National Air Emissions Monitoring Study

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Purdue Agricultural Air Quality Laboratory

Agricultural and Biological Engineering

Purdue University
**NAEMS Objective**

Determine whether livestock farms are likely to emit PM and VOC in excess of CAA thresholds, or NH$_3$ and H$_2$S in excess of CERCLA and EPCRA reporting requirements.

- 8 states
- $14.6M (incl. admin + contingency)
- 2.5 yrs
- 24 months of monitoring

Air emissions from two to three barns per site will be measured for 24 months using accepted methods.
NAEMS Timeline

- Protocol development
- PI selection, staffing, budgeting
- Producer Signup
- EPA's review of Consent Agreements
- QAPP development
- Site selection, SOPs, SMPs
- EPA’s QAPP review
- Equipment acquisition
- Site setup
- Data collection (2 yrs)
- EPA’s Development of Emission Estimation Methodologies
- Purdue Training Session
- NAEMS

EEM
Study Design Summary

- Twenty representative livestock production sites.
- Outdoor manure facilities (9) and corral (1) monitored every season
  - Hydrogen sulfide (UVDOAS or pulsed fluorescence with S-OP).
  - Ammonia (TDLAS, UVDOAS, photoacoustic spectroscopy)
  - Ethanol, methanol, NMHC (photoacoustic spectroscopy)
  - Tomography or Radial Plume Mapping with TDLAS
  - Backward Lagrangian stochastic (BLS) modeling
- Barns (38) monitored continuously
  - Hydrogen sulfide (pulsed fluorescence)
  - Ammonia (photoacoustic spectroscopy)
  - Ethanol, methanol, NMHC (photoacoustic spectroscopy)
  - Non-methane HC (photoacoustic spectroscopy, GC-FID)
  - Carbon dioxide (photoacoustic spectroscopy)
  - TSP, PM$_{2.5}$, PM$_{10}$ (TEOM)
  - Barn airflow (fan speed, pressure, velocity, portable fan tester)
- Integrated Sampling
  - VOCs: GC-MS (canisters, tubes), IC (impingers)
- EPA-approved standard operating procedures
NAEMS Purdue Team for Barn Monitoring

Al Heber
Erin Cortus  Connie Li
Hua Xu       Bill Bogan
Claude Diehl Kaiying Wang
Richard Liu  Teng Lim
Juan Carlos Ramirez
Jeong Ha

Sam Hanni
Jiqin Ni
Site Principal Investigators at Eight Cooperating Universities

- Lim/Ni/Grant – Purdue University
- Jacobson - University of Minnesota
- Mitloehner/Zhang – University of California - Davis
- Koziel/Hoff/Harmon – Iowa State University
- Casey – Texas A&M University
- Ndegwa – Washington State University
- Robarge/Wang – North Carolina State University
Legend
1 – Broilers
2 – Layers
3 – Swine finishers
4 – Sows (swine)
5 – Dairies
A – Open source
B – Barn source

National Air Emissions Monitoring Study Sites
# Summary of NAEMS Sites

<table>
<thead>
<tr>
<th>Species</th>
<th>Barns per Site</th>
<th>Total number</th>
<th>Number of Area Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2-b 3-b 4-b</td>
<td>Sites</td>
<td>Barns</td>
</tr>
<tr>
<td>Swine</td>
<td>0   4   1</td>
<td>5</td>
<td>16</td>
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<tr>
<td>Dairy</td>
<td>3   2   0</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Layers</td>
<td>2   0   1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Broilers</td>
<td>1   0   0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>6   6   2</td>
<td>14</td>
<td>38</td>
</tr>
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</table>
Equipment Acquisition Winding Down
Purdue Training Session
Equipment Received

