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US Army Corps of Engineers
Engineer Research and Development Center

Determining Atmospheric Plume Opacity Using Low-Cost Digital Still Cameras

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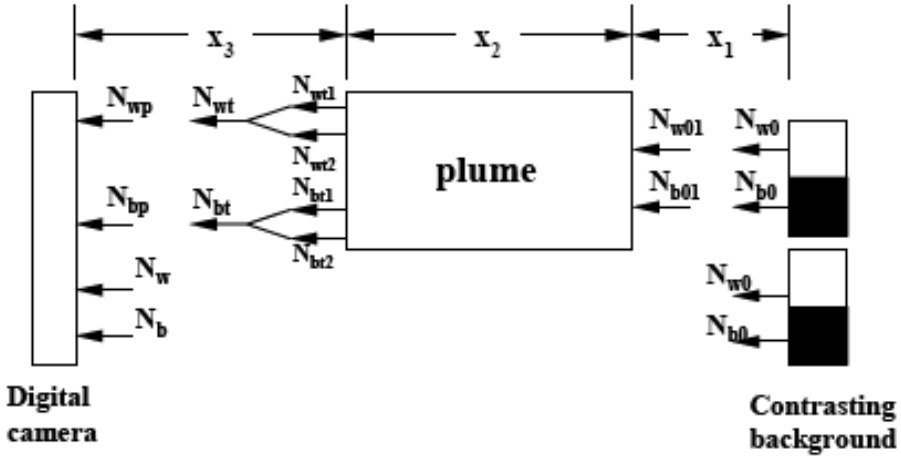
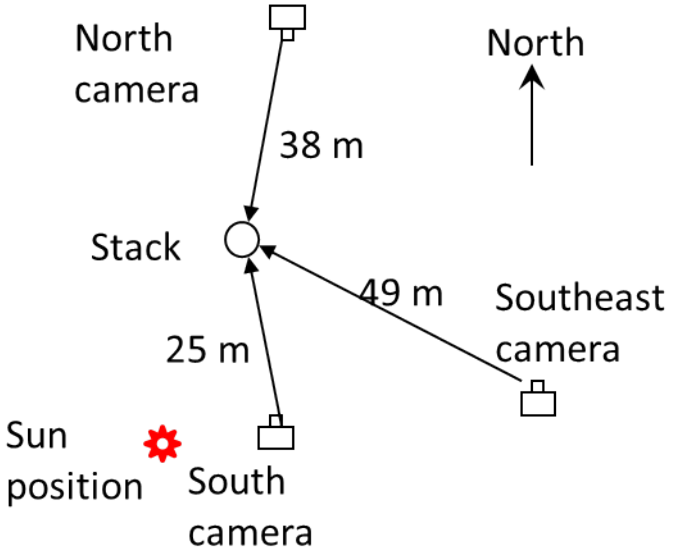
Overview

