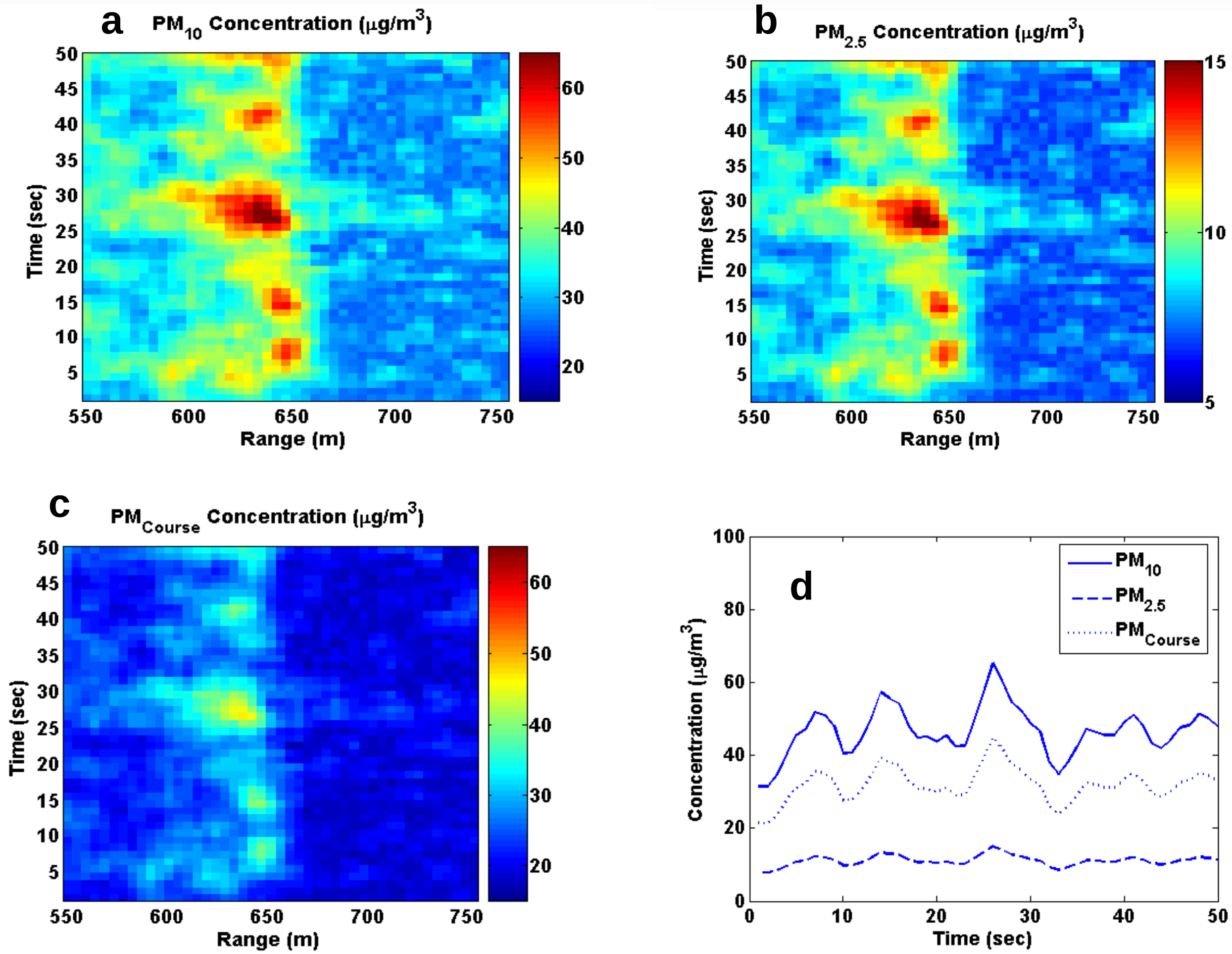
With the beam stationary near the top of the tower, the intermittent characteristic of the lofting plume can be visualized.

These data have been averaged into 1-second bins.



The lidar derived fractions for the PM_{10}, $PM_{2.5}$ and PM_{coarse} fractions in a 50-second time sequence from a swine operation.

