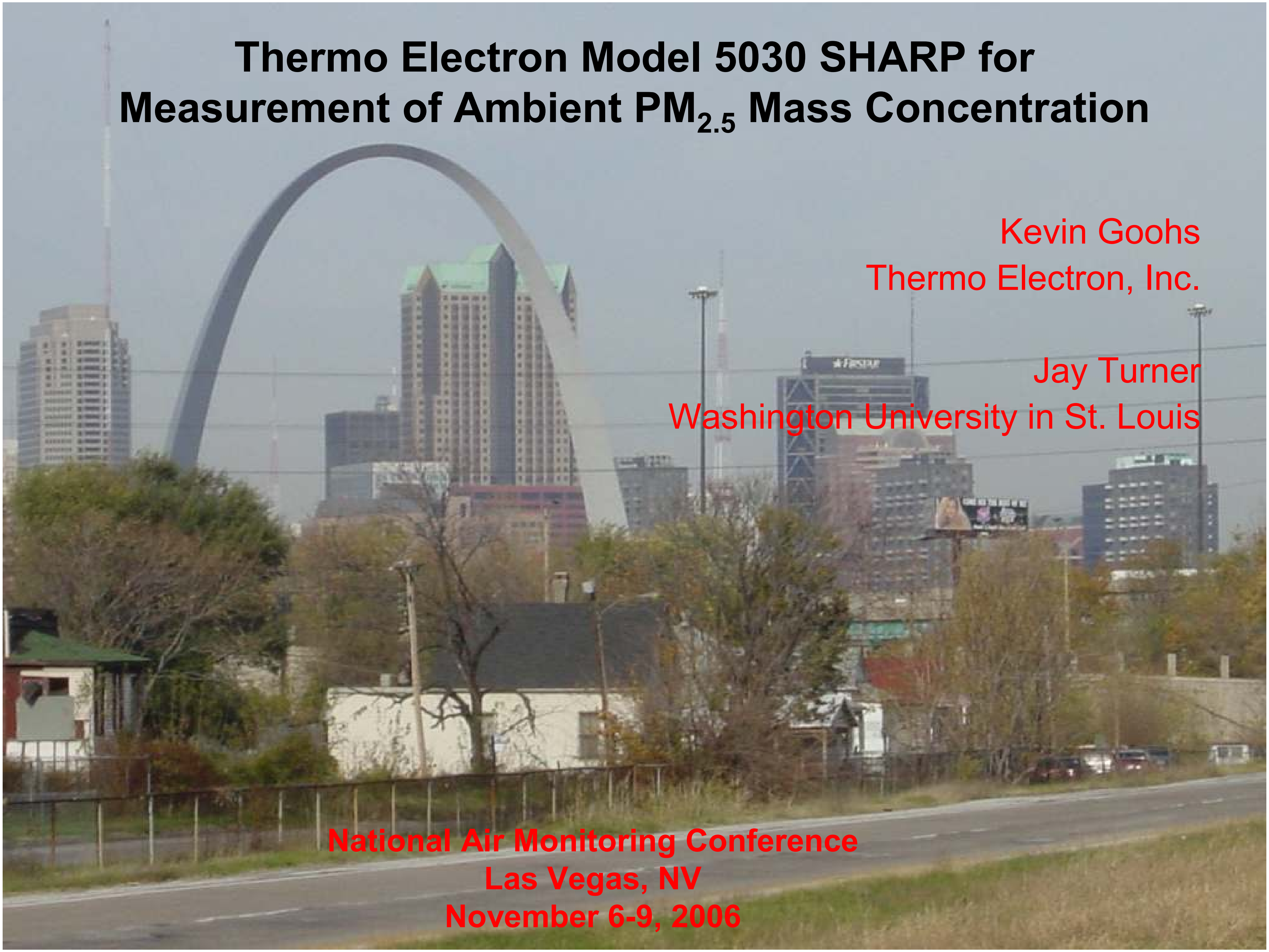
Thermo Electron Model 5030 SHARP for Measurement of Ambient $PM_{2.5}$ Mass Concentration



Kevin Goohs
Thermo Electron, Inc.

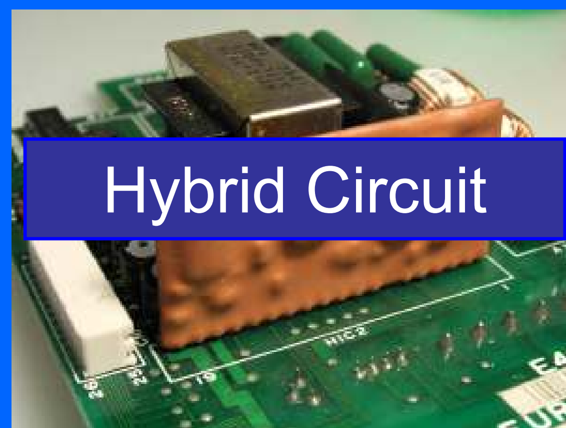
Jay Turner
Washington University in St. Louis

National Air Monitoring Conference
Las Vegas, NV
November 6-9, 2006

Hybrid Concepts

The continuous use of two (2) compatible technologies on a combined platform to enhance the overall performance while maintaining it's original function.

Hybrid Spudgun



Hybrid Circuit

Hybrid Bicycle

Hybrid Vehicle

Hybrid Concepts (continued)

Thermo
ELECTRON CORPORATION

Washington
University in St. Louis

This Presentation

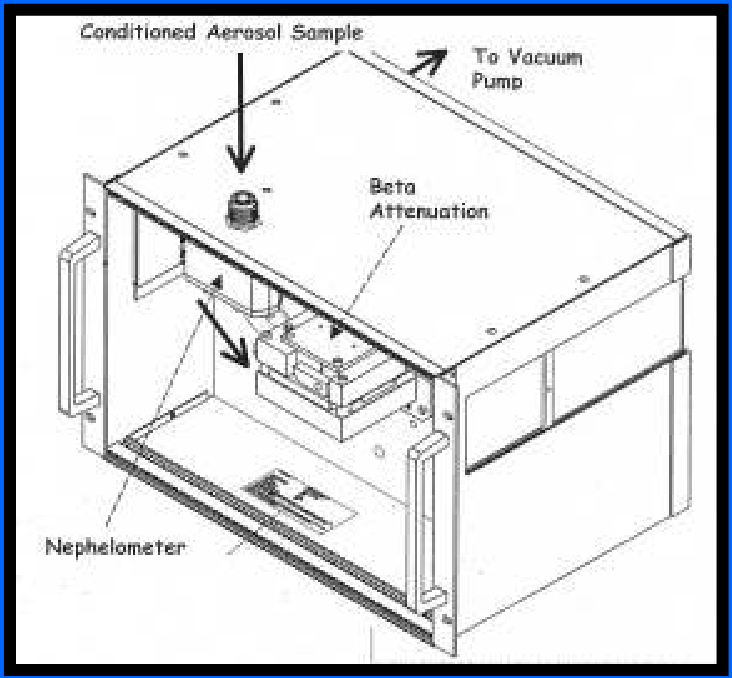
- de-Gooh'zd
- Turner-ized

Thermo SHARP

- Nephelometry
- Beta attenuation

Synchronized **H**ybrid **A**mbient **R**eal-Time **P**articulate Monitor (SHARP)