- Cal gases and regulators (air, SO₂, CO₂, NH₃, H₂S)
- TFS TEOM, Beta Gage, and Partisol PM samplers
- Teflon sampling tubing and static pressure tubing
- Gas diluters from Environics and Thermo Fisher
- Instrument trailers, and most outfitting materials
- Data acquisition computer systems for all sites
- VOC canisters, sorbent tubes, and impingers
- Gas sampling system (GSS) components
- Uninterruptible power supply (UPS) units
- Roof-mounted weather station towers
- Methane/non-methane HC analyzer
- CAPECAB data analysis software
- RH/T chilled mirror hygrometer
- Multi-conductor signal cables
Instrument Trailers (13)

- Modifications:
  - Steps
  - Compartment vent
  - AC exhaust hoods
  - Shelves, ductwork
  - Lightning arrestor
  - Furniture
Equipment Received

- Differential pressure sensors
- Fan monitoring sensors
  - RPM sensors (142/240)
  - Current switches (134)
- Custom TEOM enclosures
- Solar sensors and shields
- DAQ I/O modules (93%)
- Temperature calibrator
- Low pressure calibrator
- Thermocouple wires
- Airflow calibrators
- Activity sensors
- $H_2S$ analyzers
- Heating cable
Equipment Ordered

- Multigas (NH$_3$, CO$_2$, VOC) analyzers (10/15 rec’d)
- Custom Beta Gage Enclosures (1 rec’d)
- Wind Sentry anemometers (1/14 rec’d)
- VOC calibration gases and regulators
- Ultrasonic anemometers (50% rec’d)
- DAQ I/O modules (7%)
- Fan monitoring sensors
  - RPM sensors (98/240)
  - Propeller anemometers
- MSA CO$_2$ analyzers (2)
- FANS analyzers
- RH/T sensors
Equipment to Order

- 55C connection hardware
- Balance of RPM sensors
- RH/T transfer standards
- FANS trailers
- Misc.
Fan Monitoring Methods

- Hall effect sensors (RPM sensors)
- Current switches
- Propeller anemometers
- Vibration sensors

[Bar chart showing the proportion of active fans across different sites, with bars indicating no direct monitoring, current switches, and RPM sensors.]
Cal Gases Checked by FTIR

A closed-cell FTIR is used to check calibration gas cylinders.
VOC Sampling Methods

Canister

Impinger

Sorbent tube

Tube sampler
VOC Analysis

GC-MS (Dr. Hua Xu)

Ion Chromatograph (Dr. Connie Li)
Major Changes to Original Protocol

- Use TEOM for PM2.5, PM10, TSP
- Use Innova 1412 for NH3, CO2, VOC
- Use RPM sensors, current switches
- Considering synthetic open path
The TEOM air inlets shown here can measure total suspended particulate, PM10 or PM2.5.
Area Site Layouts

All layouts have been staked out on site.

Stakes color-coded to indicate what kind of instrument is installed at each location.
Concrete tower bases & anchors

<table>
<thead>
<tr>
<th>Site</th>
<th>Status</th>
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<tbody>
<tr>
<td>IN4A</td>
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<tr>
<td>NC3A</td>
<td>Done</td>
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<tr>
<td>NC4A</td>
<td>Done</td>
</tr>
<tr>
<td>OK3A</td>
<td>Done</td>
</tr>
<tr>
<td>OK4A</td>
<td>Done</td>
</tr>
<tr>
<td>WA5A</td>
<td></td>
</tr>
<tr>
<td>WI5A</td>
<td>Done</td>
</tr>
<tr>
<td>IA3A</td>
<td>Done</td>
</tr>
</tbody>
</table>

Installing anchors

Installing tower bases in concrete
Setup: Erecting towers

<table>
<thead>
<tr>
<th>Site</th>
<th>Status</th>
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<td>IN4A</td>
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<tr>
<td>NC4A</td>
<td>Done</td>
</tr>
<tr>
<td>OK3A</td>
<td>Done</td>
</tr>
<tr>
<td>OK4A</td>
<td>Done</td>
</tr>
<tr>
<td>WA5A</td>
<td></td>
</tr>
<tr>
<td>WI5A</td>
<td></td>
</tr>
<tr>
<td>IA3A</td>
<td></td>
</tr>
</tbody>
</table>
Hardware/Software Configuration