- Background

- Methods



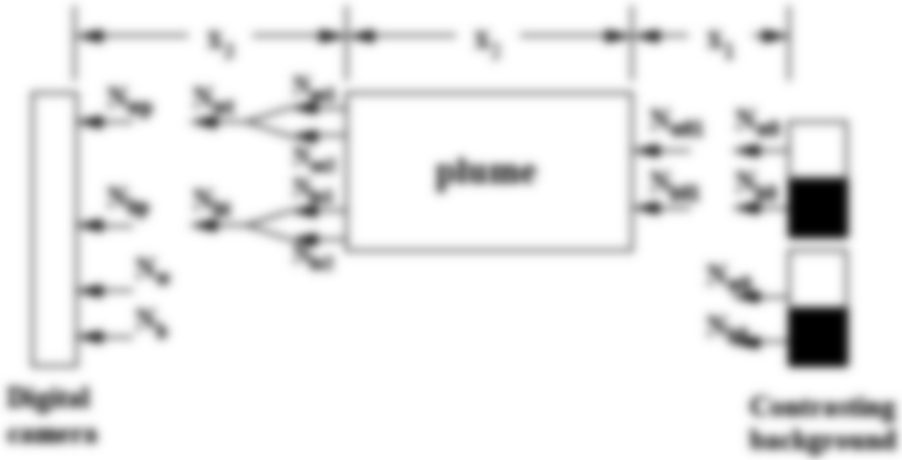
- Field Implementation & Results



Overview

- **Background**

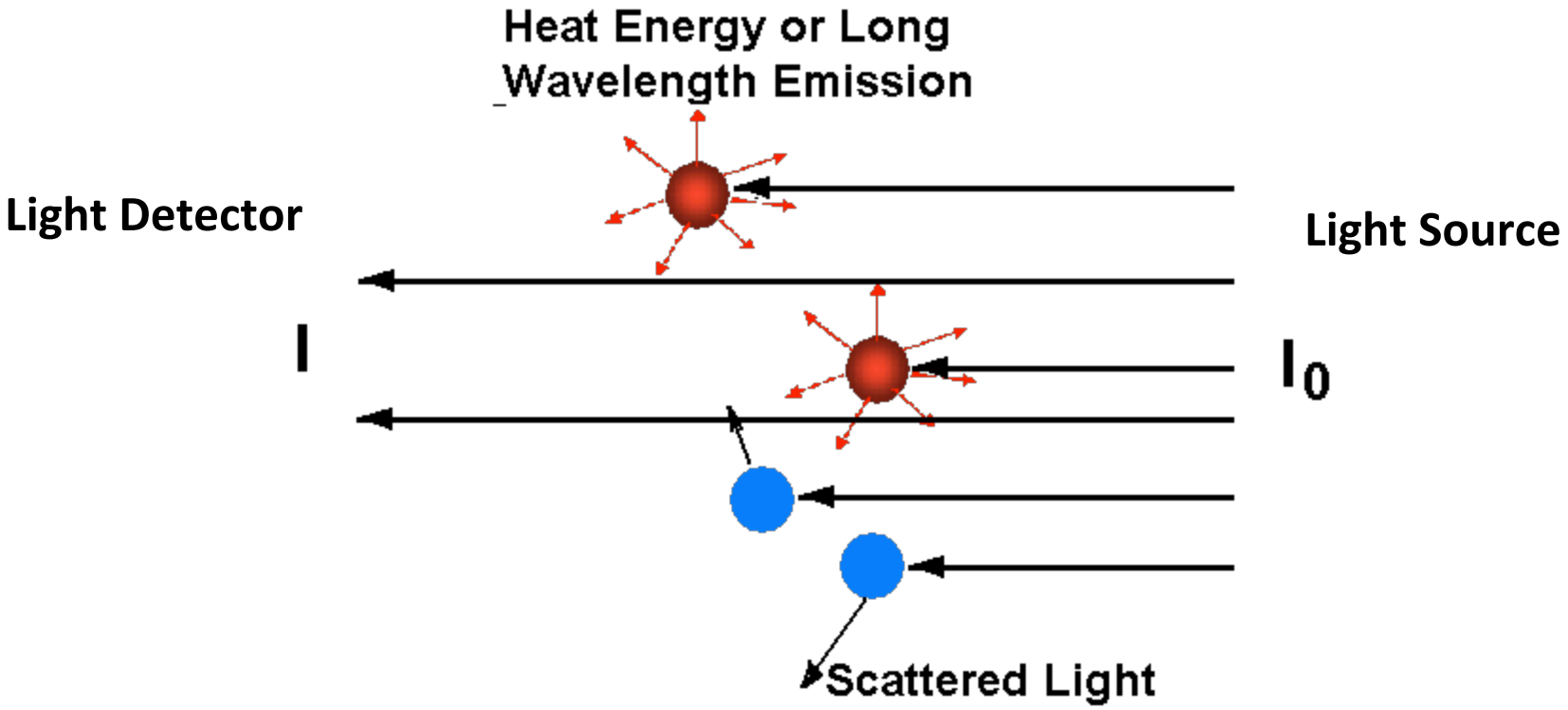
- Methods



- Field Implementation & Results

Definition of Plume Opacity

- Opacity: Percent of light attenuated by plume



$$\text{Opacity} = \left(1 - \frac{I}{I_0}\right) * 100$$

Timeline 1

1979

USEPA Method 9 developed to determine atmospheric plume opacity, requires field certification of human observers every six months