- Accuracy of a beta gauge with high time resolution of a nephelometer
  - Heater on the inlet line for moisture control
  - Nephelometer and beta gauge in series
  - Dynamic digital filtering of both data streams to continuously adjust the nephelometer response using the beta gauge response



- No HVAC control needed –
  - Can be sited outdoors in an environmental shelter, better chance to capture FRM-like artifacts
  - Can be sited indoors
- Digital filtering stabilizes the typically noisy beta gauge response
  - can lead to complicated signal dynamics
- High time resolution
  - 1 minute concentration output

Hybrid Dynamic Digital Filtering

General Equation

$$SHARP_n = R_n * (C_\beta f\_\tau_v / Rf\_\tau_v)_n$$

R_n = *Nephelometer 1 minute running average*

$C_\beta f\_\tau_v$ = *Dynamically filtered Beta-derived conc.*

Rf_τ_v = *Dynamically filtered Neph-derived conc.*

Dynamic Digital Filtering

$$\tau_v = \tau_o * A'$$

A' = dynamic time constant factor

τ_v = dynamic digital filtering time constant

Conceptualize as a mass scattering efficiency that is dynamically adjusted using the relationship between aerosol light scattering intensity by nephelometry and aerosol mass concentration by beta attenuation

SHARP Beta Gauge

- ^{14}C beta emission source
  - Low energy electrons, inelastic scattering with the atomic nucleus of the absorbing material... Generally follows Beer's Law and is relatively insensitive to composition of the absorber
  - In contrast, high energy electrons susceptible to bremsstrahlung radiation (inelastic scattering with the nuclear column field) which can be very sensitive to composition of the absorber
  - thus, can we rule out site-to-site variations in SHARP response (compared to a reference method) being driven by differences in aerosol composition?
- Calibrations performed with muscovite films, mass absorption properties similar to ammonium sulfate and other major components in ambient aerosol

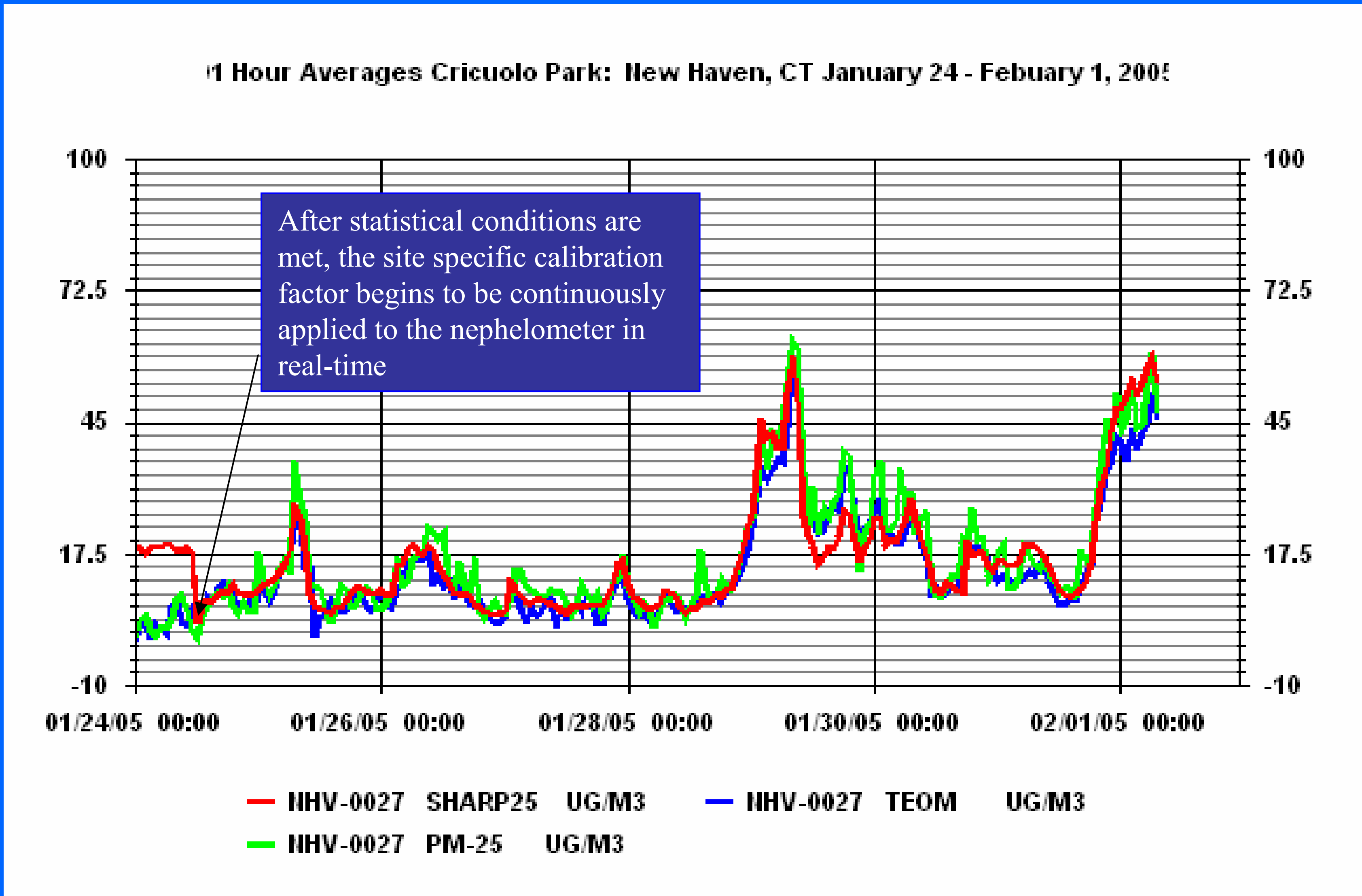
Sample Conditioning

- Relative humidity measured immediately upstream of the beta gauge filter tape
  - User-selected setpoint RH
    - Typically 40% RH USA and 65% RH EU
  - Sample stream is conditioned upstream of the nephelometer
    - PID controller for applying a heater duty
  - Above setpoint RH, heating is applied subject to a constraint for the maximum allowable temperature difference
  - Below setpoint RH, heater is turned off