- Wind and meteorological/lagoon sensors (PAML)
  - Quality assurance software near completion
  - Datalogger program developed
  - Testing of RF communications
  - Design & manufacturing of communications & power configurations
- Design lagoon float for pH, redox, and water temperature (PAML)
  - Testing to be done at nearby pond.
- Design and testing of TDLAS communications (Boreal Laser)
- RPM software under development (Arcadis)
  - Final testing by PAML awaiting receipt of one complete scanning TDLAS system from Boreal Laser and installation of towers at IN4A.
- PC systems for in-trailer and lab use under development (PAML)
Open Source Methods Testing

- **Synthetic Open Path vs. UVDOAS**
  - Testing using release of 10% SO\(_2\) in open field
  - 10-orifice system w/ fluorescence detected SO\(_2\) at 20 m
  - UVDOAS calibration verified for SO\(_2\) using function cell.
  - UVDOAS 100-m path has alignment problems in winds

- **Open Path UVDOAS H\(_2\)S evaluation**
  - Current modeling efforts have RMSE at approximately 1 ppm-m for both NH\(_3\) and H\(_2\)S.
  - Manufacturer testing and modification near completion
  - Will be tested against S-OPS at lagoon near Purdue.

- **TDLAS NH\(_3\) scanning system testing**
  - Testing at dairy lagoon.
  - Scanner reliably moved between 3 retroreflectors (6 h).
  - TDLAS detected NH\(_3\) at levels <1 ppm-m (measurements failed QA due to sub MDL (5 ppm-m) levels).
Site IN2B has one OFIS in place

OFIS trailer in place between the two high-rise layer barns, with raceways extending into each barn. All-weather access to trailer.

Setup of high-rise portion completed by Dr. Ni’s team in Dec./Jan.
Site IN2B Setup
(High rise houses)

- 14 inside sampling points
- 1 outside sampling point
- Teflon tubing (3500 ft)
- Thermocouples (10)
- Static pressure sensors (4)
- Activity sensors (4)
- Temperature/humidity probes (4)
- Propeller anemometers (12)
- Vibration sensors (48)
- Fan stage relays for automatic stage control (24)

Installing sampling line and port at a fan in the lower level of the HR barn
Site IN3B Progress

- All hardware installed
- Currently troubleshooting DAQ
- Training session site last week.
## Trailer Delivery Schedule

<table>
<thead>
<tr>
<th>Date</th>
<th>Locations</th>
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<tbody>
<tr>
<td>April 1</td>
<td>IN3B</td>
</tr>
<tr>
<td>April 30</td>
<td>IA4B</td>
</tr>
<tr>
<td>May 7</td>
<td>IN5B, IN2B</td>
</tr>
<tr>
<td>May 14</td>
<td>WI5B, CA1B</td>
</tr>
<tr>
<td>May 21</td>
<td>NC2B, OK4B</td>
</tr>
<tr>
<td>May 28</td>
<td>CA5B</td>
</tr>
<tr>
<td>June 4</td>
<td>NC3B, CA2B</td>
</tr>
<tr>
<td>June 11</td>
<td>NY5B, WA5B</td>
</tr>
<tr>
<td>June 18</td>
<td>NC4B</td>
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### NAEMS Dairy Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Site type</th>
<th>Vent type</th>
<th># Units Meas.</th>
<th>Manure collection</th>
<th>Manure storage¹</th>
<th>Bedding type⁵</th>
<th>Places</th>
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</thead>
<tbody>
<tr>
<td>NY5B</td>
<td>Freestall</td>
<td>MV</td>
<td>2³</td>
<td>Scrape</td>
<td>Dig./SS/Basin</td>
<td>SDS</td>
<td>470</td>
</tr>
<tr>
<td>IN5B</td>
<td>Freestall</td>
<td>MV</td>
<td>2</td>
<td>Scrape</td>
<td>Dig./SS/Basin</td>
<td>SDS</td>
<td>1600</td>
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<tr>
<td>WI5B</td>
<td>Freestall</td>
<td>MV</td>
<td>3³</td>
<td>Flush</td>
<td>SP/Basin</td>
<td>Mattress/shavings</td>
<td>325</td>
</tr>
<tr>
<td>CA5B</td>
<td>Open Freestall²</td>
<td>NV</td>
<td>2</td>
<td>Flush</td>
<td>SP/Basin</td>
<td>Soil/MS/Alm. shells</td>
<td>600</td>
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<tr>
<td>WA5B¹</td>
<td>Open Freestall²</td>
<td>NV</td>
<td>2</td>
<td>Flush</td>
<td>SP/SS/Basin</td>
<td>MS</td>
<td>650</td>
</tr>
</tbody>
</table>

