An Evaluation of a Digital Camera System for Measuring Smoke Plume Opacity

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Presentation Topics

- Why we should be interested in camera methods for measuring smoke plume opacity.

- The Digital Opacity Compliance System, version II (DOCS II).
  - How it works
  - DEQ results

- How to overcome some of the limitations of Complex Analyses in DOCS II.

- Summary and next steps.

Why should we be interested in camera methods…

- Digital camera methods can eventually be more accurate than Method 9.

- Pictures document visible emission violations well & provide excellent evidence.

- Visible emission evaluations are frequently performed – it is a common test and it should be a good one.

Why should we be interested in camera methods…

- Time and cost savings
  - Camera methods could potentially lower staff training time and costs by avoiding Method 9 certification training.
    - At the DEQ, instead of certifying 47 staff to perform Method 9.
    - DEQ could train inspectors to take pictures and have them forward the pictures to a regional office or contractor for analysis.

Why should we be interested in camera methods…

- Method 9 is often poorly performed by facilities and contractors

  Zero percent opacity?
  The Method 9 contractor thought so…

Why should we be interested in camera methods…

- Young tech-savvy staff can't believe we are still using an old visible method….

> Dude, this Method 9 is so retro '70s! You got an app for my phone?

Why should we be interested in camera methods…

- All air agencies should be interested in camera methods because of:
  - All the reasons previously discussed.
  - National time and cost savings:
    - State and local agencies spend about $885,000 per year on certifying their staff to perform Method 9. [1]
    - The regulated community (government & industry) also spends considerable time and money performing Method 9.
  - *A quick and easy, accurate method of determining stack opacity would save everyone time and money.*

[1] NACAA annual cost estimate does not include travel and lodging costs.

Digital Opacity Compliance System, Version II (DOCS II)

DOCS II

- DOCS II is a commercial product that uses:
  - a digital camera,
  - software, and
  - a trained user

  to measure smoke plume opacity.

DOCS II

- DOCS II is sold by Virtual Technology LLC. See: http://www.virtuallc.com/
- Contact Person: Shawn Dolan, President of Virtual Technology, LLC:
  - shawn.dolan@virtuallc.com
  - (888) 872-3836
- Cost: About $5,495
- Virtual Technology offered DEQ a free trial of the system in September 2011.

The Camera

- Canon PowerShot G11 (a Nikon camera is also available).

- To comply with EPA Alternative Method 82:
  - The camera was operated in:
    - Default auto focus mode
    - Default auto exposure mode
  - The camera generated EXIF 2.1 JPG (or higher) output files.
  - Optical zoom on.
  - Digital zoom off.

EXIF = Exchangeable Image File Format

Photographing the Plume

- Position yourself as you would for Method 9.
- Position yourself to maximize the contrast between the plume and its background.
- Turn off digital camera features such as: flash, optical filters, digital zoom, image stabilization.
- Do not photograph steam….
- Center pictures on the plume observation point.
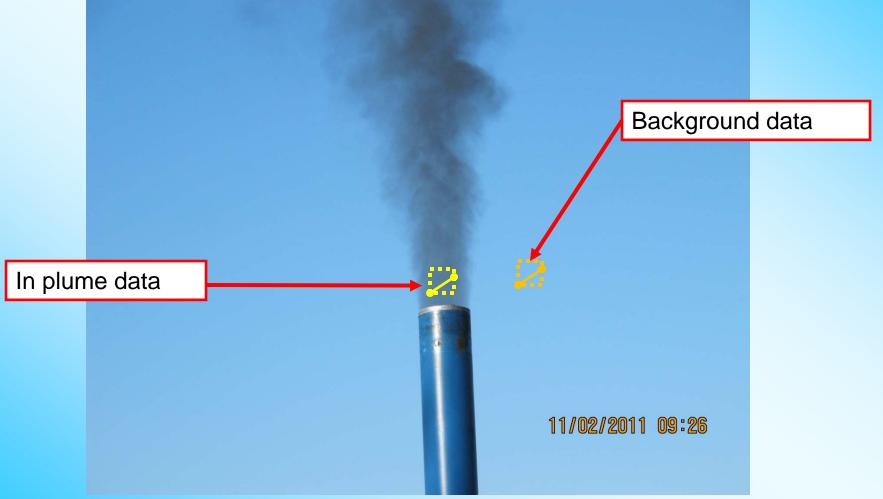- Take JPEG images every 15 seconds.

Analyzing the Photographs

- Download the photographs to a PC.

- Exclude photographs that should not be used.

