Detection and Identification of Toxic Air Pollutants using Airborne LWIR Hyperspectral Imaging

David J. Williams, Barry Feldman
US EPA

EPA Regional Science Seminar
March 2nd, 2005

Why Hyperspectral Imaging?

- A Different way to look at emissions

  Test to identify and characterize gaseous chemical compounds.

- Difficult for industry and EPA to characterize some emissions

- There are over 21,000 permitted emission points in Harris County. Where is the problem?

- Funded through a RARE grant

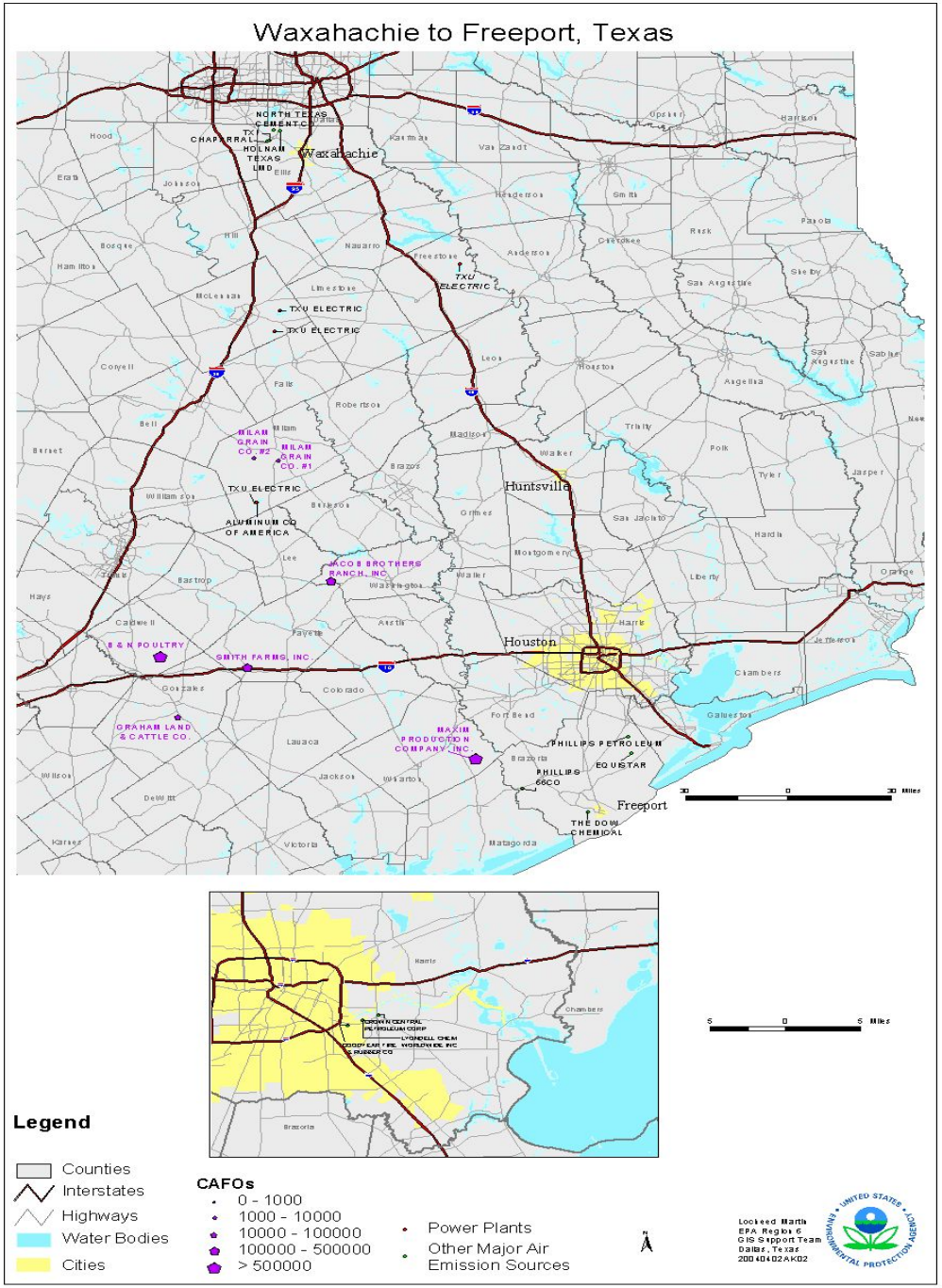
Participants

- EPA Region 6- 6PD, 6EN, Houston Lab
- EPA RTP
- TCEQ
- Harris County Pollution Control
- DOW Chemical Co.

Instrumentation

- o Airborne Hyperspectral Imager for Remote Sensing in the longwave 8-12 micron (thermal) Infrared.
- o Leak Surveys Inc. Portable midwave infrared 3-5 micron.
- o Passive monitors NO, NO2, NOx, O3.
- o Portable gas chromatograph and mass spectrometer.
- o Hand held OVA
- o Measured release of SF-6 @ 60 and 120 grams/hour
- o On site met station