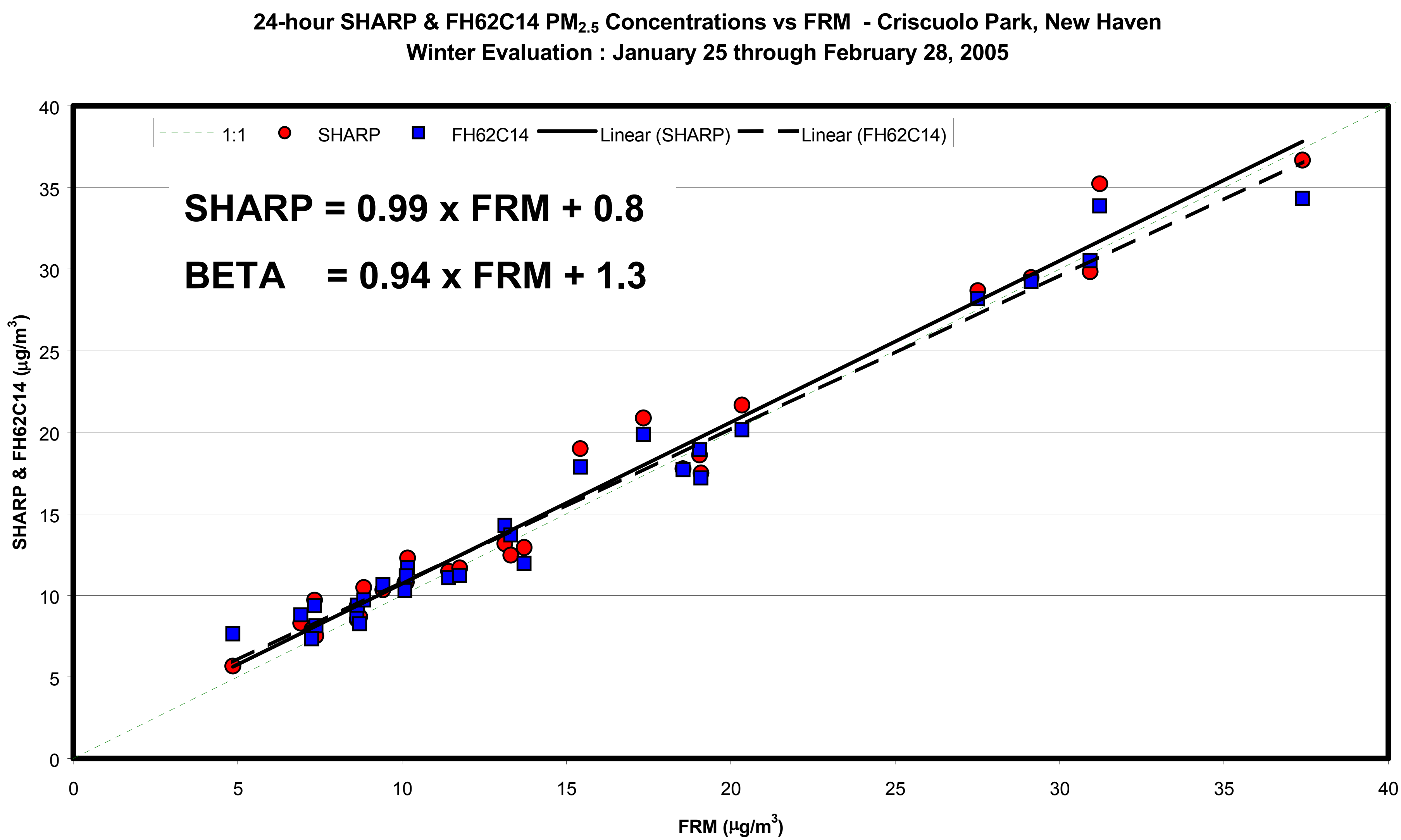
Field Tests

- New Haven, CT
- East St. Louis, IL (St. Louis – Midwest Supersite)
- Bakersfield, CA
- Dayton, CA

Field Testing – New Haven, CT

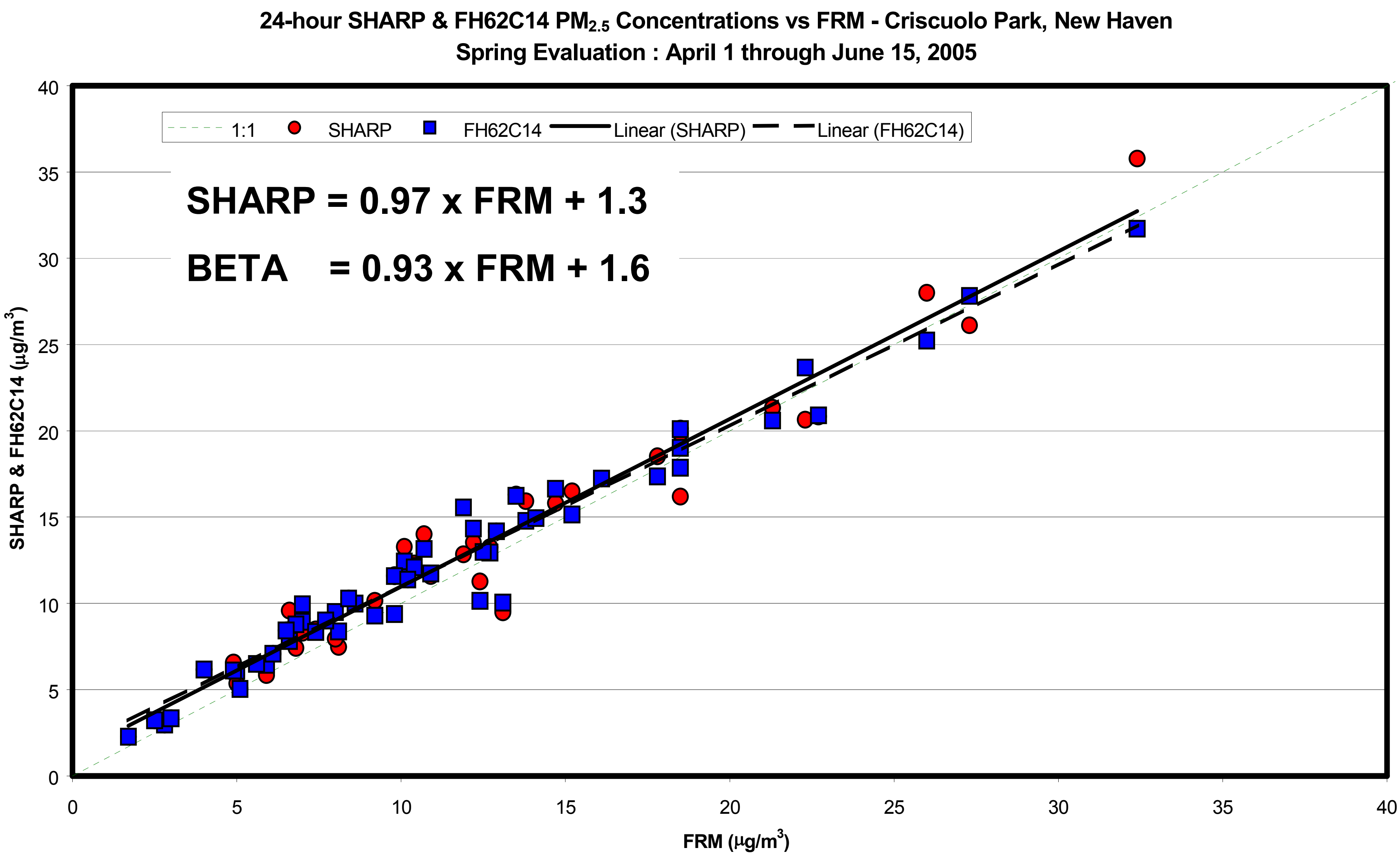


Field Testing – New Haven, CT
January 25 -February 28, 2005



Field Testing – New Haven, CT

April 1 – June 15, 2005



Field Testing – New Haven, CT (2005)