Facility and Operations Flux (1)

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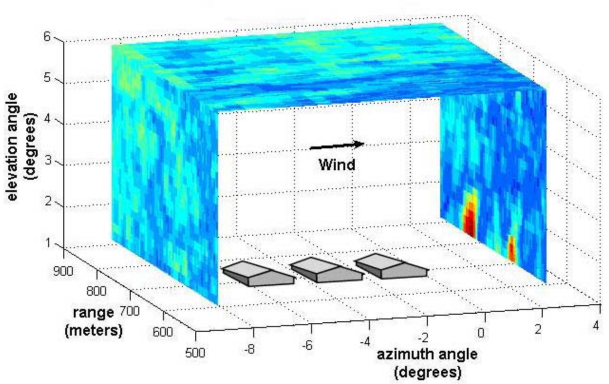
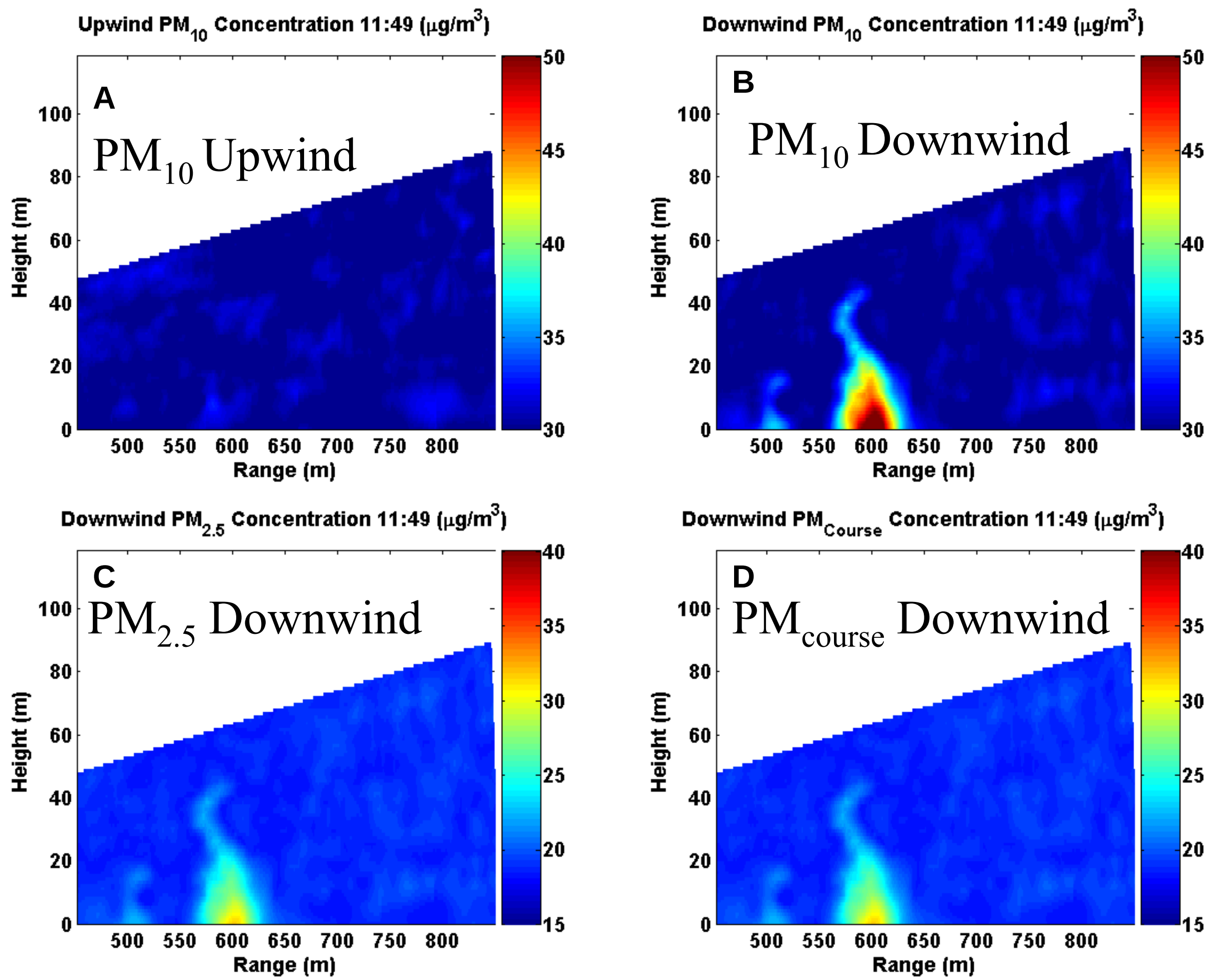
A single upwind and downwind scan provides a high resolution look at the *instant* aerosol emission strength.