- Analyze the photographs with software.

  – Compare "in the plume" areas to "background" areas adjacent to the plume.

  – The difference between "in the plume" values and "out of the plume" values is correlated to opacity.

- DOCS II offers two options: Simple or Complex Analysis Modes

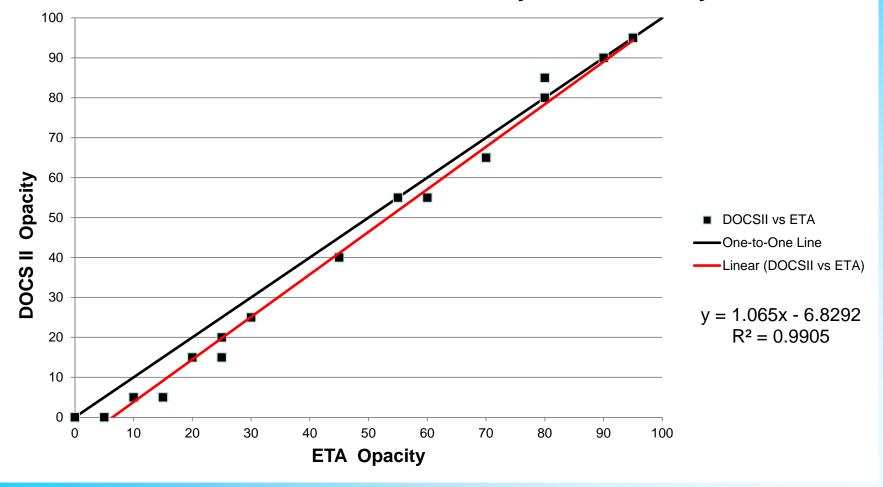# Simple vs. Complex Analysis

- Simple Analysis:
  - Use Simple Analysis for homogenous backgrounds (but not gray backgrounds).
  - Example: black or white smoke on blue sky.

- Complex Analysis:
  - Use Complex Analysis on heterogeneous backgrounds and gray backgrounds.
  - Examples: forest or gray sky backgrounds.

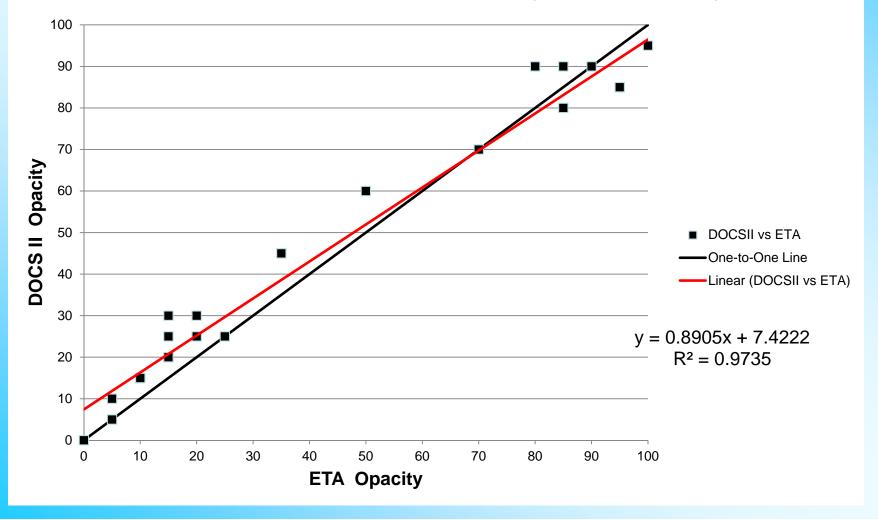# Analyzing a Series of Photographs in Simple Analysis Mode

Background data

In plume data

11/02/2011 09:26

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Some Simple Analysis Results