- Hourly comparisons between Thermo SHARP, Thermo FDMS TEOM and MetOne 1020 BAM [posted materials will show scatter plots]
- Regression of Monitor "X" on SHARP…

	Period	1/25-2/28	4/1-6/15	6/16/-9/29
FDMS TEOM	Slope	0.90	0.98	1.05
	Intercept	0.08	-0.49	0.24
	R^2	0.90	0.80	0.91
MetOne 1020 BAM	Slope	1.03	0.94	1.02
	Intercept	2.00	3.08	-0.01
	R^2	0.80	0.62	0.83

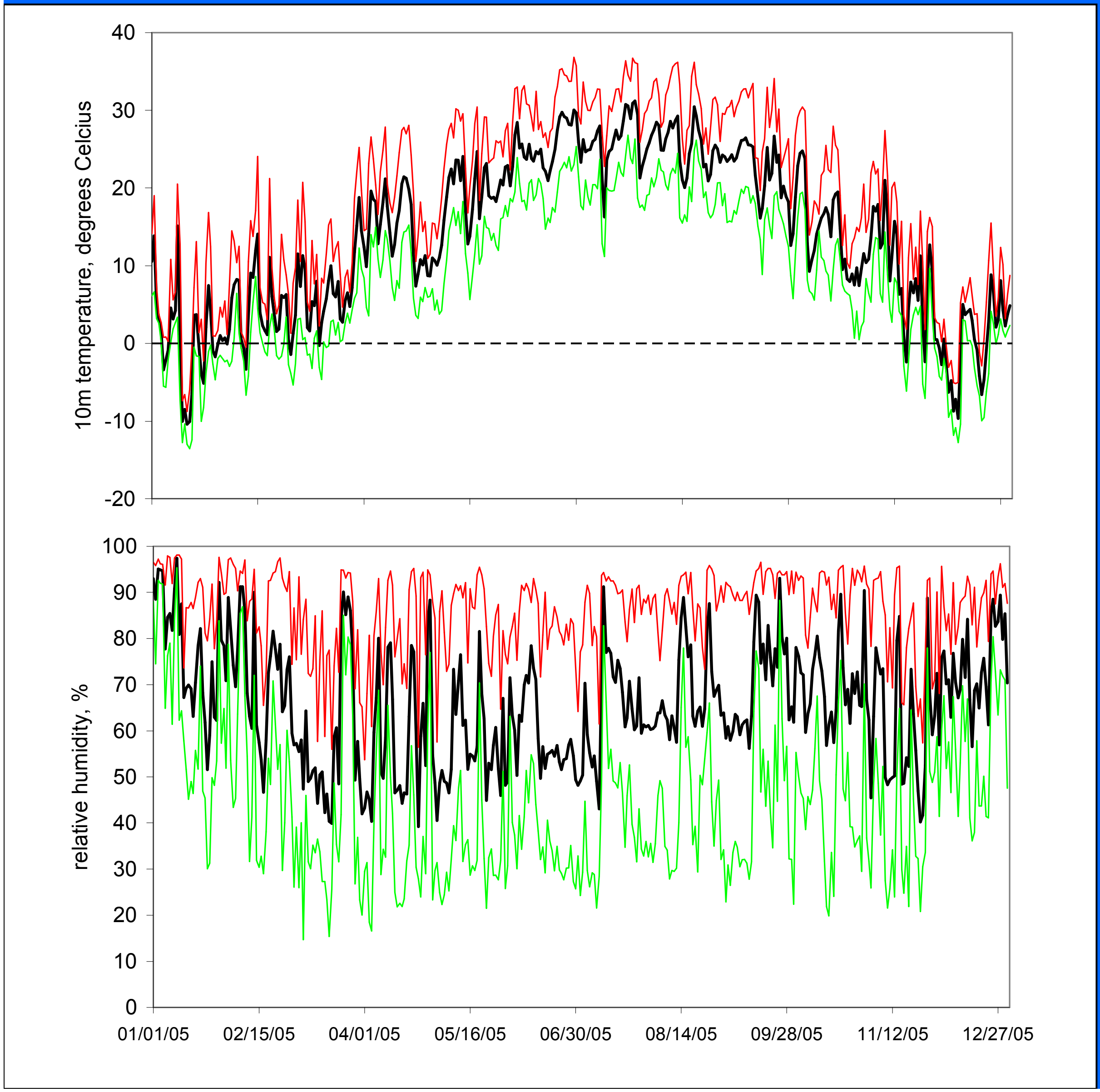
East St. Louis SHARP Deployment

- Beta testing with prototype units commenced in spring 2004
  - Numerous hardware and software revisions
- One-year field performance evaluation with production units commenced April 2005
  - No revisions to the hardware or software were implemented
  - Two units: a primary monitor and collocated monitor
    - Primary monitor used for comparisons to FRM
    - Collocated unit typically operated identical to primary unit for estimating precision
      - Operating conditions periodically changed, e.g. dynamic zero sampling (HEPA filter on inlet), different beta gauge tape advance schedules
- Default operating conditions:
  - Both units outdoors in environmental shelters but with no HVAC control
  - One/day beta gauge tape advances (midnight CST)

East St. Louis SHARP Deployment

- Virtually no field operations issues
  - Routine maintenance performed weekly; much lower frequency likely needed
  - One instance of the tape advance system not resealing after a tape advance event at very cold temperature (not an issue for deployments inside a HVAC-controlled shelter)
- Beta gauge recalibrated after one year in the field – 0.5% change