Scan velocity here is 0.1°/s, providing a 1-second averaged uncertainty of 0.5µg/m³ for each 5m bin.



A vertical downwind scan shows the plume profile and fractions.

Facility and Operations Flux (2)

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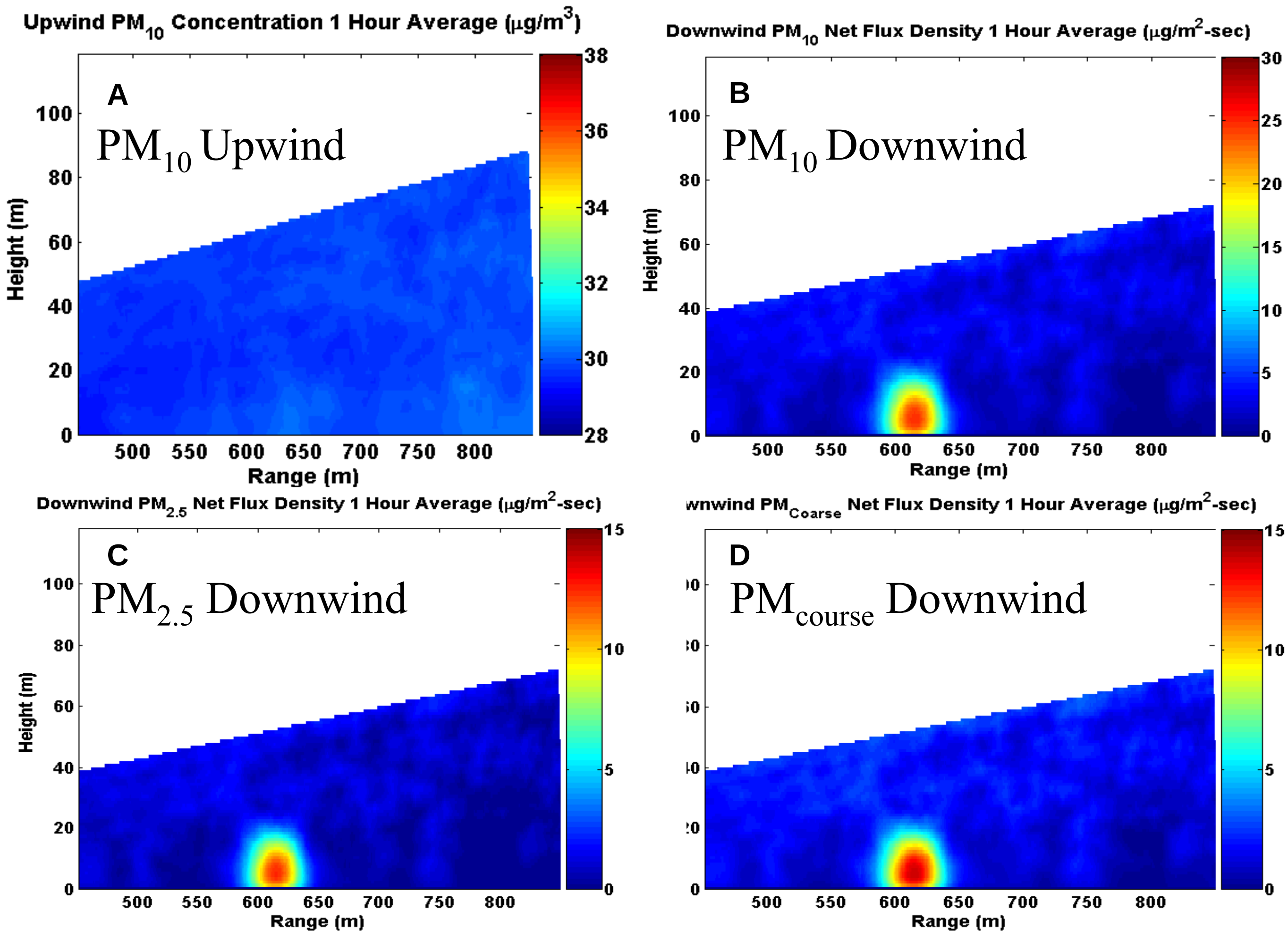
Individual scans can be averaged to provide facility emission source strength and size characterization information for management practice assessment and model input.