Motivation for Development of DOM

- Human perception is subjective

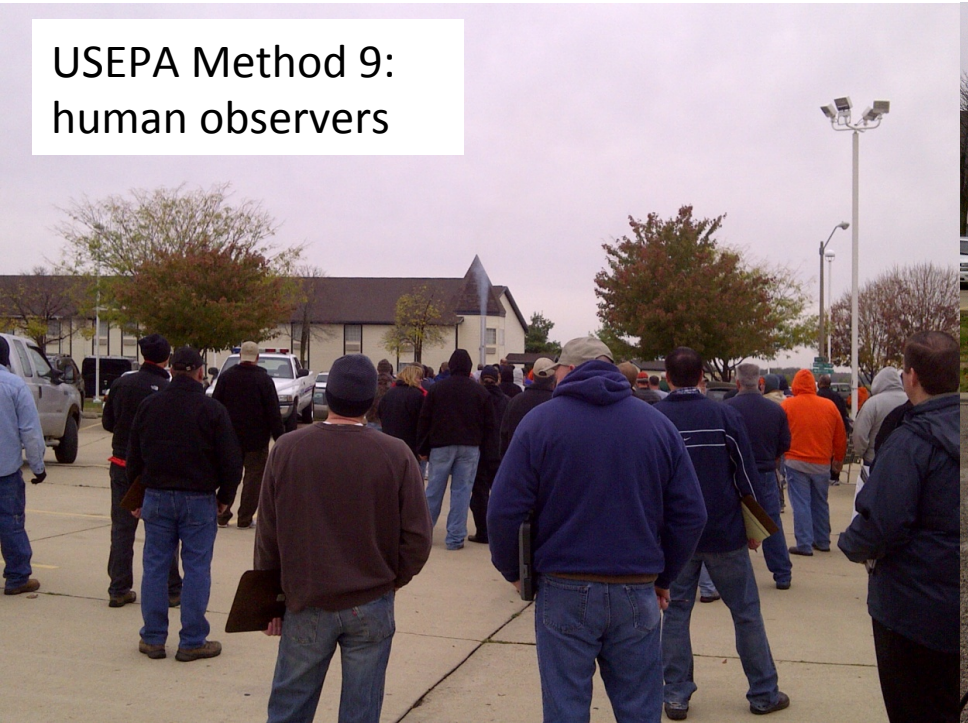
Timeline 2

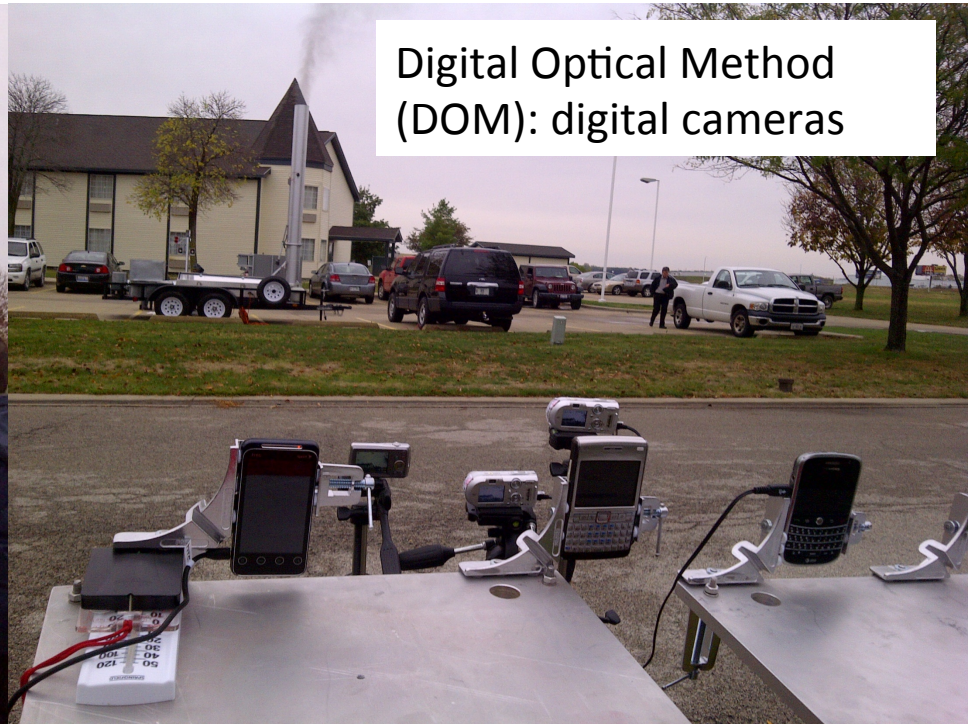
2002-2003

Development of Digital Optical Method (DOM) software to quantify plume opacity with low-cost digital still cameras

Methods to Measure Plume Opacity

- USEPA Method 9
- Digital Optical Method (DOM)





Digital Optical Method (DOM)

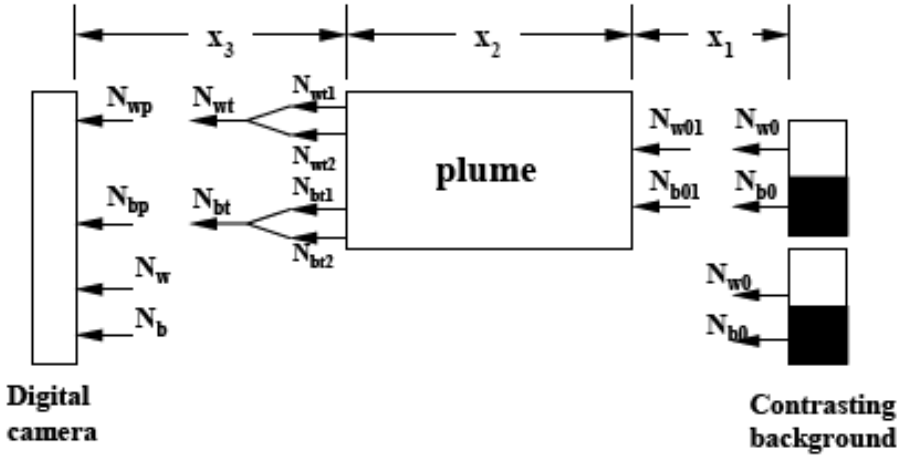
Advantages of using digital cameras compared to Method 9

- More objective then human observations
- Potential to save at least $200 M/yr compared to Method 9 (USEPA, 2006)
- Provide archival digital records of plume and environmental conditions
- Deployable with low-cost digital cameras allowing rapid data analysis, geo-positioning, and data dissemination