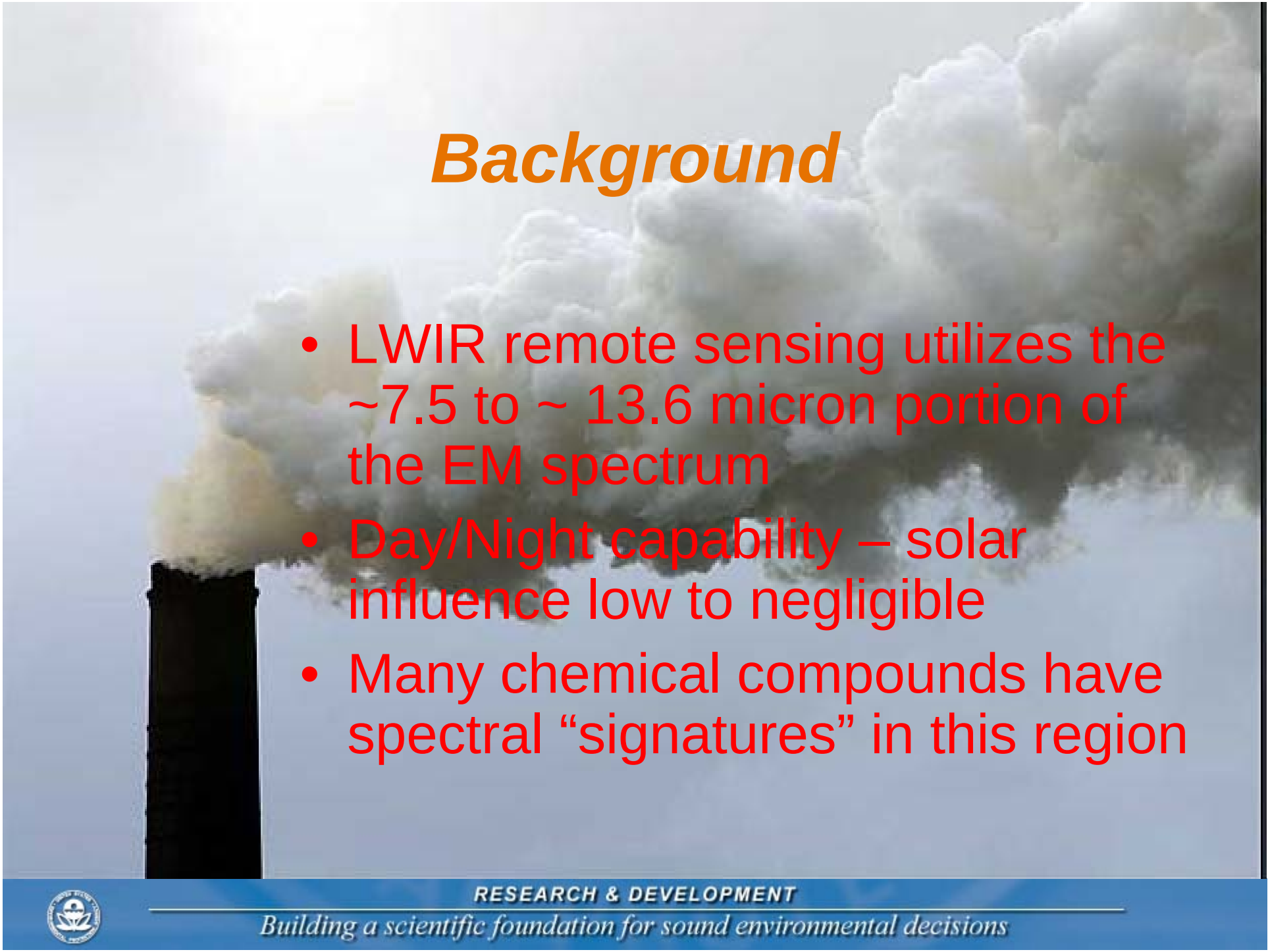
Flight Path


Waxahachie to Freeport, Texas
Waxahachie
Huntsville
Houston
Freeport
TXU ELECTRIC
ALUMINUM CO OF AMERICA
JACOBS BROTHERS RANCH, INC.
B & N POULTRY
SMITH FARMS, INC
GRAHAM LAND & CATTLE CO
MAXIM PRODUCTION COMPANY, INC
PHILLIPS PETROLEUM
EQUISTAR
Legend
Counties
Interstates
Highways
Water Bodies
Cities
CAFOs
0 - 1000
1000 - 10000
10000 - 100000
100000 - 500000
> 500000
Power Plants
Other Major Air Emission Sources
Lockheed Martin
EPA Region 6
GIS Support Team
Dallas, Texas
2004042AK02

Hyperspectral Sensor

Outline

- Background
- Project
  - Sensor
  - Data analysis
  - Results
- Applicability to EPA mission
- Future work