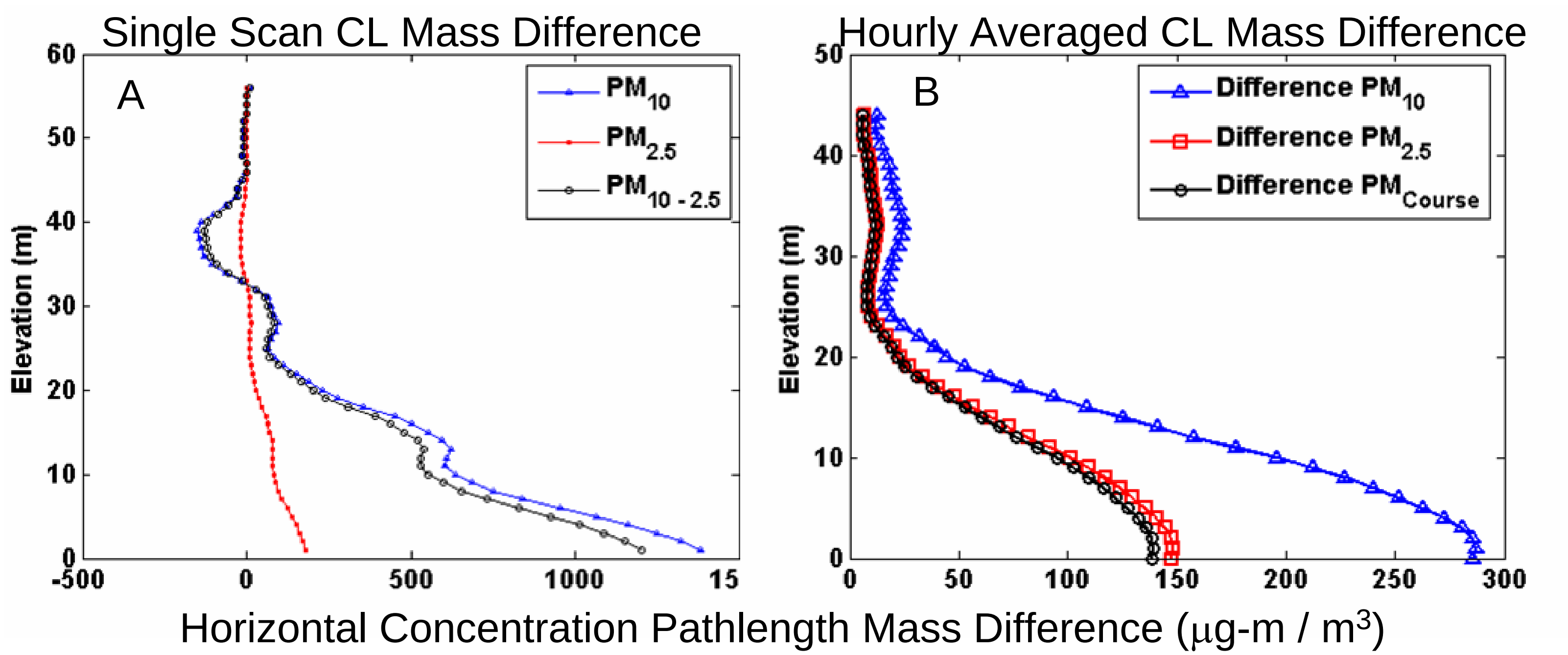


Hourly averaged plume emission fractions for noon, September 5, 2005

Facility and Operations Flux (3)

Differencing the concentration pathlength of the downwind – upwind scans at 1-meter heights allows calculation of the *instantaneous* plume mass concentration profile.

Averaging the scan concentration pathlength differences for extended periods provides an accurate method of determining emission strength and characteristics.



Aerosol mass in the plume cross section is calculated by difference.

Facility and Operations Flux (4)