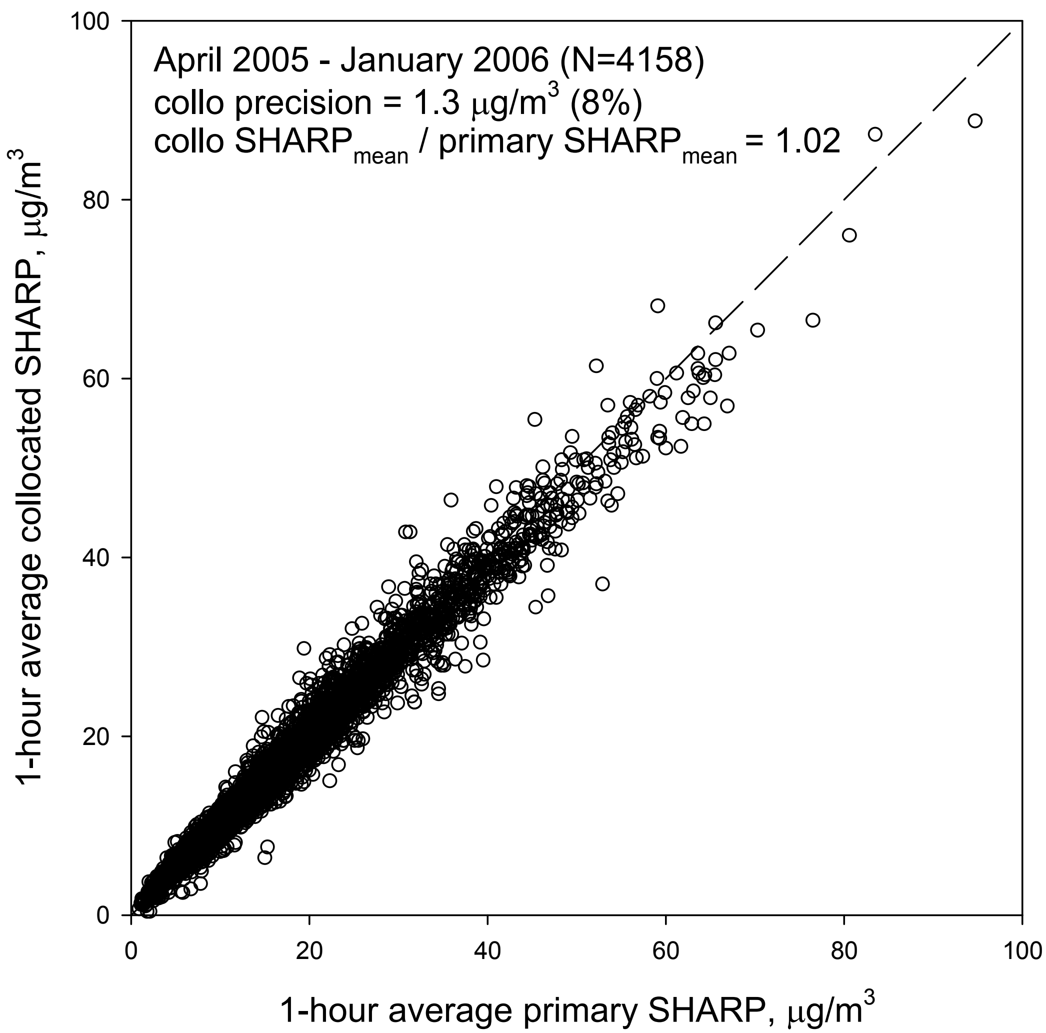
Challenging the Moisture Control System: Environmental Conditions in East St. Louis



sustained, subfreezing temperatures in the winter

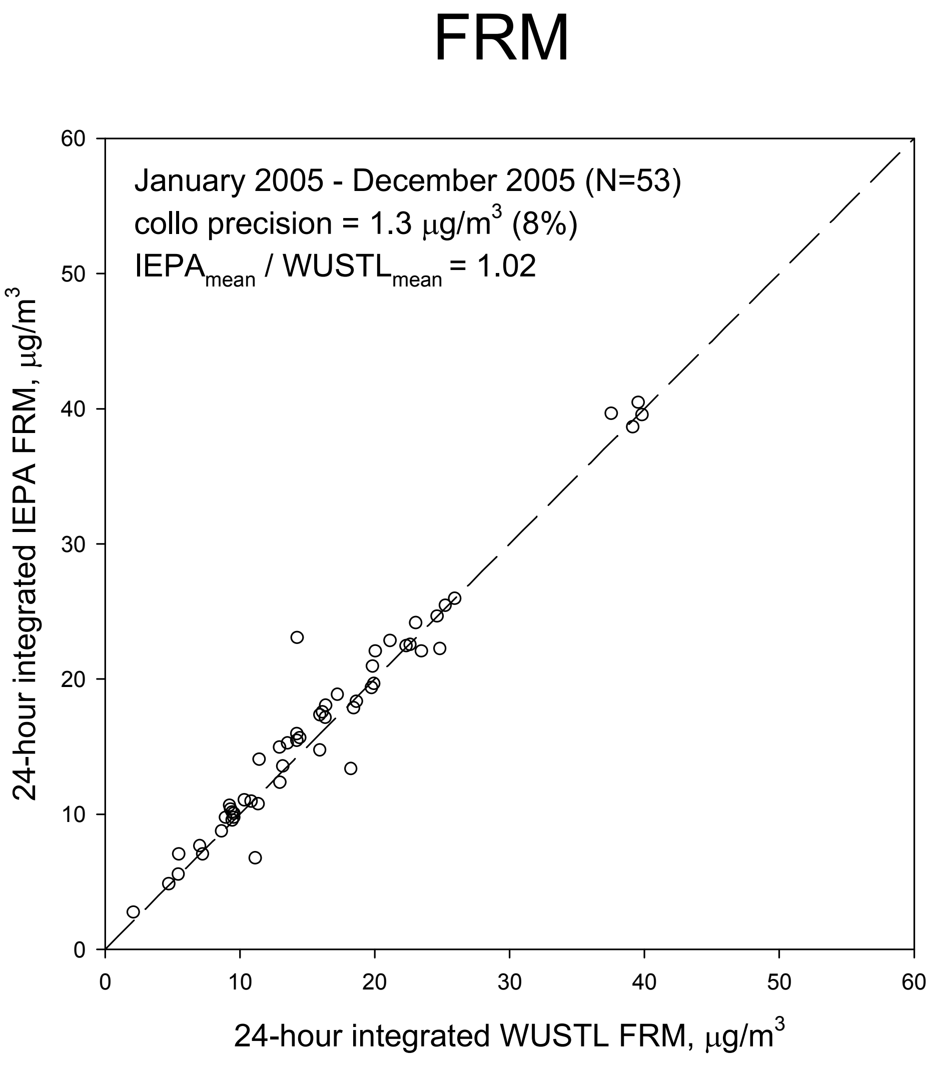
daily maximum RH routinely exceeds 85%, regardless of season