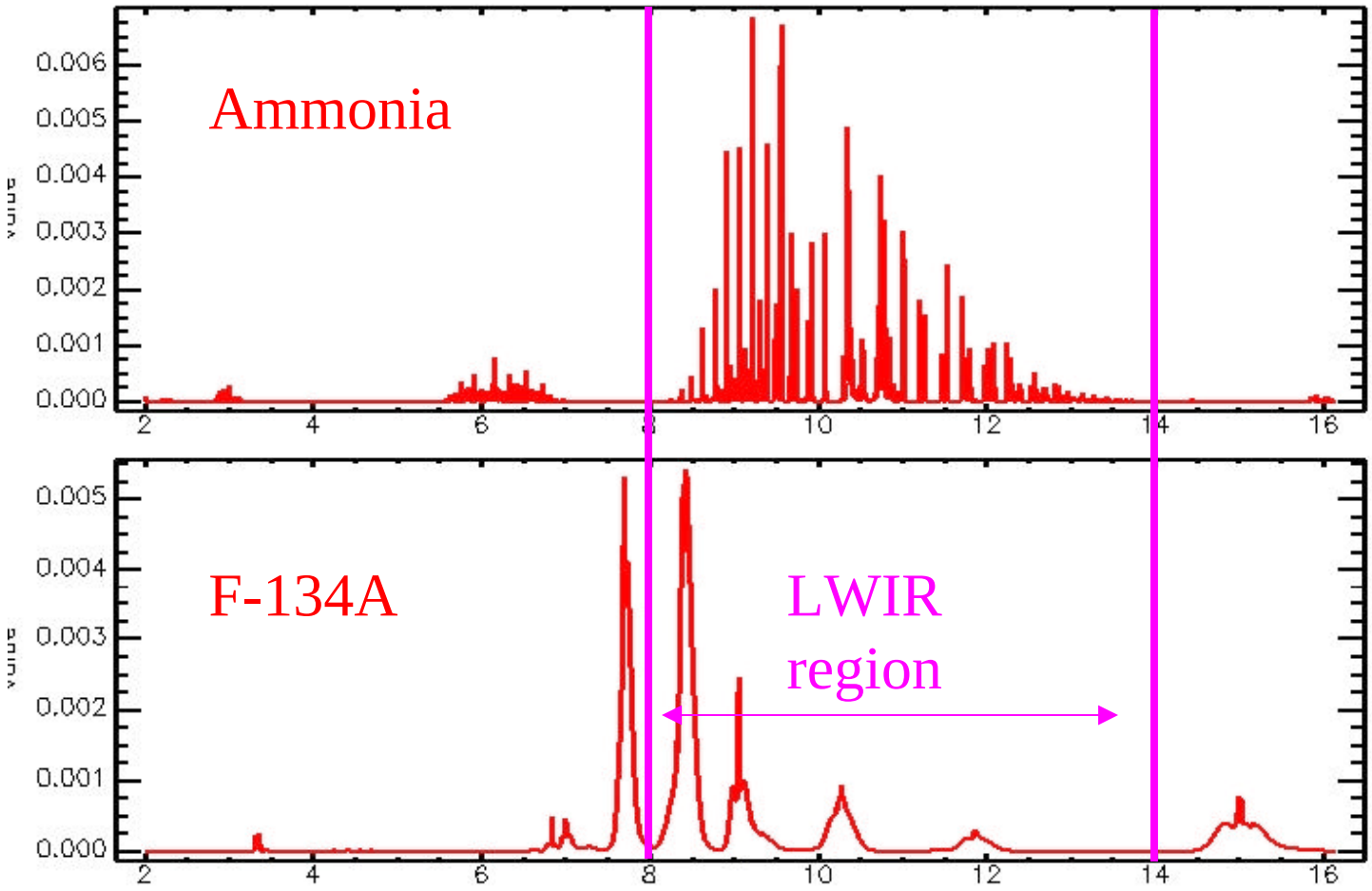
Background

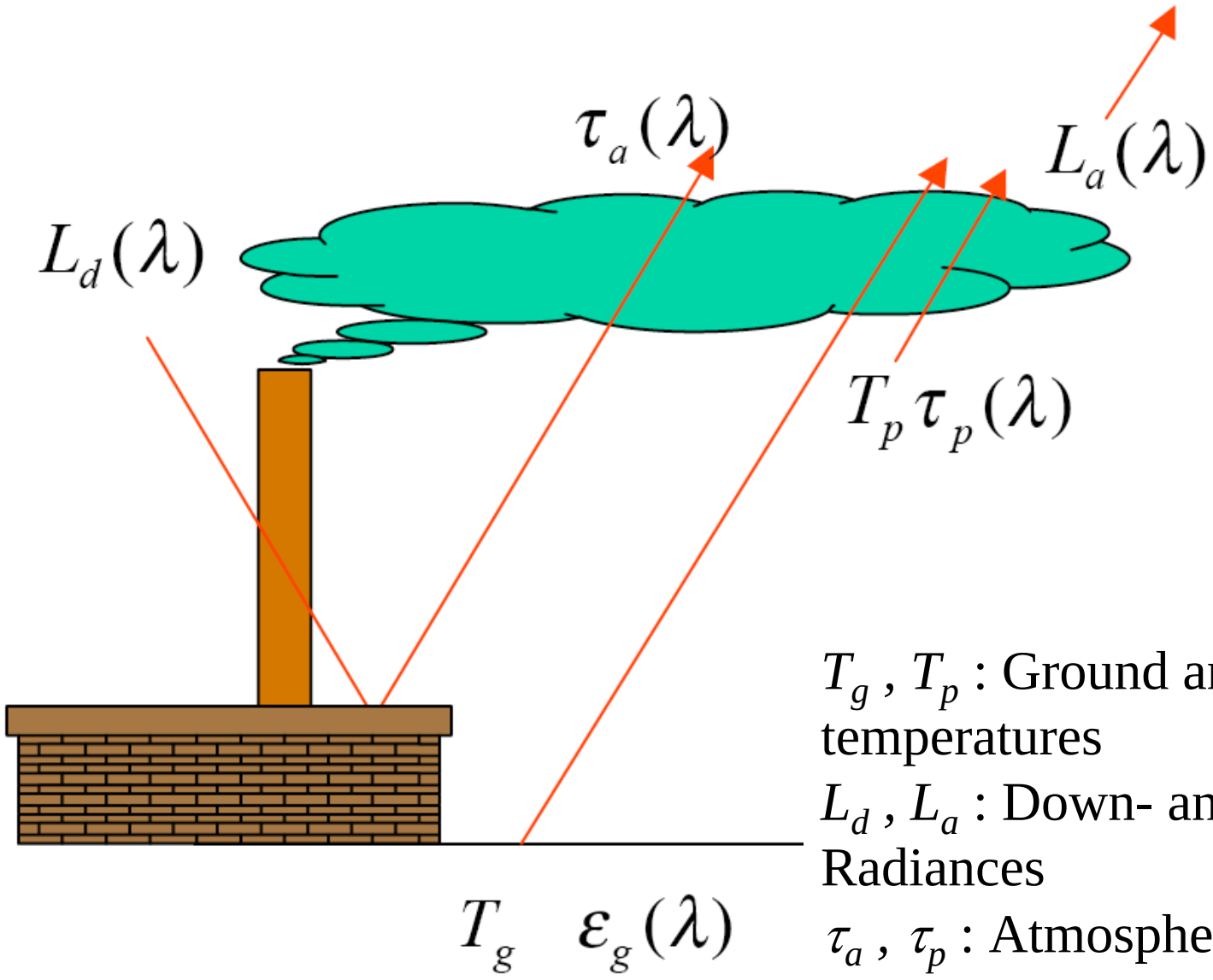
- LWIR remote sensing utilizes the ~7.5 to ~ 13.6 micron portion of the EM spectrum
- Day/Night capability – solar influence low to negligible
- Many chemical compounds have spectral “signatures” in this region