Overview

- Background

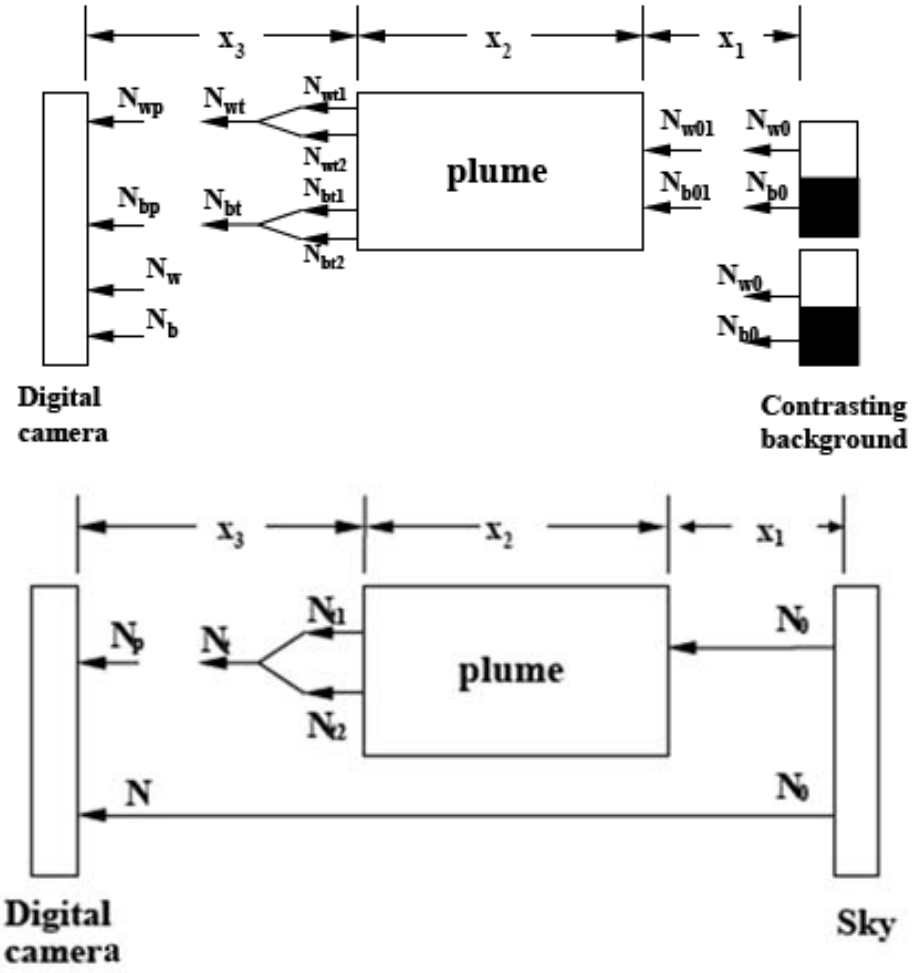
- **Methods**



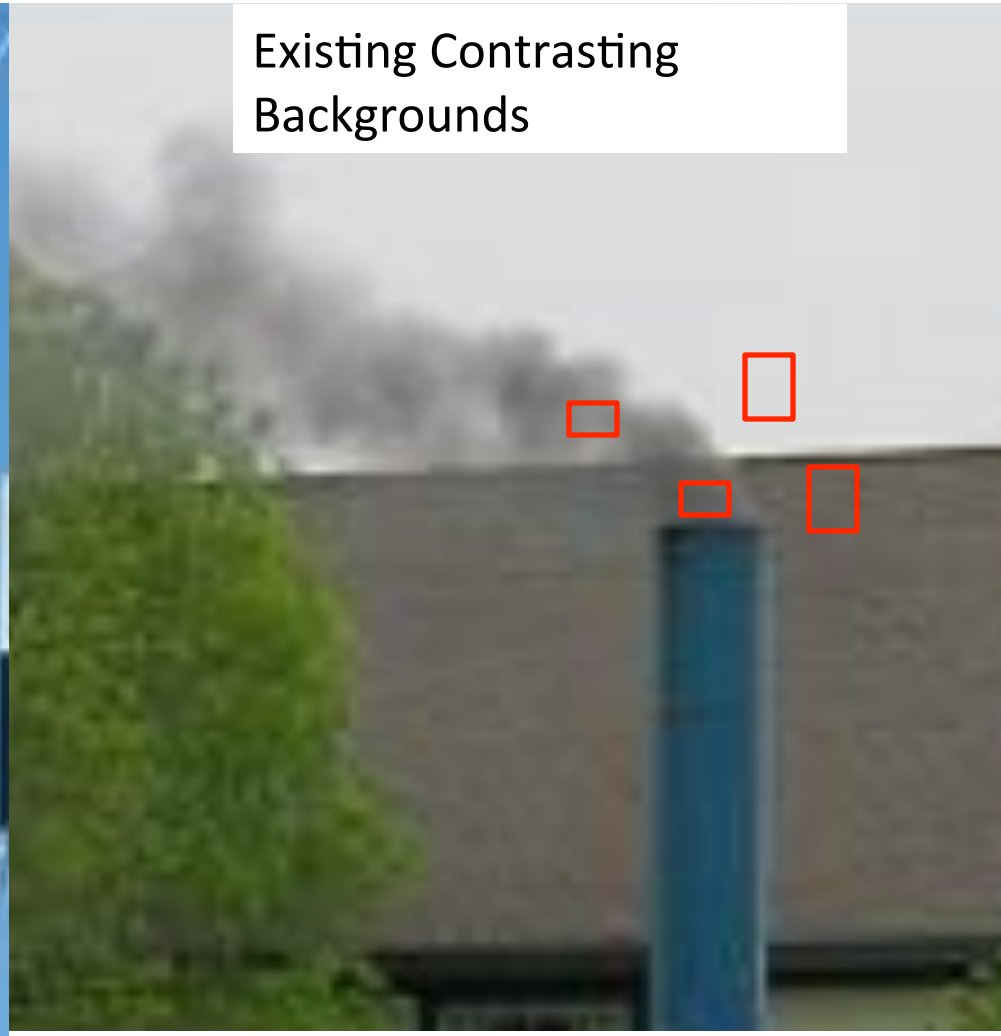
- Field Implementation & Results

Methods

- **Two DOM Models**
  - **Contrast Model:** use two contrasting backgrounds behind and next to the plume
  - **Transmission Model:** use a uniform contrasting background behind and next to the plume