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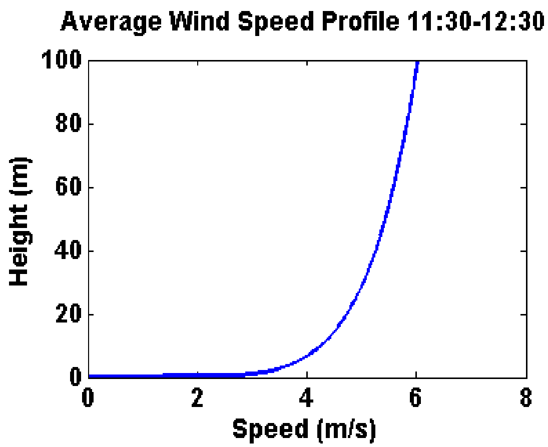
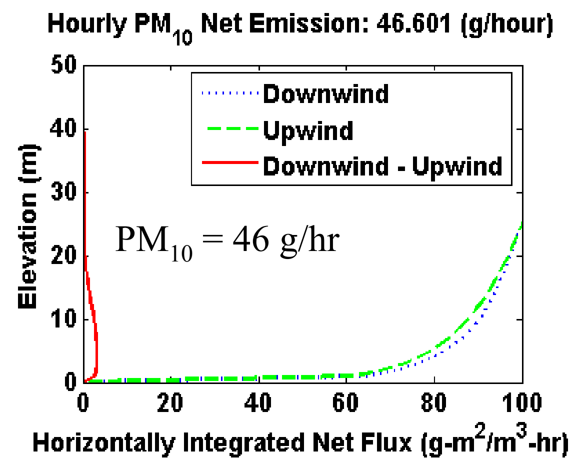
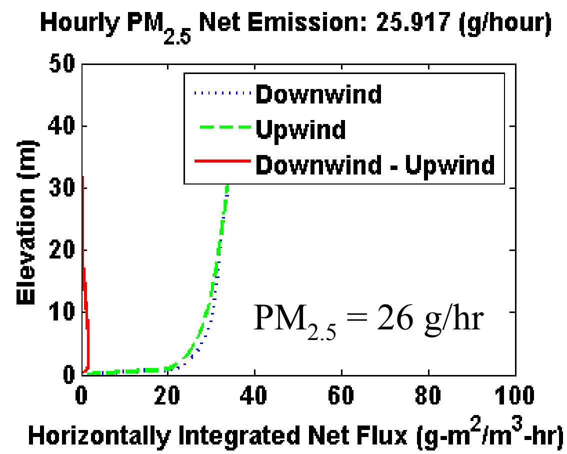
By placing the downwind scan some distance from the structures, a standard meteorological tower can be utilized to provide the required wind speed and direction.

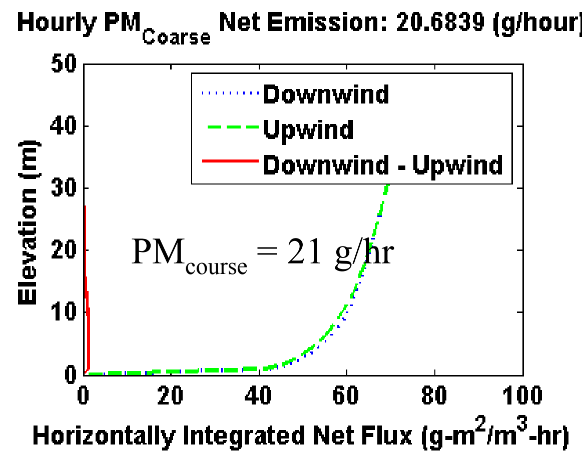
Each cosine corrected scan CL must be multiplied by its corresponding speed and direction to correct the lidar concentration profile for its off perpendicular distance.

Total flux is calculated from the vertical flux profile (red).









The vertical flux profile is calculated by multiplying the wind speed profile by the particulate fraction mass concentration for each height.