¹Barn sites that also have measured area sources
²Cattle free to walk from open freestall barn into dry lots between barns.
³Monitored units include milking center.
⁴SP = settling pond
⁵MS = Manure solids
SDS = Separated digested solids
Freestall barn

Milking Center

Site monitoring plan for continuous air emission testing.
New York Dairy Site (NY5B)

Cross section of the freestall barns showing measurement locations.
Site monitoring plan for continuous air emission testing at freestall barns 1 and 2, and in the holding barn associated with the milking parlor.
Cross section of freestall barns 1 and 2 and side view of milking center showing measurement locations.
Wisconsin Dairy Site (WI5B)

Site monitoring plan for continuous air emission testing.
Cross section of the freestall barns showing measurement locations.
Site monitoring plan for continuous air emission testing.
Cross section of the freestall barns showing measurement locations.
Cross section of the freestall barns showing measurement locations.
Barn top-view showing measurement locations.
Barn 2 layout showing measurement locations.
## Layer and Broiler Sites

### Layer Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Type</th>
<th>Ventilation Type</th>
<th># of Units Meas.</th>
<th>Manure Collection</th>
<th>Manure Storage</th>
<th>Places</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC2B</td>
<td>High-rise</td>
<td>MV (tunnel)</td>
<td>2</td>
<td>CBC(^1)</td>
<td>First floor</td>
<td>103,000</td>
</tr>
<tr>
<td>IN2B</td>
<td>High-rise</td>
<td>MV (sidewall)</td>
<td>2</td>
<td>CBC</td>
<td>Belt Shed</td>
<td>250,000</td>
</tr>
<tr>
<td></td>
<td>Belt battery</td>
<td>MV (sidewall)</td>
<td>2</td>
<td></td>
<td>First floor</td>
<td>280,000</td>
</tr>
<tr>
<td></td>
<td>Manure shed</td>
<td>MV</td>
<td>1</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>CA2B</td>
<td>High-rise</td>
<td>MV (side wall)</td>
<td>2</td>
<td>DB(^2)</td>
<td>First floor</td>
<td>74,000</td>
</tr>
</tbody>
</table>

\(^1\)CBC = curtain backed cages  
\(^2\)DB = dropping boards under cages

### Broiler Site

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Type</th>
<th>Ventilation Type</th>
<th># Units Meas.</th>
<th>Manure Collection</th>
<th>Manure Storage</th>
<th>Places</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA1B</td>
<td>Litter on floor</td>
<td>MV (tunnel)</td>
<td>2</td>
<td>Scraper</td>
<td>None</td>
<td>21,000</td>
</tr>
</tbody>
</table>
Site monitoring plan for continuous air emission testing.
Indiana Layer Site (IN2B)