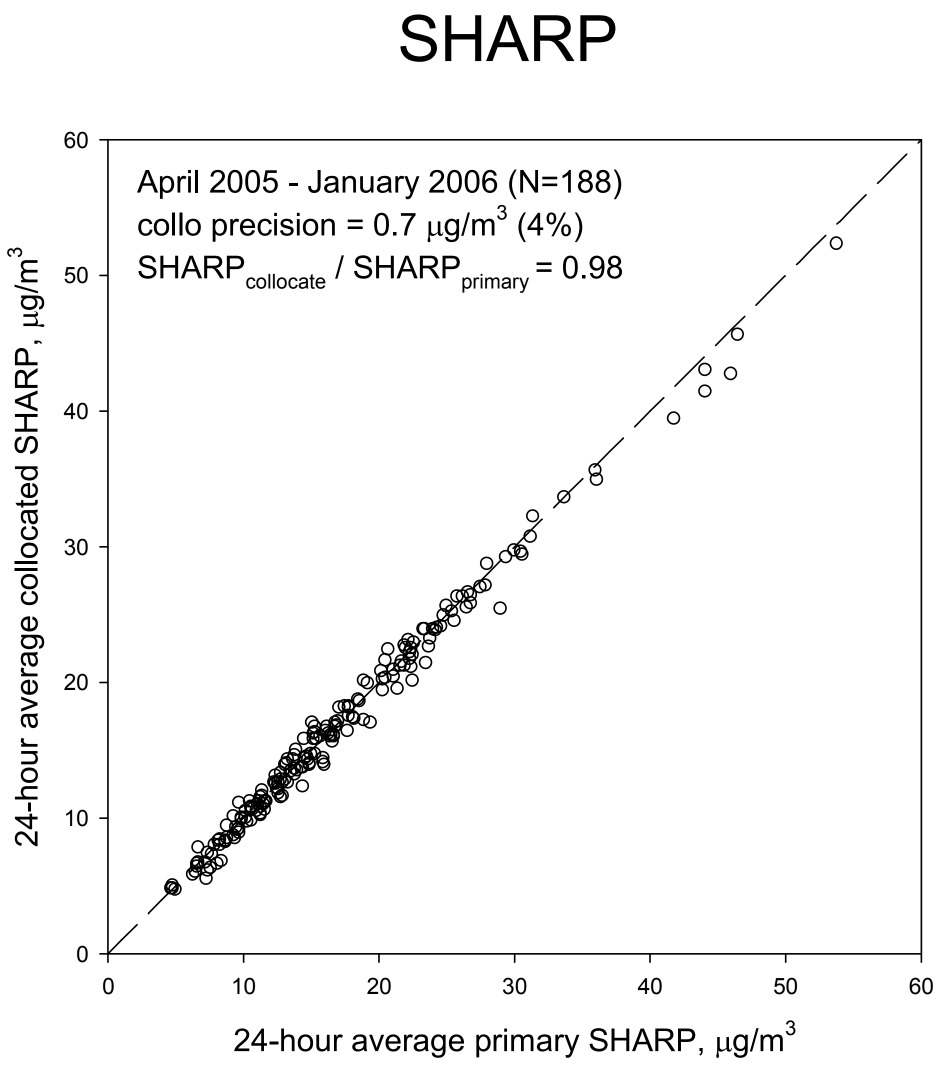
Hourly Average Collocated SHARP



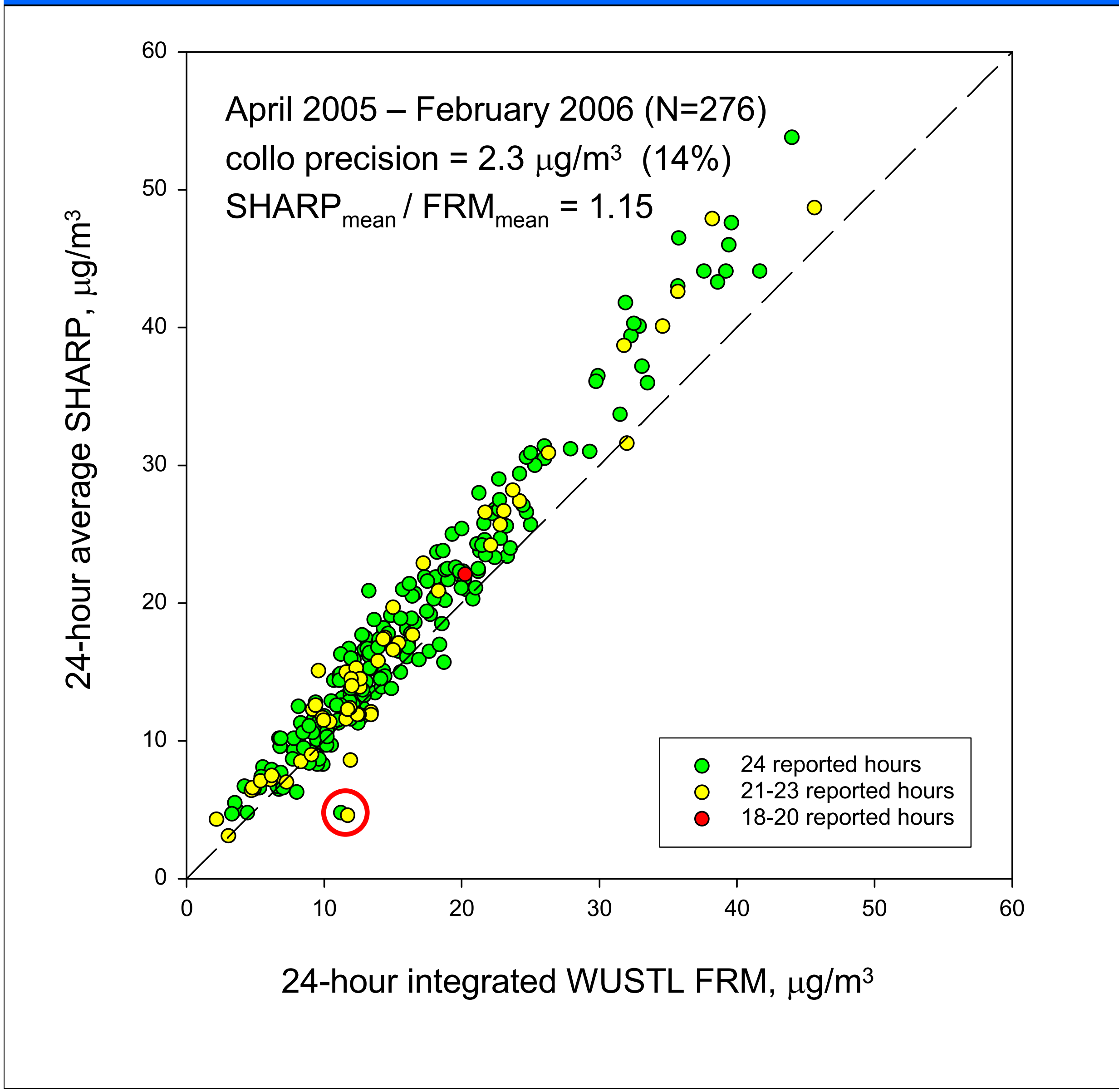
excellent agreement between collocated SHARP instruments