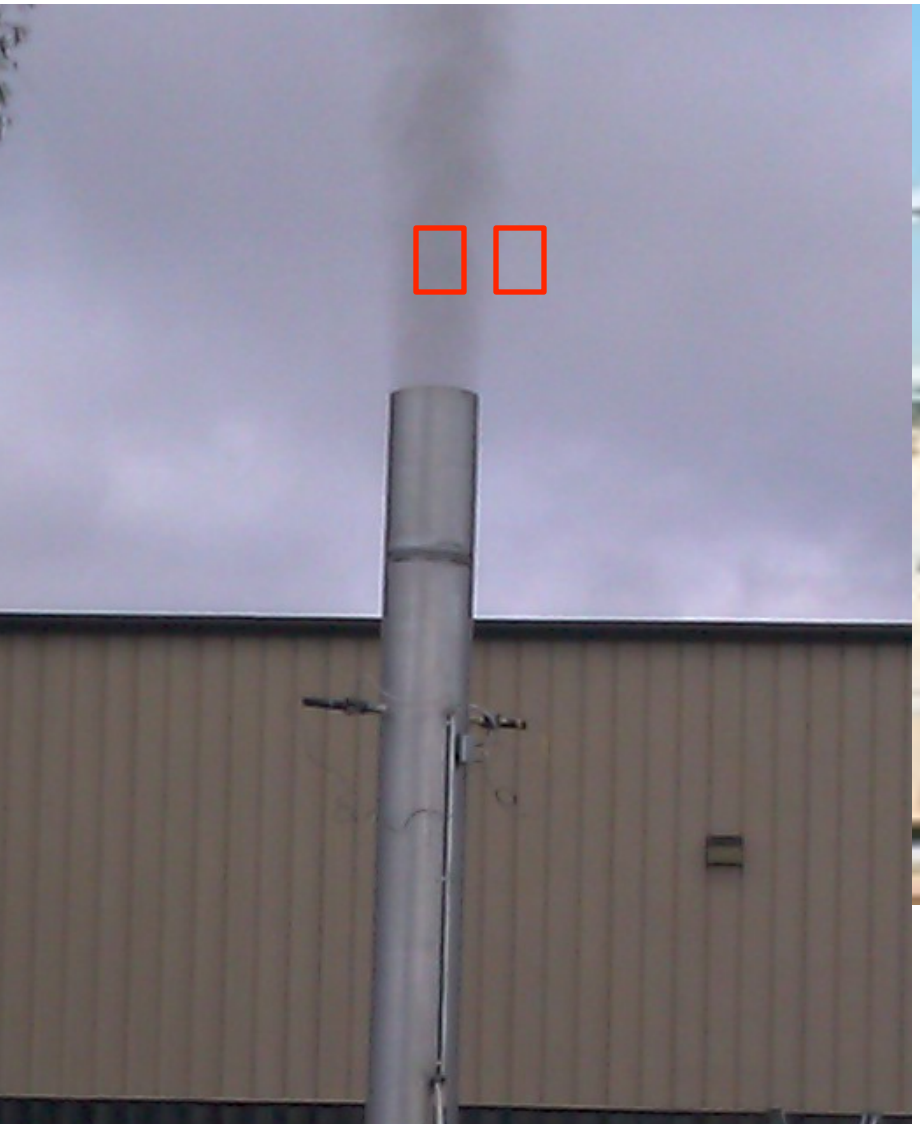


Application of Contrast Model



Application of Transmission Model

Cloudy Sky Background

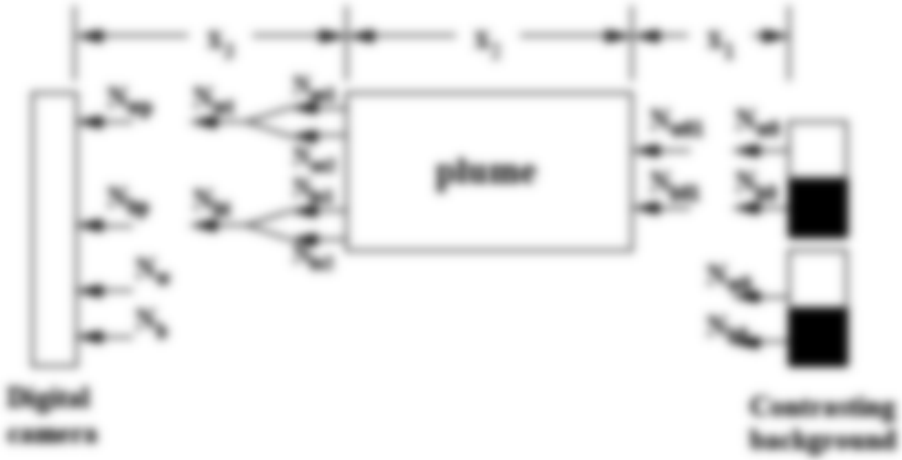


Clear Sky Background

Overview

- Background

- Methods



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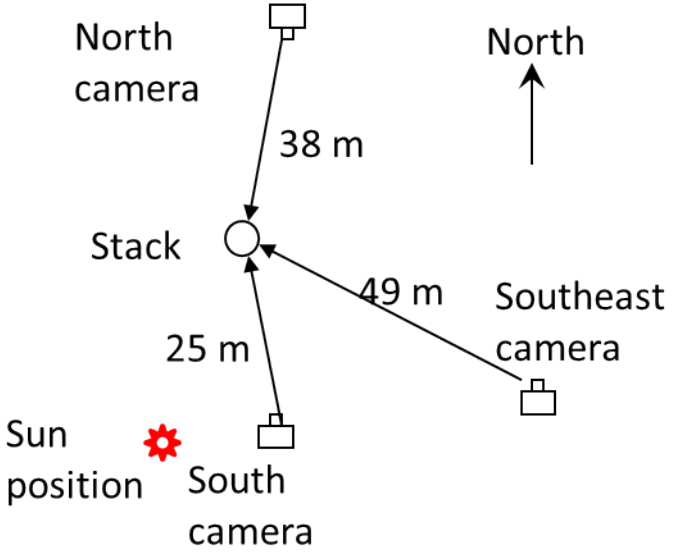


Timeline 3

2003

July: DOM successfully demonstrated during first field campaign at IEPA during ideal conditions

2004

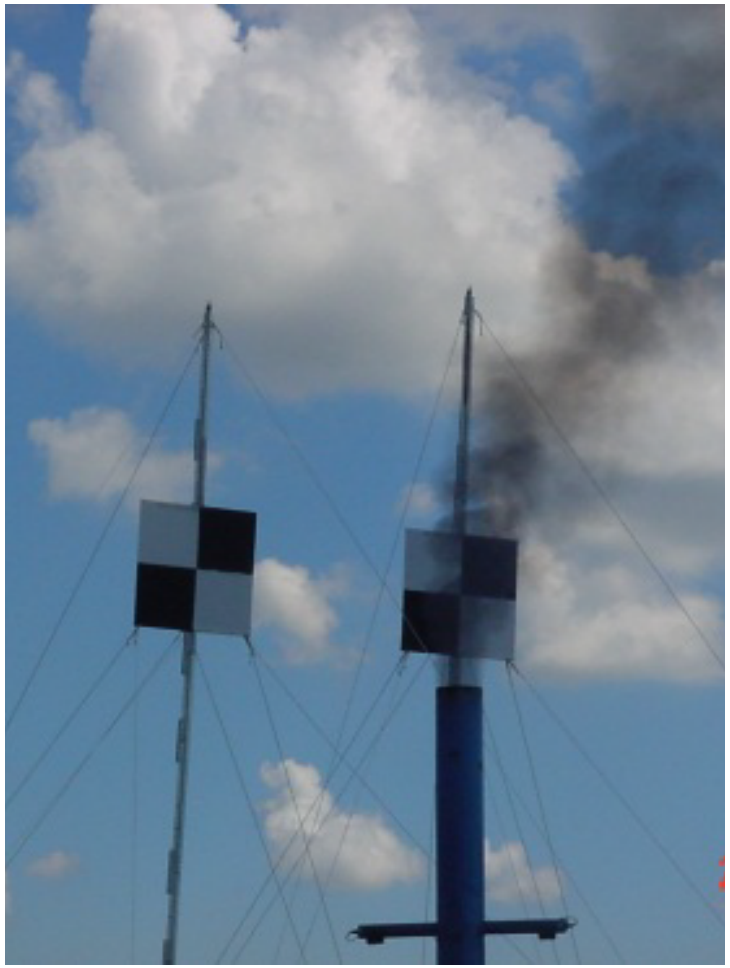
April: Second field campaign at IEPA Smoke School