Basic Principles

- Solar energy heats materials on the earth's surface
- This energy is then emitted back into the atmosphere at longer wavelengths
- When this emitted energy passes through a plume, some of the energy gets absorbed at specific wavelengths
- Absorption signature = chemical ID

Spectral Signatures





T_g , T_p : Ground and Plume temperatures

L_d , L_a : Down- and Up-welling Radiances

τ_a , τ_p : Atmosphere and Plume transmissivities

ε_g : Ground emissivity

Project

- Project investigates use of advanced remote sensing technologies to:
  - Identify fugitive emissions from industrial facilities
  - Characterize and monitor known source emissions
  - Assimilate airborne, ground-based and laboratory data to model air quality

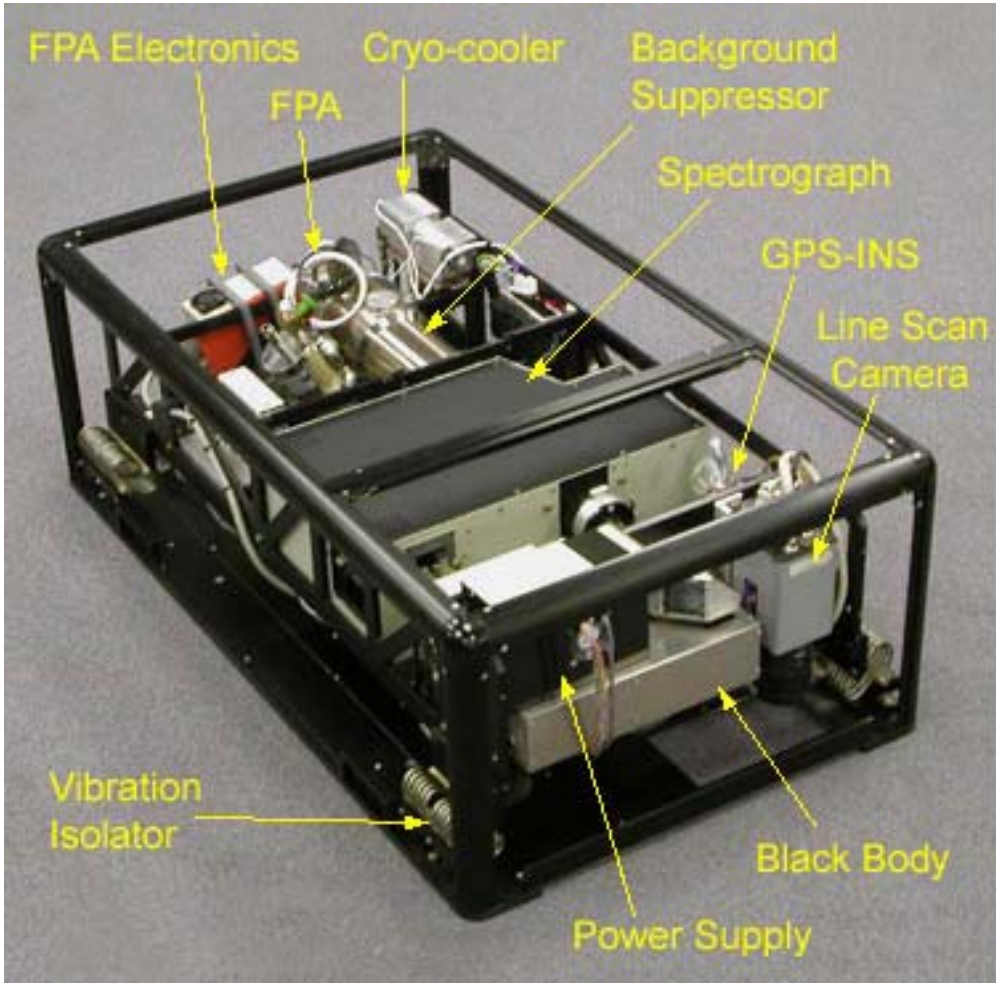
Objectives and Outcomes

- Objectives:
  - Investigate sensor systems for acquiring useful data on air pollutants
  - develop data analysis techniques that can be transferred to Regional clients
- Outputs: provide EPA Regions with methods to improve emission inventories, enhance permit compliance monitoring and to target inspections of facilities
- Outcome – reduction in the uncertainty in national and community based air toxic assessments

Data Collection

- Remote sensing data was collected using the Airborne Hyperspectral Imager (AHI), designed and built by the Hawai'i Institute of Geophysics and Planetology (HGIP) at the University of Hawai'i.
- The AHI system consists of:
  - a 256 band hyperspectral sensor
    - spectral range of 8-12 microns
    - spectral resolution of 32 wavenumbers
  - a boresighted 3 color visible CCD linescan camera
  - an onboard GPS/INS system

AHI System



- Unit size
  - Length
    - 47 inches
    - 1.2 m
  - width
    - 27 inches
    - 0.69 m
  - Height
    - 17 inches
    - 0.43 m

Study sites

- Study sites were in southeast Texas, USA
- AHI collected data over petrochemical facilities, refineries, electrical power generating stations, and Confined Animal Feeding Operations (CAFO)
- CAFOs produce large amounts of ammonia, which is an particulate matter (PM2.5) precursor

Data collection parameters

- Flight operations took place on April 19-20, 2004, between the hours of 1700-2100 UTC
- Data was collected at altitudes of 600 m to 1,500 m above sea level
- Weather was generally good, with moderate winds and scattered clouds