Cross section of the barns showing measurement locations.
Barn cross section showing measurement locations.
Site monitoring plan for continuous air emission testing.
# Swine Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Production phase</th>
<th># units meas.</th>
<th>Places</th>
<th>Manure collection</th>
<th>Manure storage&lt;sup&gt;2&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>NC4B&lt;sup&gt;1&lt;/sup&gt;</td>
<td>B/GF</td>
<td>2</td>
<td>850</td>
<td>PPR&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Lagoon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>20</td>
<td>PPR</td>
<td>Lagoon</td>
</tr>
<tr>
<td>NC3B</td>
<td>Finisher</td>
<td>3</td>
<td>800</td>
<td>PPR</td>
<td>Lagoon</td>
</tr>
<tr>
<td>IA4B</td>
<td>B/GF</td>
<td>2</td>
<td>1100</td>
<td>Deep pit&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Deep pit&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>24</td>
<td>PPR</td>
<td>Gest. pits</td>
</tr>
<tr>
<td>IN3B</td>
<td>Finisher</td>
<td>4</td>
<td>1000</td>
<td>Deep pit&lt;sup&gt;4&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>OK4B&lt;sup&gt;1&lt;/sup&gt;</td>
<td>B/GF</td>
<td>2</td>
<td>1200</td>
<td>PPR</td>
<td>Lagoon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>24</td>
<td>PPR</td>
<td>Lagoon</td>
</tr>
</tbody>
</table>

<sup>1</sup>Barn Sites that also have measured area sources, which are described in the open-source QAPP
<sup>2</sup>Characterizes type of farm, not necessarily a measurement location.
<sup>3</sup>PPR = pull plug with recharge
<sup>4</sup>Storage is inside the barn so separate measurement not needed for storage.
Barn top-view layout showing measurement locations.
Cross section of the barns showing measurement locations.
North Carolina Swine Site (NC3B)

Barn top-view layout showing measurement locations.

- Static pressure port
- Thermocouple
- Solar sensor
- RH/Temp probe
- Air sampling
- Exhaust fan
- TEOM
- Wind sensor
- Anemometer
- Activity sensor
- Instrument shelter
- Heated raceway

Each room is 165 ft x 41 ft
Cross section of the barns showing measurement locations.
Barn top-view layout showing measurement locations.
Cross section of the barns showing measurement locations.
Indiana Swine Site (IN3B)

Barn top-view layout showing measurement locations.

Each room is 200 ft x 42 ft.

- **Heater**
- **Activity sensor**
- **Static pressure port**
- **RH/Temp probe**
- **TEOM**
- **Thermocouple**
- **Air sampling**
- **Wind sensor**
- **Solar sensor**
- **Exhaust fan**
- **Pit Fan**
- **Anemometer**
- **TEOM outdoor enclosure**

Ventilation stage

Loadout

Room 7

Fan number

Room 8

Wind sensor

Room 6

Room 5

OFIS

N

Indiana Swine Site (IN3B)
Cross section of a barn showing measurement locations.
Barn top-view layout showing measurement locations.
Site monitoring plan for continuous air emission testing.
What Comes After NAEMS?

- NAEMS Pollutants?
  - Ammonia as precursor to PM2.5?
  - Hydrogen sulfide: property line limits?
  - TSP: no longer regulated by states?
- Add-on studies
- Greenhouse gas mitigation tests
- Odor mitigation studies
- Atmospheric dispersion studies
- Emission models

Check out www.AgAirQuality.com
# Add-on Studies

<table>
<thead>
<tr>
<th>PI</th>
<th>Topic/Sponsor</th>
<th>Site(s)</th>
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</thead>
<tbody>
<tr>
<td>Jacobson</td>
<td>Odor emissions <em>(USDA NRI)</em></td>
<td>IA&amp;OK4B, IN&amp;WI5B</td>
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<tr>
<td>Mitloehner</td>
<td>VOCs @ GHGs <em>(CA Dept. of Food, Ag. &amp; Dairy)</em></td>
<td>CA5B</td>
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<tr>
<td>Lim</td>
<td>Downwind Dairy Odor Survey <em>(Purdue Ag)</em></td>
<td>IN5B</td>
</tr>
<tr>
<td>Ni</td>
<td>Air emissions <em>(USDA-NRI)</em></td>
<td>IN2B</td>
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<tr>
<td>Koziel</td>
<td>GHG <em>(ISU)</em></td>
<td>IA4B</td>
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</tbody>
</table>
Summary of NAEMS Progress