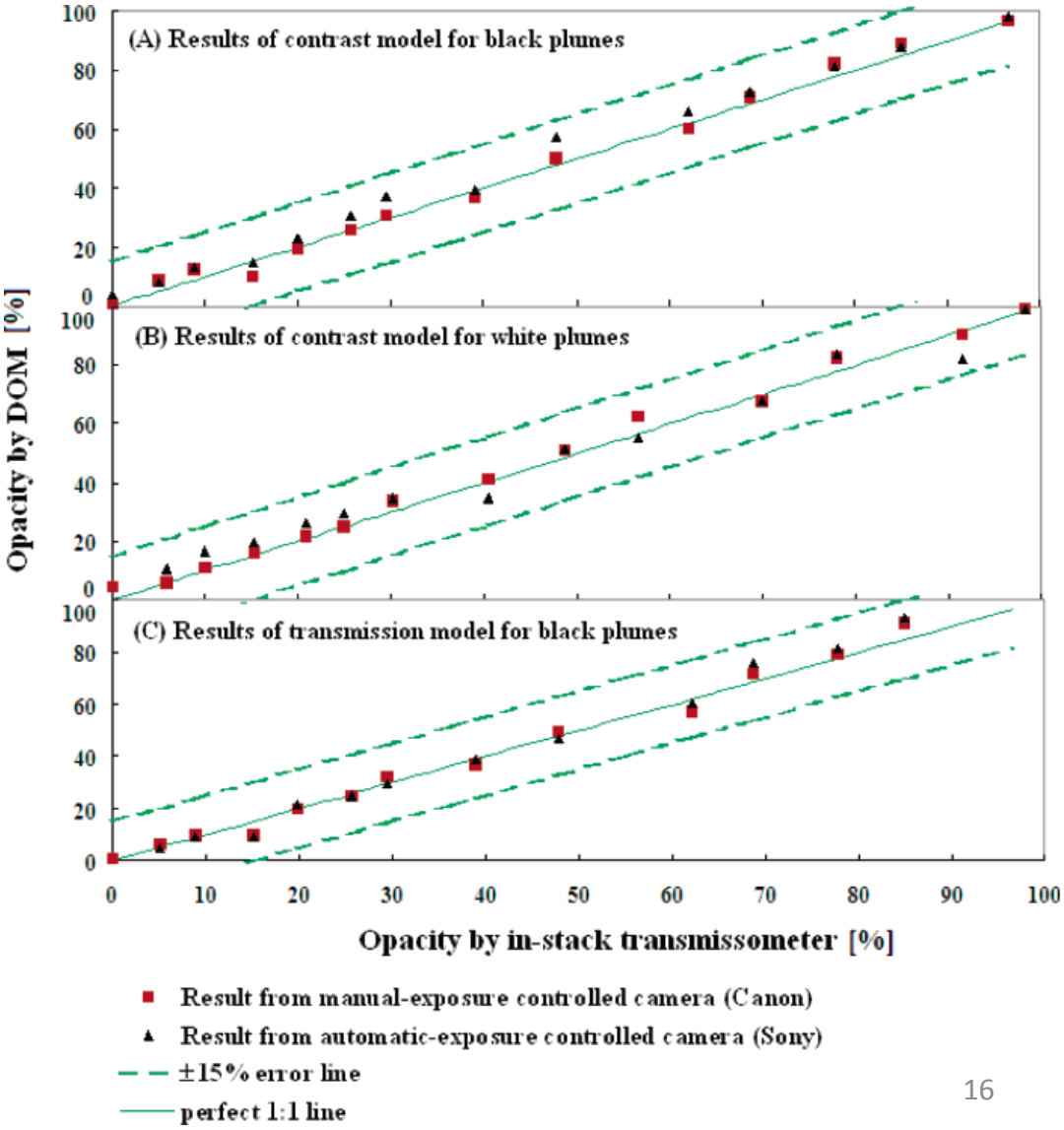
June: AWMA Annual Conference Proceeding and DoD-DOM lecture, Austin, TX

July: DOD Texas Air Workgroup Meeting, DOD-DOM lecture, Ft. Hood, TX

Oct: Third field campaign at IEPA Smoke School, compared to human observations, DOD-DOM lecture in Anchorage, AK

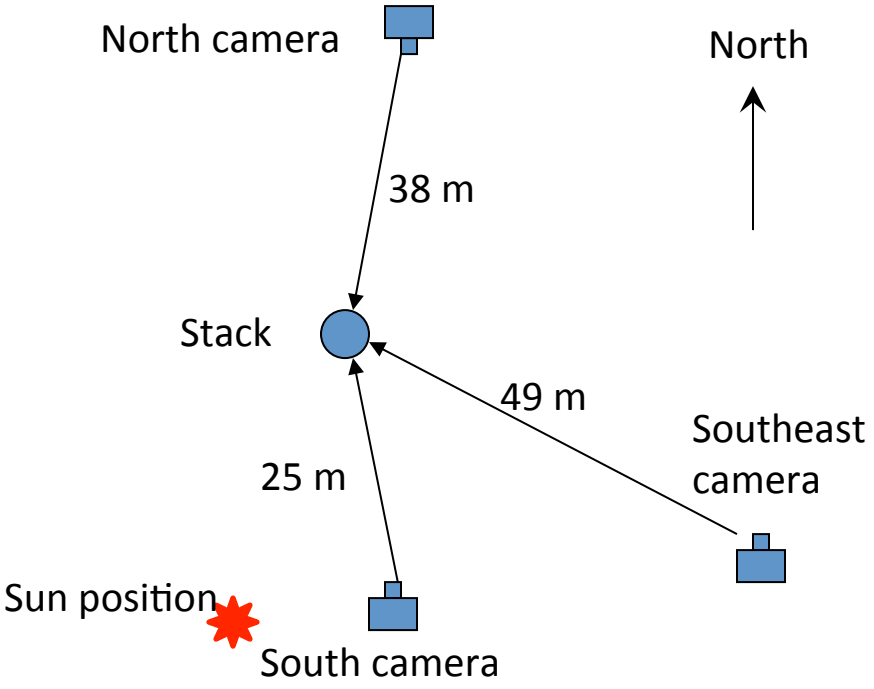
Daytime Field Evaluation (1)