Baltimore ETA Smoke School, November 2, 2011,
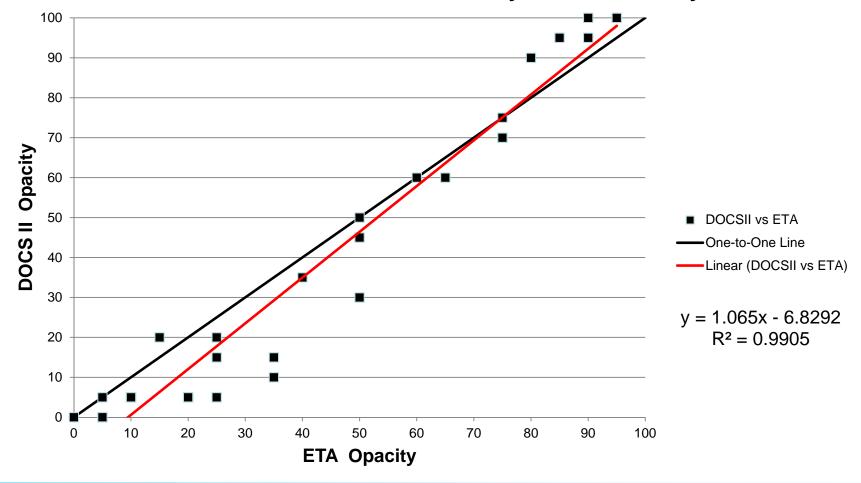**Run #1, Black Smoke on Blue Sky, P. Thaler Analyst**

■ DOCSII vs ETA
— One-to-One Line
— Linear (DOCSII vs ETA)

$y = 1.065x - 6.8292$
$R^2 = 0.9905$

Some Simple Analysis Results

Baltimore ETA Smoke School, November 2, 2011
Run #2, White Smoke on Blue Sky, P. Thaler Analyst

Legend:
- DOCSII vs ETA
- One-to-One Line
- Linear (DOCSII vs ETA)

$y = 0.8905x + 7.4222$
$R^2 = 0.9735$

X-axis: ETA Opacity
Y-axis: DOCS II Opacity

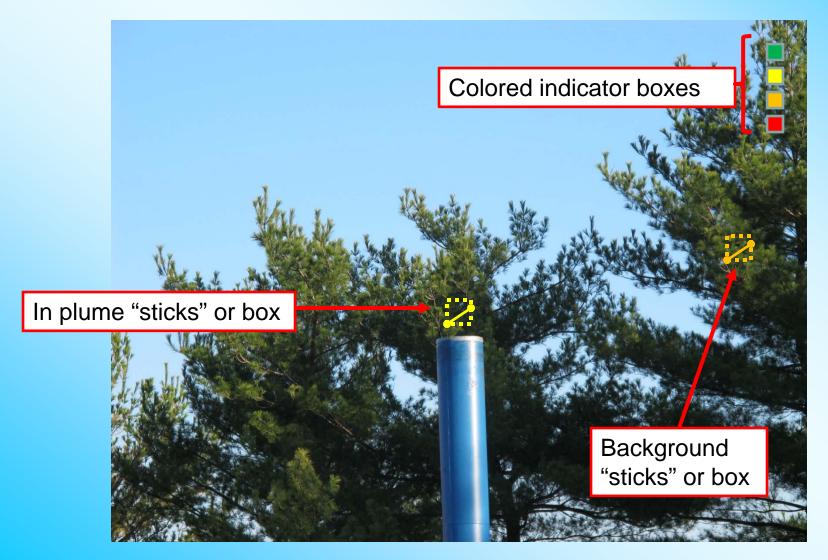# Some Simple Analysis Results

Pohick Bay ETA Smoke School, April 5, 2012,
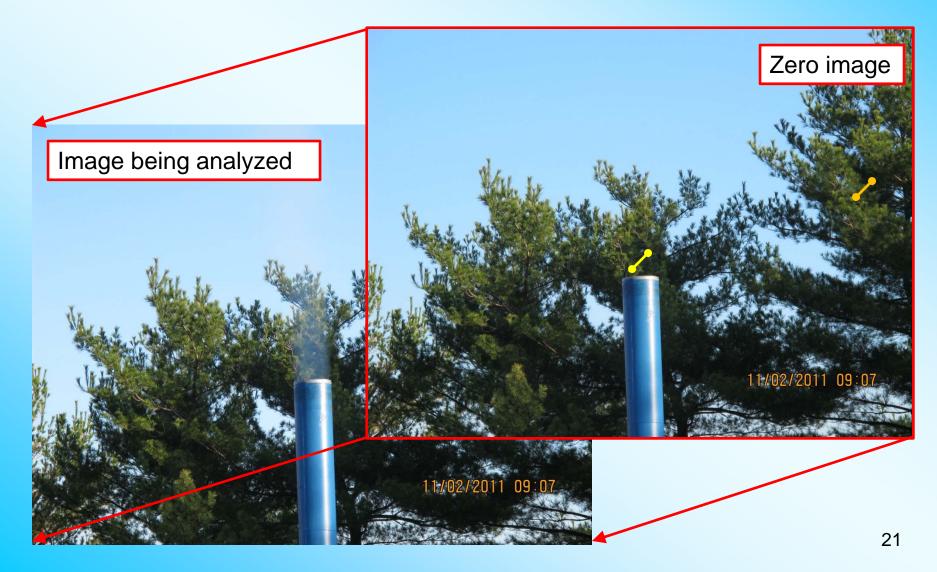Run #6, Black Smoke on Blue Sky, P. Thaler Analyst

Analyzing a Series of Photographs in Complex Mode

- Select a zero opacity image.