- Subcontracts established with 7 universities
- Equipment acquisition nearly complete.
- Training of all personnel last week.
- Site setup period has begun.
- Data gathering begins after setup.
- NAEMS web site: www.AgAirQuality.com
Data Scalability

Are the impacts of a single 4000-hd unit the same as the combined impacts of 8 500-hd units?

Yes, if all major factors are similar.
- Manure volume, surface area per animal.
- Animal-specific floor area

No, if the animal-specific parameters change with size.

NAEMS will not determine these impacts.
Model Properties

- What model parameters will result from this study?
  - We will characterize sites for validation of models.
  - See tables shown previously.
Parameter Definitions

- What are the specific parameter definitions of each monitored site?
- See tables of site descriptions.
## PM and H2S Measurements

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>PM2.5, PM10, TSP</th>
<th>H2S</th>
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</thead>
<tbody>
<tr>
<td>CA1B</td>
<td>Broilers</td>
<td>TEOM</td>
<td>TFS 450i</td>
</tr>
<tr>
<td>NY5B</td>
<td>Dairy</td>
<td>TEOM</td>
<td>TFS 450i</td>
</tr>
<tr>
<td>WA5B</td>
<td>Dairy</td>
<td>TEOM</td>
<td>TFS 450i</td>
</tr>
<tr>
<td>WI5B</td>
<td>Dairy</td>
<td>TEOM</td>
<td>TFS 450i</td>
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<td>TFS 450i</td>
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<td>Dairy</td>
<td>TEOM</td>
<td>TFS 450i</td>
</tr>
<tr>
<td>CA2B</td>
<td>Layers</td>
<td>TEOM</td>
<td>TFS 450i</td>
</tr>
<tr>
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## NH3 and VOC Measurements

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PM Oversampling

- Does the sampling methodology and analysis of results include measures to address sampler bias?
  - No, but we acknowledge the difference between regulated PM10 and true PM10.

- Will corrections be applied to field measurements?
  - Not unless EPA requires it.

- Will TSP measurements be taken in conjunction with particle size distributions as a point of comparison with PM10 and PM2.5 measurements?
  - No. However, an AARC-approved add-on study has been proposed that will do this for poultry PM.

- If not, what method(s) will be used to ensure measurement of “true” PM?
  - Since EPA regulates based on response of a particular method or instrument rather than “true” PM10 or PM2.5, EPA did not require the assessment of “true” PM for the consent agreement.
PM Related Questions

- Will the measurement timeframe and method for PM2.5 adequately represent the PM2.5 concentrations for subsequent inclusion in a dispersion model?
  - PM2.5 will only be measured for a total of 4 weeks.
  - PM2.5 of layer PM is about 10% of PM10.
- Which models will be used and evaluated for accuracy in the study?
  - Evaluating models is beyond the scope of the study itself.
  - Add-on proposals are expected.
Figure 8. One minute means of TSP, $PM_{10}$, and $PM_{2.5}$ concentrations in a laying hen house, June 4, 2002.
Fate and Transport

- What is the fate and transport of any of the pollutants measured? Producers need to know also what is leaving the property and in what quantities.

- The NAEMS will not measure downwind concentrations or pollutant dispersion.
Conservation Practices

- Will conservation management practices be evaluated as part of the study to determine the efficiency of various practices for each pollutant?
  - No. This is beyond the scope of the study.