Aircraft platform : DC-3

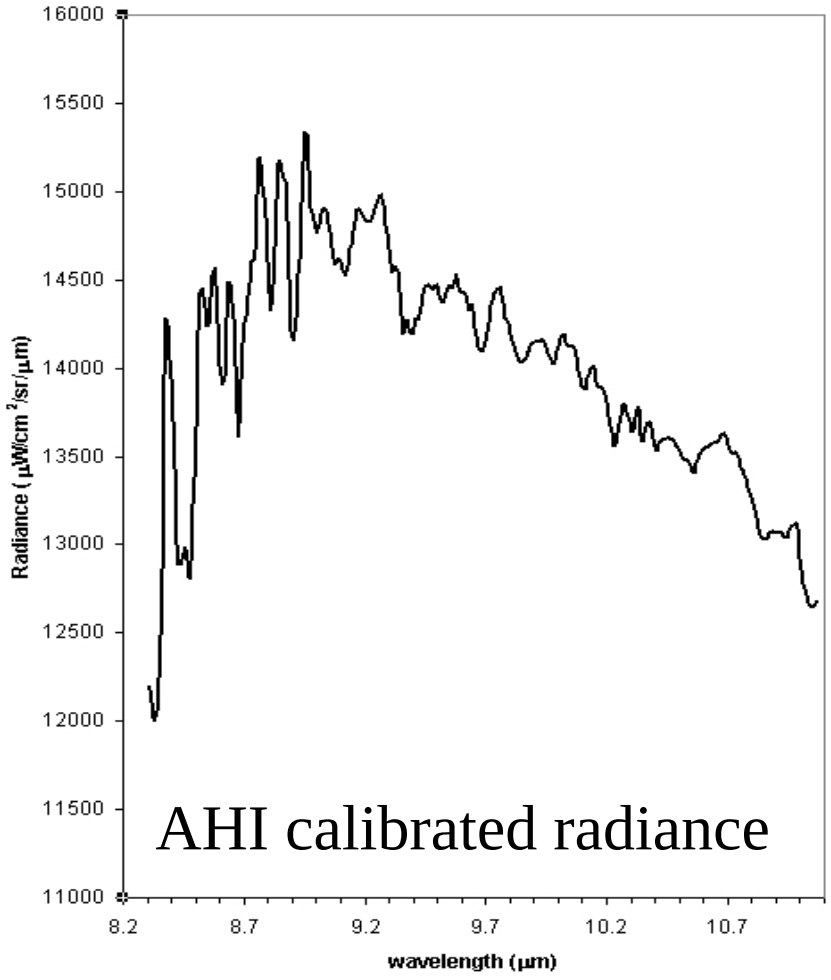
Data Analysis

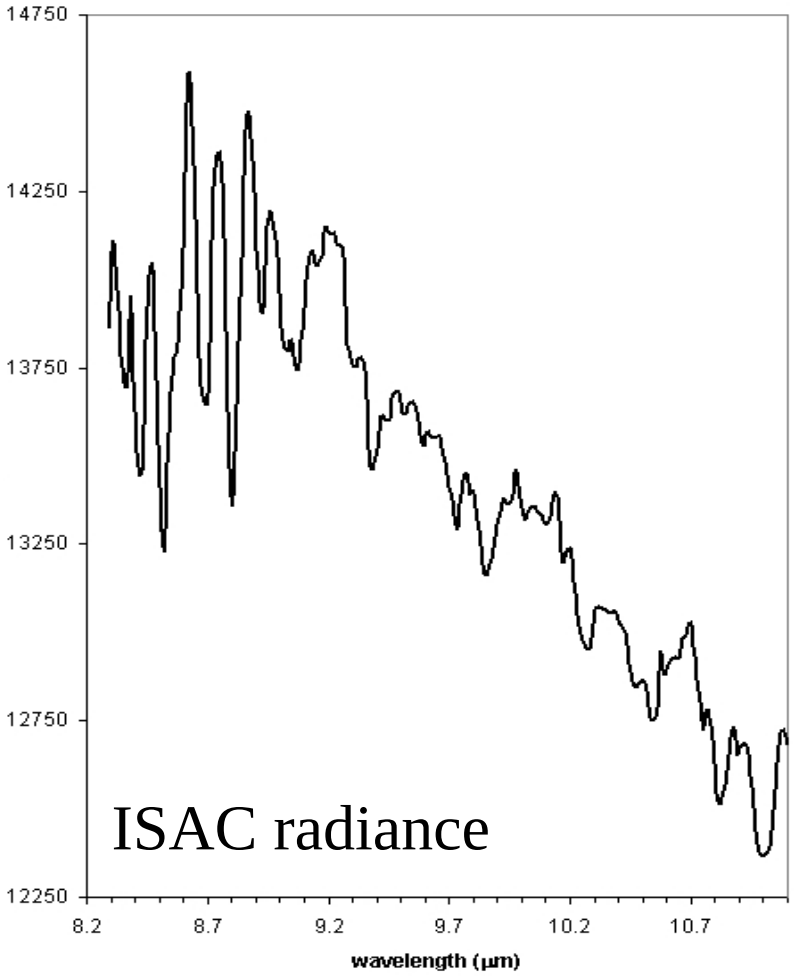
- Calibration
  - Accomplished by U. Hawai'i Spectral Technology Group
- Atmospheric compensation
  - Used ISAC (In-Scene Atmospheric Compensation)
- Plume detection
  - Spectral Match Filter
- Compound identification
  - Signature match against the PNNL spectral library
- Validation
  - EPA Emission Inventory plus group inspection

Calibration

- The AHI IR system is radiometrically calibrated prior to and after each flightline overpass by rotating three flat panel blackbodies in front of the sensor.
  - first panel is set to the scene air temperature
  - second is set to the hot objects in the scene.
  - third panel is set to a temperature intermediate between the two and is used to calculate signal to noise ratio.
- Data for third blackbody is collected and reduced to radiance
  - signal to noise is calculated over all the calibrated pixels for each wavelength so that spatial nonuniformity noise is included in the calculations.
- Wavelength calibration is accomplished by viewing the second blackbody (highest temperature) through polystyrene plastic film and liquid indene cell filters.