- Use the zero image as your background photo.

- Place your "in plume" and "out of plume" sticks (boxes) on the background image until you get a green or yellow light to proceed.

- Superimpose the zero opacity/background image on each photo in your series of photos.

- Click "Accept the Boxes" on each photo.

- The software estimates the opacity.

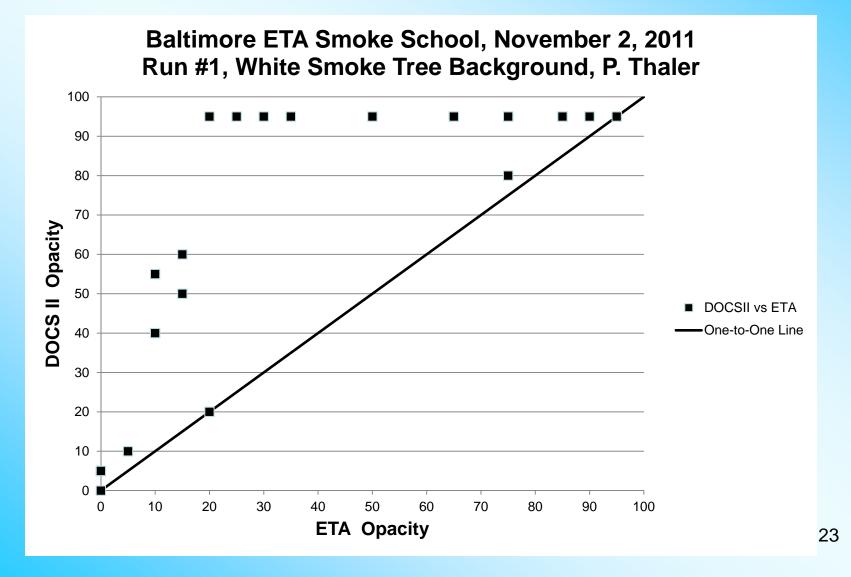# Analyzing a Background Image in Complex Analysis Mode

Colored indicator boxes

In plume "sticks" or box

Background "sticks" or box

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Superimposing a Background Image on a Photograph in Complex Mode

Zero image

Image being analyzed

11/02/2011 09:07

11/02/2011 09:07
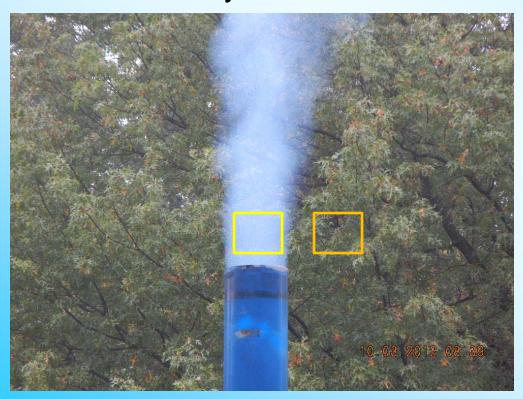
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Complex Mode Problems

- ## The No Zero Image Problem
  - In the real field work, zero images may not be available.

- ## The "Getting the Green Light" Problem
  - Getting a "green light" to accept your stick placement on a zero opacity image is difficult & time consuming.