Daily-Integrated FRM and Daily-Average SHARP Collocated Performance





Comparison of SHARP to FRM

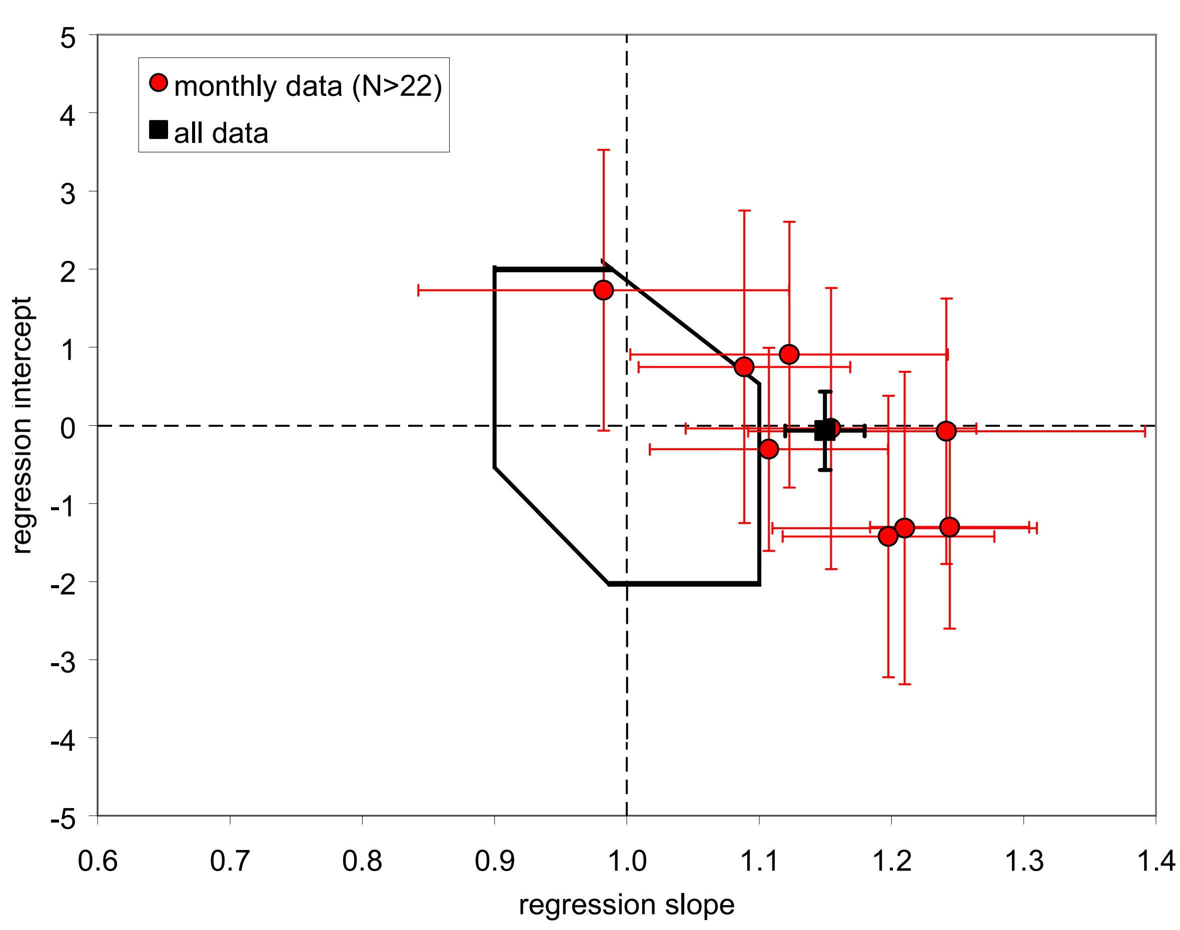


data is highly correlated

SHARP biased ~15% high with respect to FRM

circled data likely invalid for FRM based on comparisons to other data streams (not shown)

SHARP Performance and FEM Slope and Intercept Acceptance Limits (STL)



monthly data sets meet proposed FEM test sample sizes

SHARP collocated precision is acceptable (6% < 15% criterion)

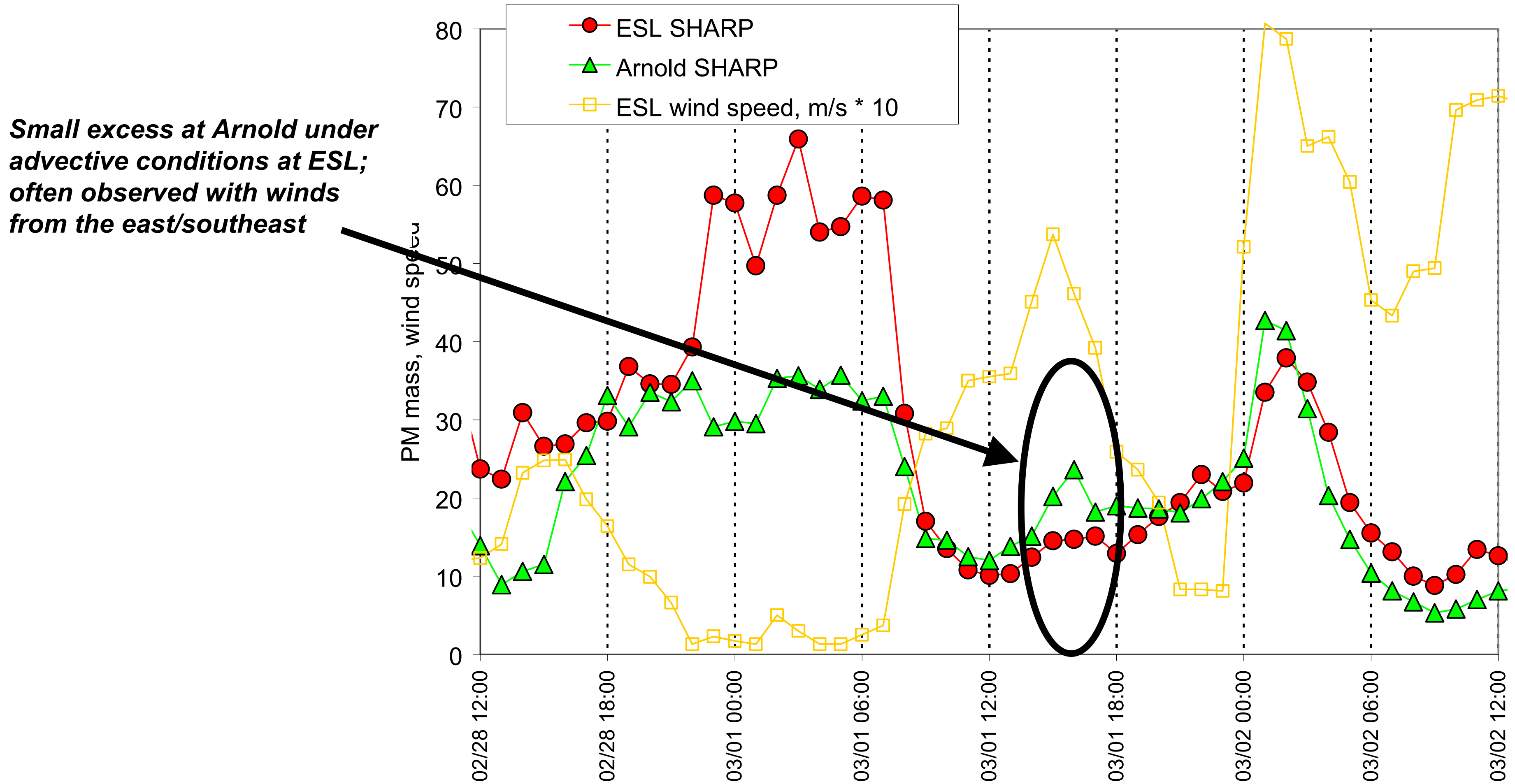
correlation between SHARP and FRM is acceptable (98% > 95% criterion)

in most cases, SHARP performance falls outside the proposed FEM slope and intercept (versus FRM) acceptance limits