Atmospheric Compensation



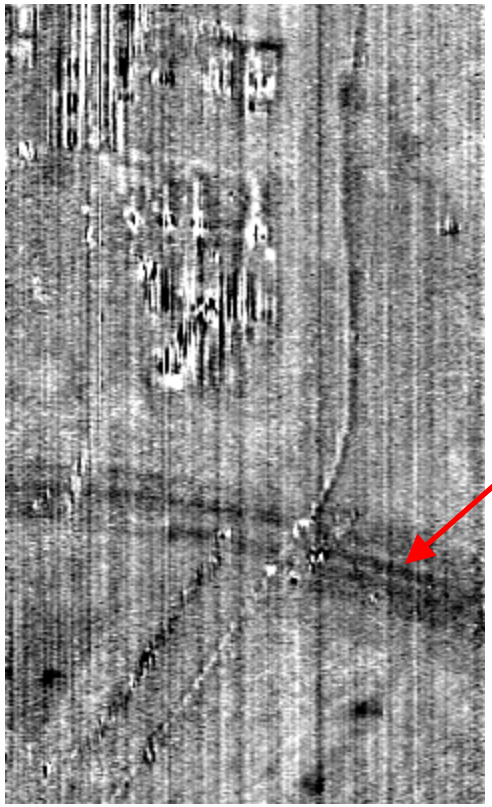


Detection

- Spectral matched filters were built for compounds that would be expected at the facility
- Atmospheric effects (US standard 1976) were added to library spectra to better compare with AHI radiance
- Match filter and F-statistics were used to determine plumes for subsequent identification