Model Comparison

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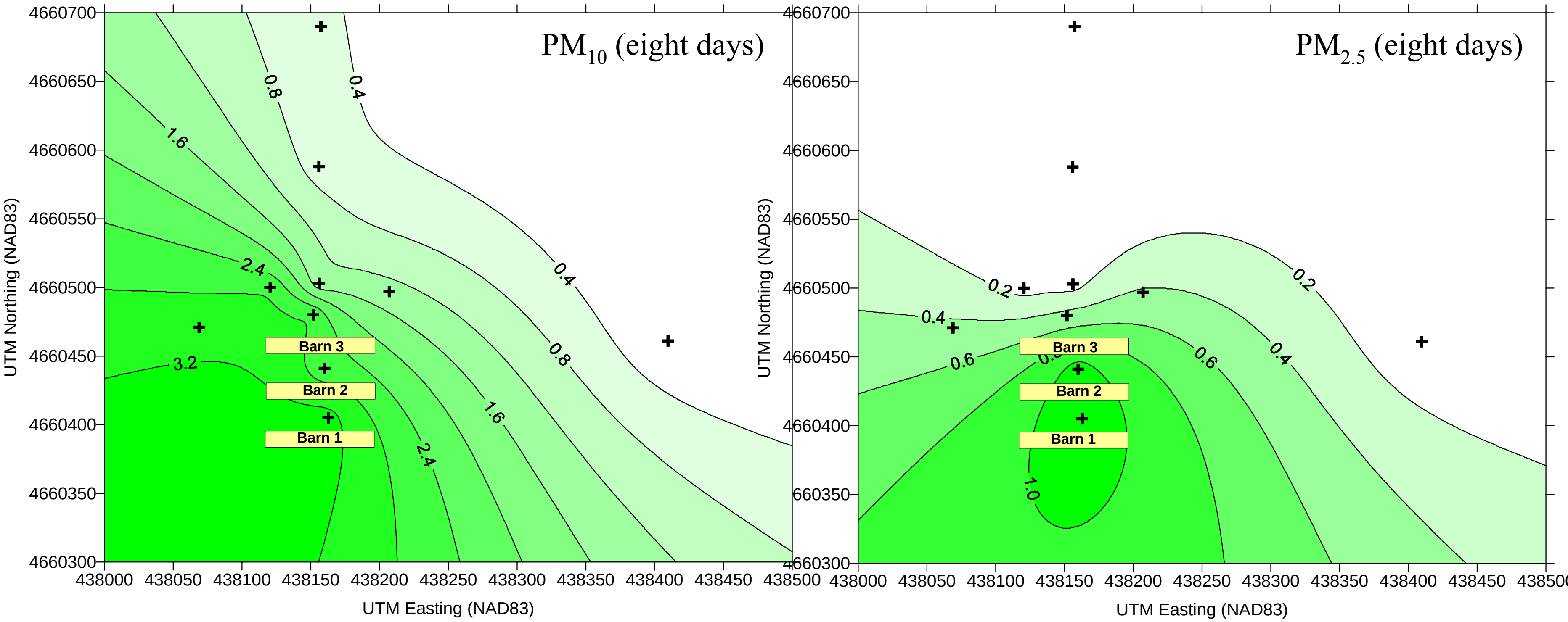

Martin et al. analyzed the filter sampler data for an 8-day period during the experiment, utilizing the ISCST3 to summarize the observed data for PM_{10} and $PM_{2.5}$.

- Observed ambient $PM_{2.5}$ concentrations ranged from 4.2 to 46.4 µg m^{-3}.
- Modeled concentrations for $PM_{2.5}$ were on the same order of magnitude
- PM_{10} average background concentration was 38.7 ± 5.4 µg m^{-3}, with a range of 31.6 to 49.8 µg m^{-3}
- Facility-derived PM_{10} concentrations averaged 10.7 ± 6.3 µg m^{-3}, with a range from the MDL to 126.0 µg m^{-3}

Vertical differences exist between model and observed concentrations.

Lidar and Sample Comparisons

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	PM samplers (23 hour base)		OPC data (23 hour base)		Lidar data (1 hour base)	
	Upwind	Downwind	Upwind	Downwind	Upwind	Downwind
PM_{10} with dust Without dust, μg/m^3	38.7±5.4	49.4±8.3	34.4±24 28.6±7.8	42.2±28 38.7±7.8	37.1±18 30.2±2.5	52.8±21 46.4±6.5
$PM_{2.5}$ with dust Without dust, μg/m^3	13.3±3.2	14.7±3.3	14,3±9.0 13.7±4.7	17.2±9.7 16.7±6.6	11.2±7.2 9.5±0.8	12.8±6.5 11.6±1.4
PM_{course} with dust Without dust, μg/m^3						39.8±12.6 20.7±1.9
Flux Measurements*		8 day base				Hourly base
PM_{10} (g/pig/day) $PM_{2.5}$ (g/pig/day) PM_{course} (g/pig/day)		0.83±0.44 0.09±0.03				0.30±0.23 0.17±0.08 0.13±0.06

*From Martin et al., 2006 modeled filter data

Aerosol mass concentration and flux measurements determined from lidar data are consistent with standard method measurements.

Summary

- Including the 3-color lidar with standard point measurements provides a direct measurement of short term and long term facility aerosol emissions.
- System demonstrations conducted at a swine production facility and a dairy show good correlation with point data collected under ideal (moderate wind) conditions.
- The lidar provides near real-time mapping of emissions and flux
- The lidar is useful in comparing “best management practices”
- Extensive field investigations are planned for the summer of 2006 in Utah and California
  - Almond orchard management practices
  - Dairy management practice and emission study
  - Cotton gin facility particulate emissions
  - Tillage operations