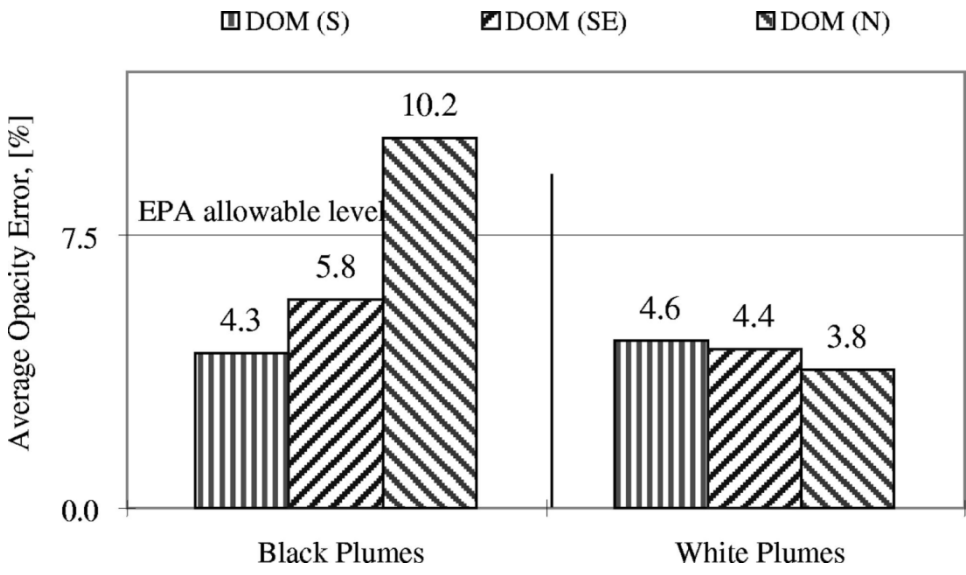




Daytime Field Evaluation (2)

- **Evaluation of DOM:**
  - Appropriate range of sun angles
  - Compare results from DOM and reference measurements by in-stack transmissometer





Timeline 4

2005

April: DOM successfully demonstrated during nighttime conditions

June: AWMA Annual Conference Proceeding

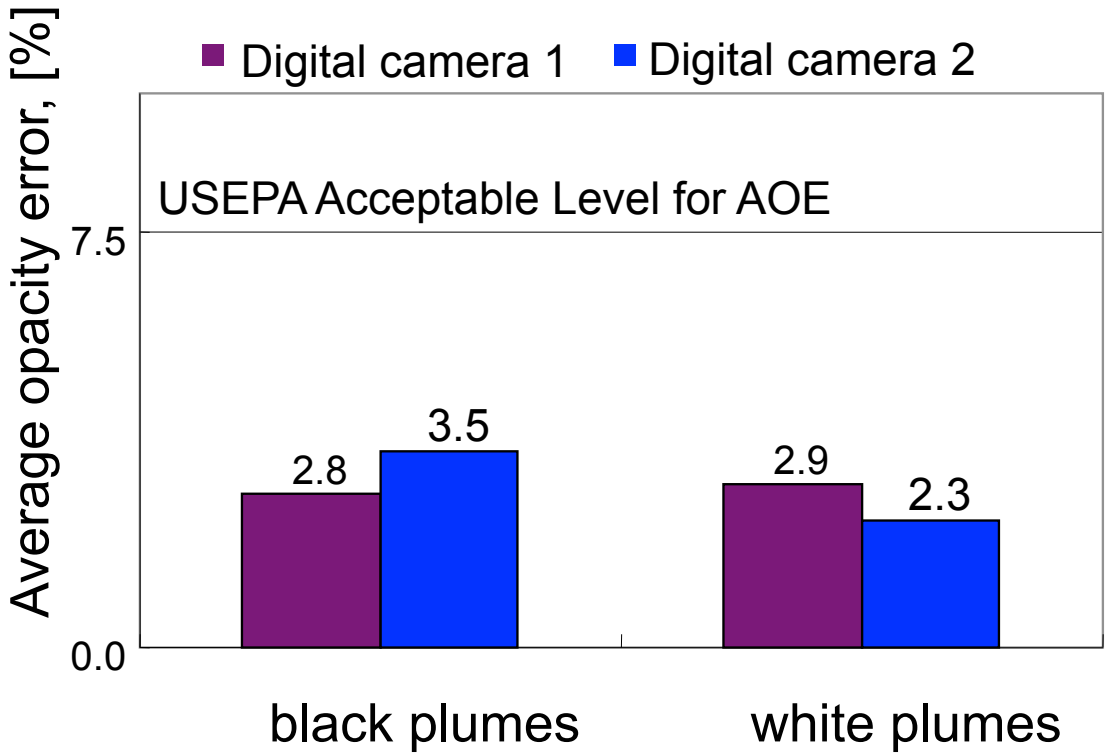
Nov: Smoke School presentation, Sacramento, CA

2006

May: Formal letter by USEPA OAQPS to regional air quality directors about USEPA's intention to include digital camera technology in future rules for visible emissions monitoring, potential savings of at least $200M/yr