- ## The Superimposing Images Problem

- ## The Erroneous Opacity Problem
  - Even when the software gave us a green or yellow light to proceed, the software often produced erroneous opacities in Complex Mode.
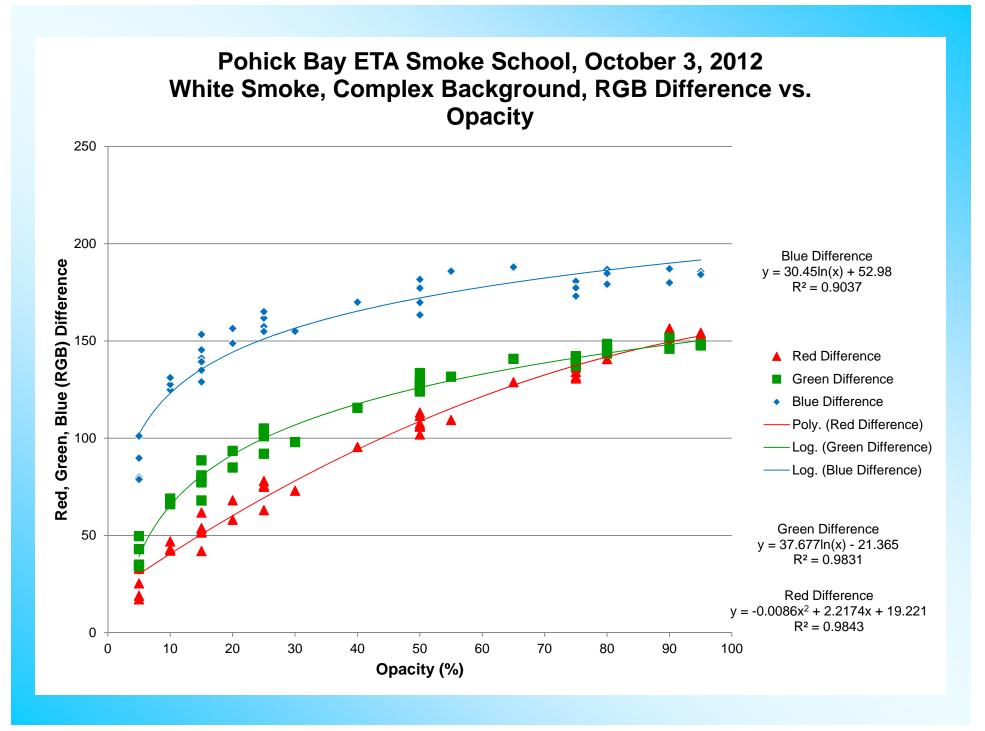
Some Complex Analysis Results

Baltimore ETA Smoke School, November 2, 2011
Run #1, White Smoke Tree Background, P. Thaler

Complex Mode Solutions

- **Determine if a zero image is really needed.**
  - Our preliminary work indicates a zero image may not be necessary.

- Calculate the average Red, Green, Blue (RGB) values in the plume and in the background using imaging software like ImageJ.

- Subtract the RGB values.

- Plot the difference.

Pohick Bay ETA Smoke School, October 3, 2012
White Smoke, Complex Background, RGB Difference vs. Opacity

Complex Mode Solutions

- Automate the "Getting the Green Light" Problem
  - If a zero image is necessary, have the software find the "sweet spots" (best locations) for placing your sticks/boxes on the zero image.

- Automate the superimposing of images
  - Have the software register/align the background image to the photo under analysis.

- If all the above are done, the Erroneous Opacity Problem will likely go away…

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Some Other Suggestions for Improved Performance

- Use better cameras that have:
  - Telephoto and greater optical zoom capability.
  - Explore whether manual focus and manual exposure control improve the accuracy of opacity measurements.

- Take more pictures than one every 15 seconds.
  - Averaging four or more pictures every 15 seconds might improve accuracy.
  - Would videos of smoke emissions improve performance?

The California Experience with DOCS II

- Al Arnone runs smoke schools for the California Air Resources Board (CARB).

- Al reports:
  - He has used DOCS II at about 14 smoke schools and likes the product.
  - He is certified to perform EPA Alt. 082, but he is not analyzing the photos he takes.
  - He sends his photos to Virtual Technology for analysis.

- This "send your photos out for analysis" is VT's new Software as a Service (SaaS) sales model.

The Software as a Service Concept

Field inspector takes photos and sends them to a central location via cell phone.

Central location or contractor analyzes the photos and determines opacities observed.

Evaluation Summary

- DOCS II in Simple Analysis Mode was:
  - Easy to use.
  - Produced reasonably accurate results similar to a Method 9 reader.
  - More field trials should be conducted.
- DOCS II in Complex Analysis Mode was:
  - Difficult and labor intensive to use.
  - Often produced inaccurate opacities.
- The Software as a Service (SaaS) model might be OK if VT can clearly demonstrate the software works in Complex Analysis Mode.

Next Steps

- Funding is needed to further develop DOCS II and other systems.

- Funding could come from EPA or State & Local, Supplemental Environmental Projects (SEPs)

- NACAA members could offer funding for further development.

- More state and local agencies need to be involved in the development and evaluation of digital camera methods.

NACAA is the National Association of Clean Air Agencies

The thought I want to leave you with is:

Digital camera methods hold enormous promise as good, objective methods for evaluating smoke opacity….

Disclaimer

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