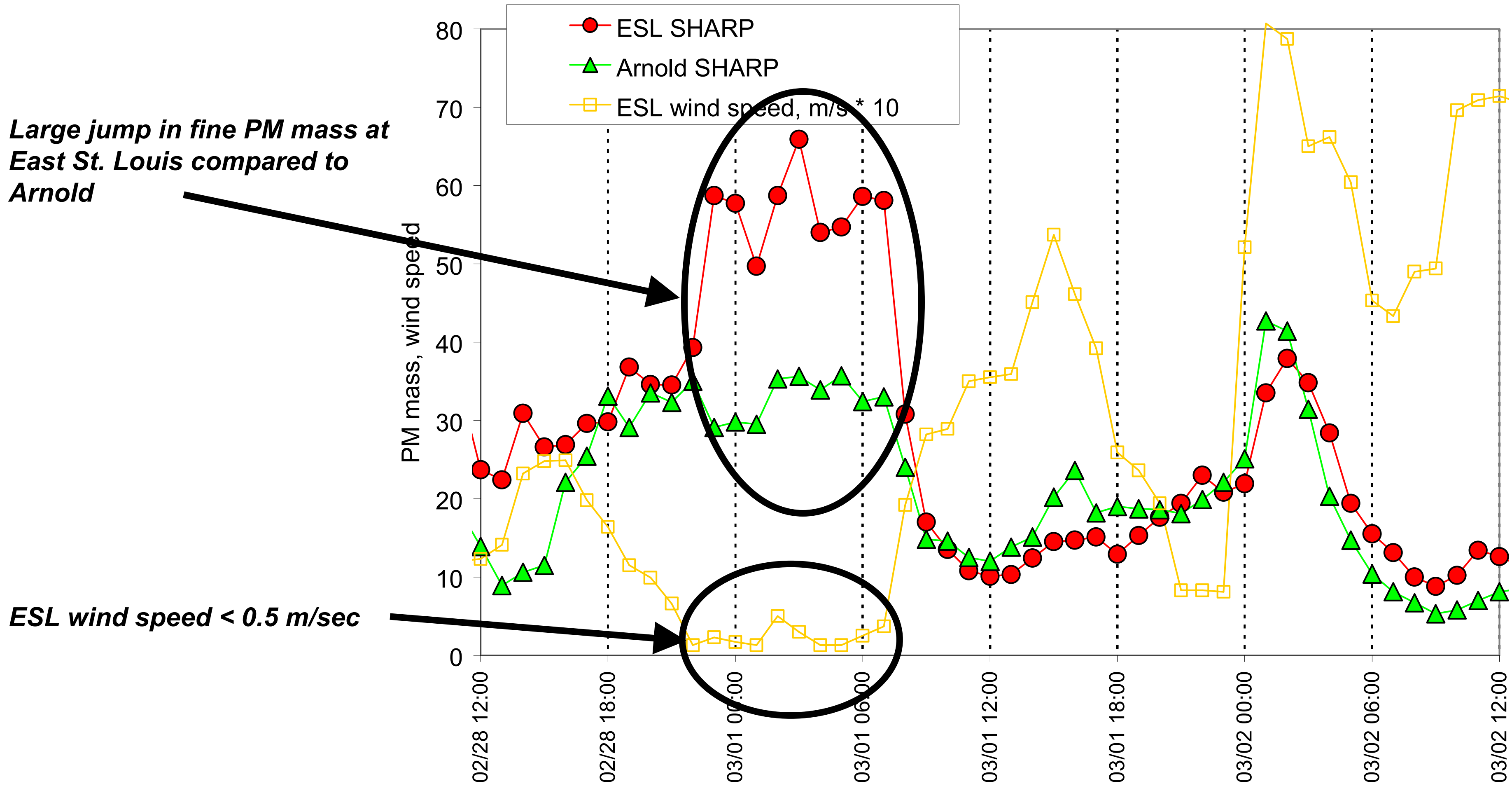
Potential Refinements to the SHARP

- Refined moisture control
  – Careful examination of 1-minute data shows there potential issues with the moisture control system
    - Cannot adequately respond to rapid RH transients (in part due to heater duty control algorithm which in STL was a constant heater duty, not PID)
    - Heater duty constraints to prevent overheating might be too stringent
  – any changes to the moisture control system must consider implications to dynamics of volatile species!
- It is not clear that aerosol water can explain the differences between the SHARP and FRM in St. Louis
  – Same relationship between SHARP and FRM (~15% difference) observed by Missouri DNR at a separate St. Louis area site… are the beta absorption properties different for the St. Louis aerosol compared to the muscovite calibration film?

Thermo SHARP $PM_{2.5}$ Mass Monitors at East St. Louis and Arnold



Thermo SHARP $PM_{2.5}$ Mass Monitors at East St. Louis and Arnold



Summary and Conclusions - I

- Field testing at exhibited:
  - New Haven, CT
    - Excellent regression slope and intercepts compared to FRM
  - East St. Louis, IL
    - Excellent durability with very low maintenance requirements
    - Excellent collocated precision
    - Highly correlated to FRM but biased about 15% high

Summary and Conclusions - II

- Efforts underway to close the gap on SHARP comparison to FRM
  - Refinements to moisture control system, examine β absorption
- Very difficult to extrapolate performance in one geographic area to other areas due to variations in aerosol and environment conditions
  - SHARP: East St. Louis, IL versus New Haven, CT (the former is outside, the latter is in a climate-controlled shelter)
  - FDMS TEOM: Bronx and Queens, NYC (Schwab *et al.* 2006)
  - potentially presents a challenge to FEM testing and subsequent deployment of designated instruments
- A preliminary examination of hourly data streams using matched instruments suggests we can gain substantial insights into intraurban variability
  - Previous efforts on St. Louis area data using monitors of different makes and models were challenging to interpret

Acknowledgements

- New Haven field and data support
  - Paul Norton, Pete Babich and other Connecticut DEP staff
- East St. Louis field and data support
  - Jason Hill, Eric Ryszkiewicz and other Turner group staff
  - Illinois EPA
- Ron Stockett (Missouri DNR) for Arnold, MO data

For More Information

- Proceedings of the 99th Annual Meeting of the Air & Waste Management Association, New Orleans, LA, June 20-23, 2006
  - K. Goohs, P. Lilienfeld, W. Harmon and J. Wilbertz, “A Synchronized Hybrid Ambient Real-Time Particulate Mass Monitor”
  - J.S. Hill, E.R. Ryszkiewicz, J.R. Turner and K.J. Goohs, “Field Performance Evaluation of the Thermo Electron Model 5030 SHARP for Measurement of Ambient PM2.5 Mass Concentration” (paper #533)