June: AWMA Annual Conference Proceeding

Nighttime Field Evaluation



Timeline 5

2007

March: *ES&T* (Du et al., 2007) describes DOM's contrast and transmission models based on first principles

July: *JAWMA* (Du et al., 2007) publication describes DOM results during daytime conditions and comparison to human observations

Sept: Ph.D. dissertation by Ke Du, now Professor Du

Timeline 6

2009

Feb: DOM™ was patented

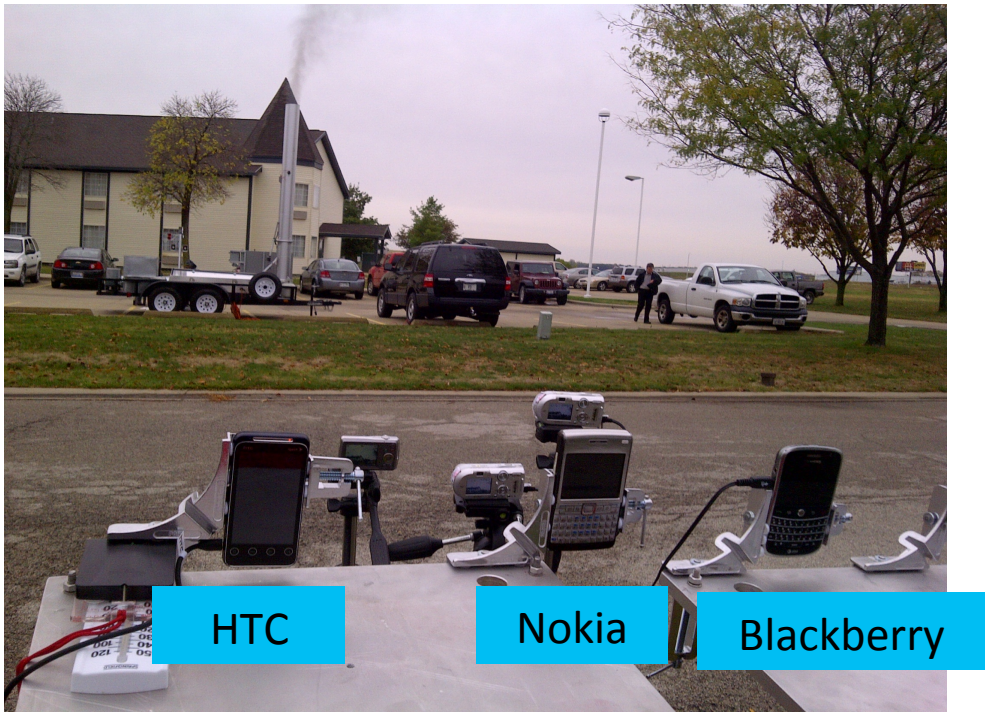
Nov: Approval of ASTM D7520-09 to determine plume opacity with digital still cameras

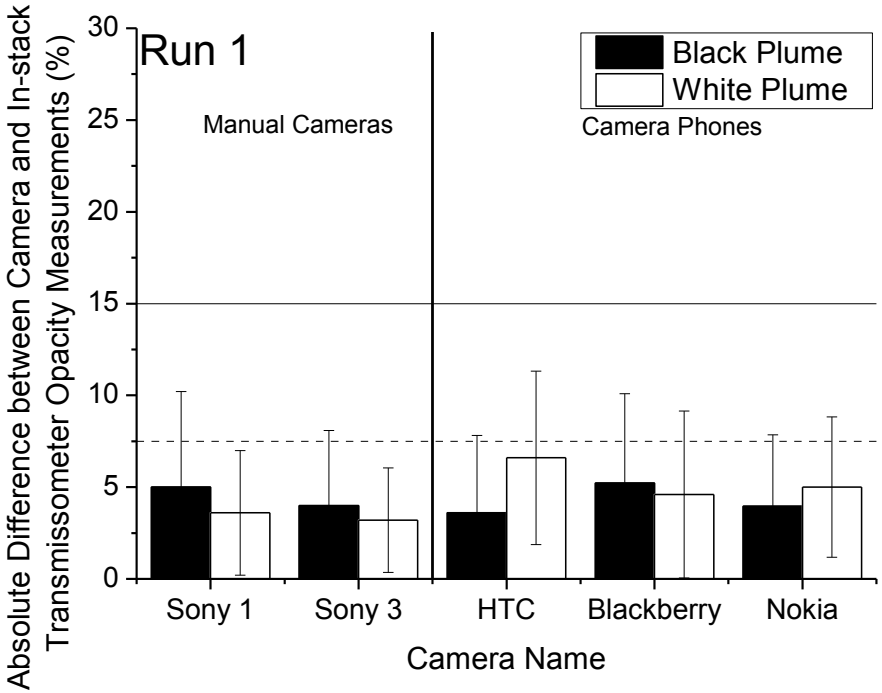
March: *ES&T* (Du et al., 2009) publication describing plume opacity during nighttime

2011

Oct: Successful field campaign using smartphone cameras determining plume opacity during smoke school

DOM Applied to Smartphones





Timeline 7

2012

Feb: Approval of using digital still cameras by USEPA as an Alternative Method (ALT-082) to Method 9 after nearly 40 yr of using Method 9

2013

Jan: Additional smartphones and digital video imaging tested with encouraging results during IEPA tests, evaluating artificial intelligence to determine opacity values

Summary and Conclusions

- Digital Optical Method (DOM) quantifies plume opacity during daytime and nighttime conditions
- Improves objectivity when compared to human observers/Method 9
- Provides archival digital/graphical records of visible emissions and their environments
- Exciting opportunity to monitor process and atmospheric emissions with low-cost readily deployable digital technology

Acknowledgements

U.S. Construction Engineering Research Laboratory-U.S. Army Engineer Research and Development Center

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Illinois Environmental Protection Agency (IEPA)

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