Detection – petrochemical facility

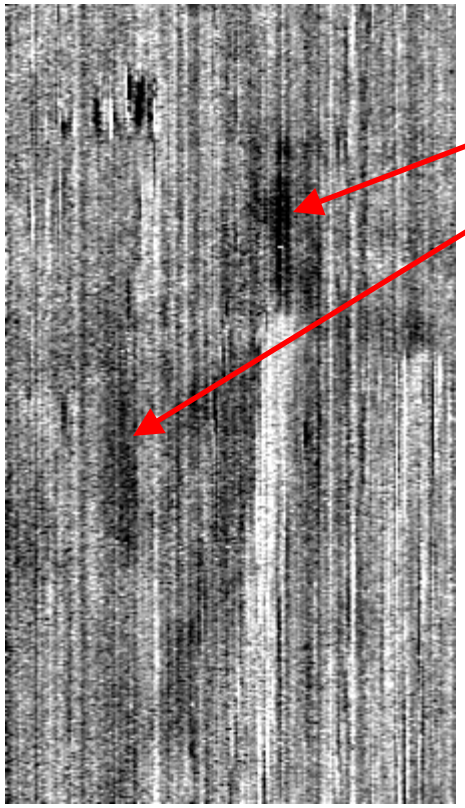
AHI image



MF result for benzene

Detection - CAFO

AHI image

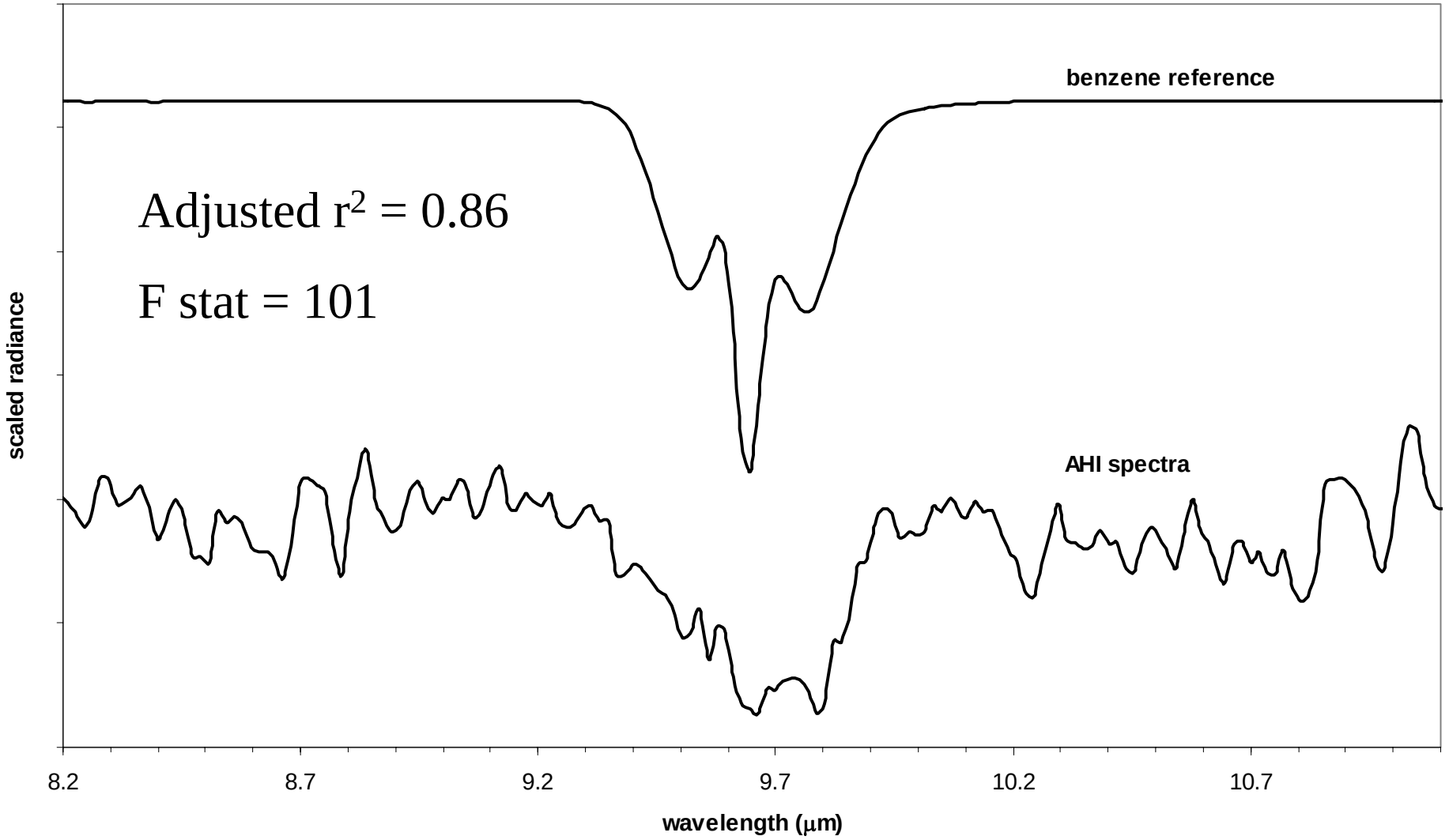


MF for ammonia

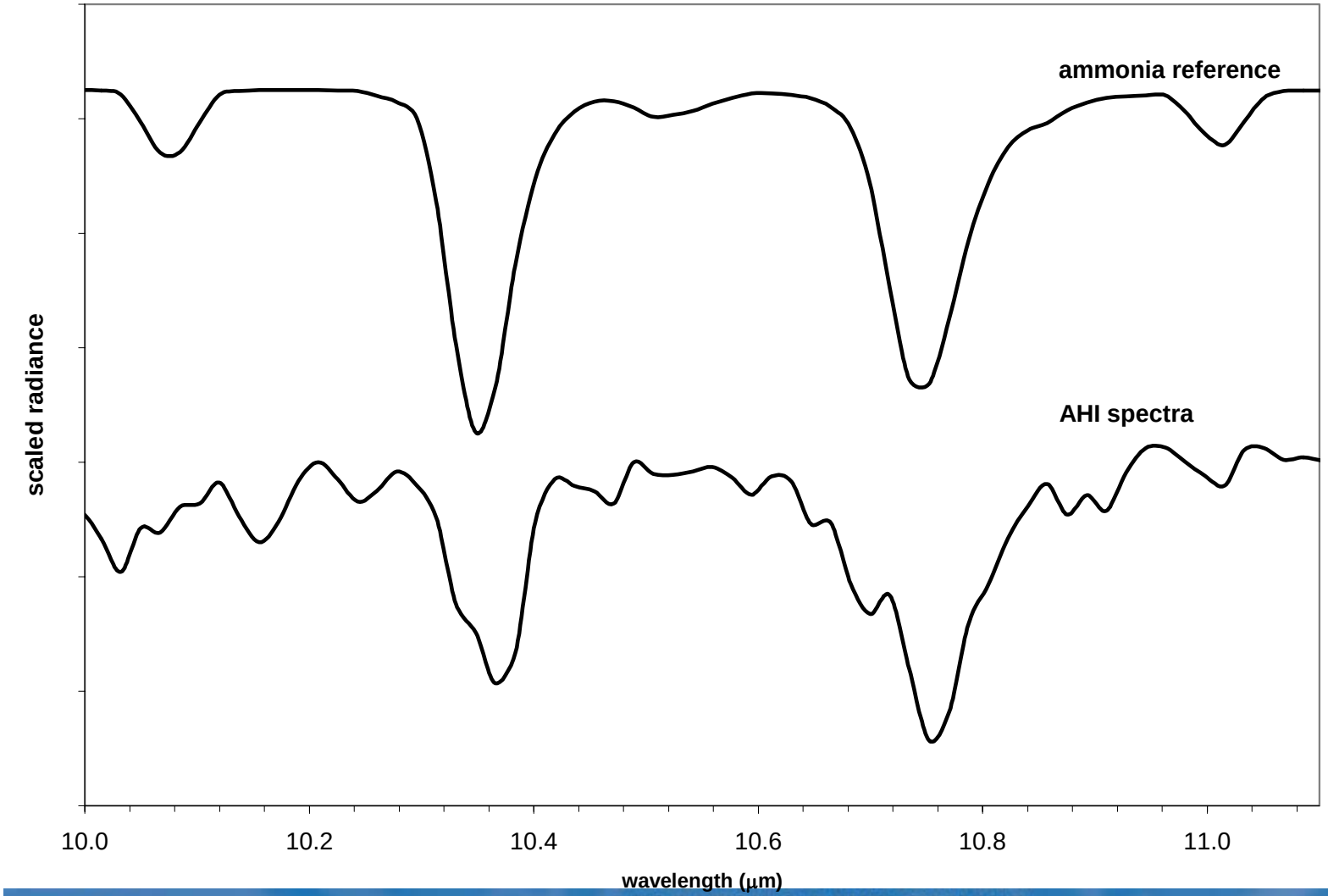
Identification

- Pixels detected by matched filter were statistically compared to the library reference spectra
- For significance, candidate plume spectra were also compared to the background
- Pixels with the best fitting spectra were mapped

Identification - benzene



Identification - ammonia

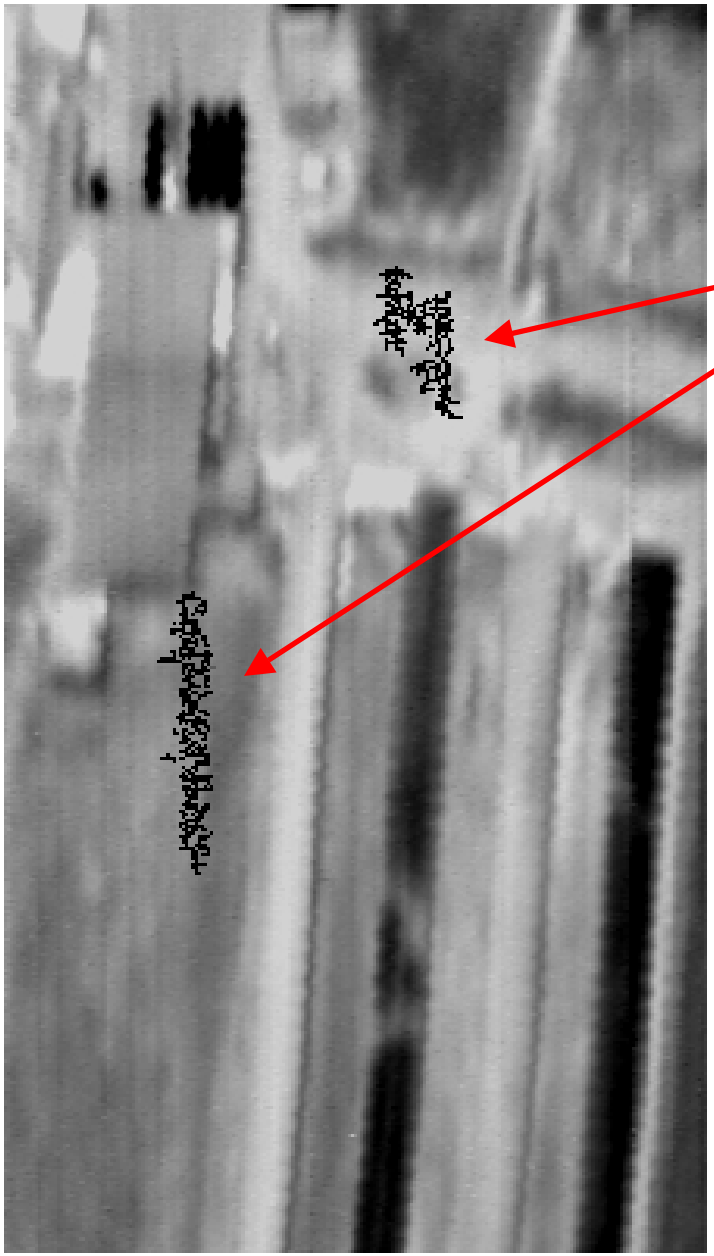


$R^2 = 0.78$

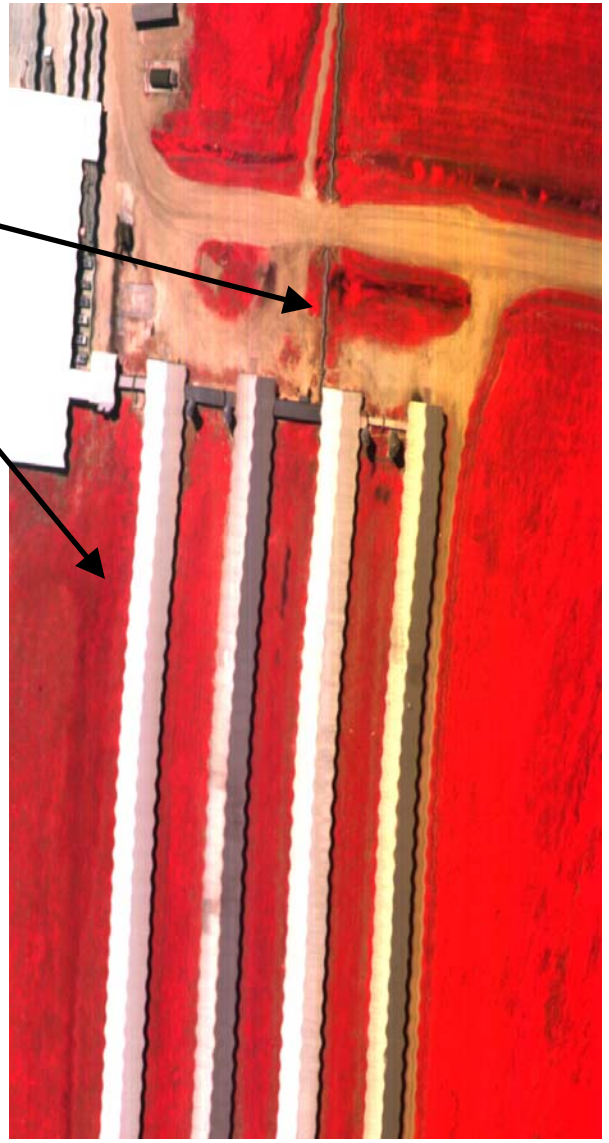
F stat = 155

Mapping plumes

benzene

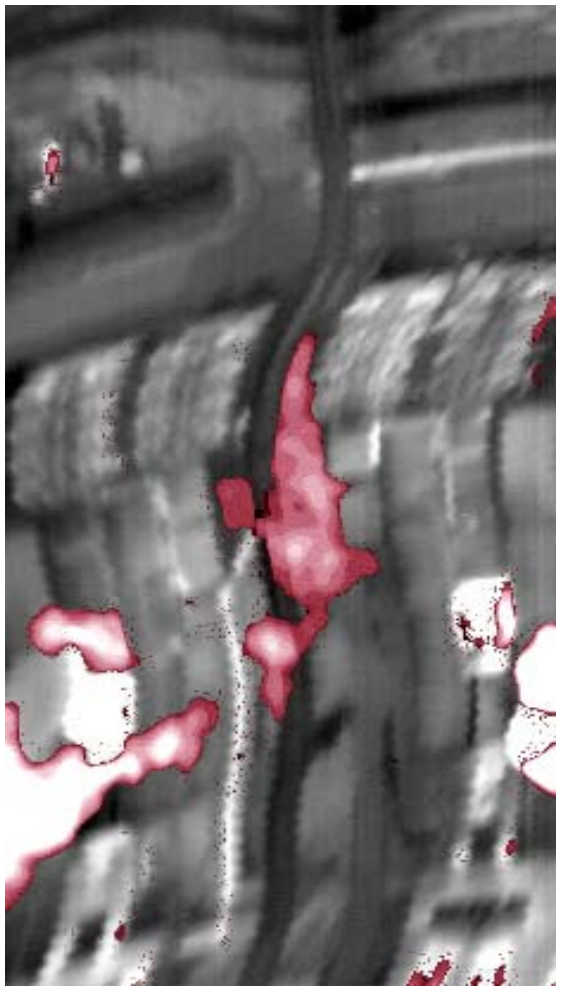


NH_3



Sulfur Dioxide Detection

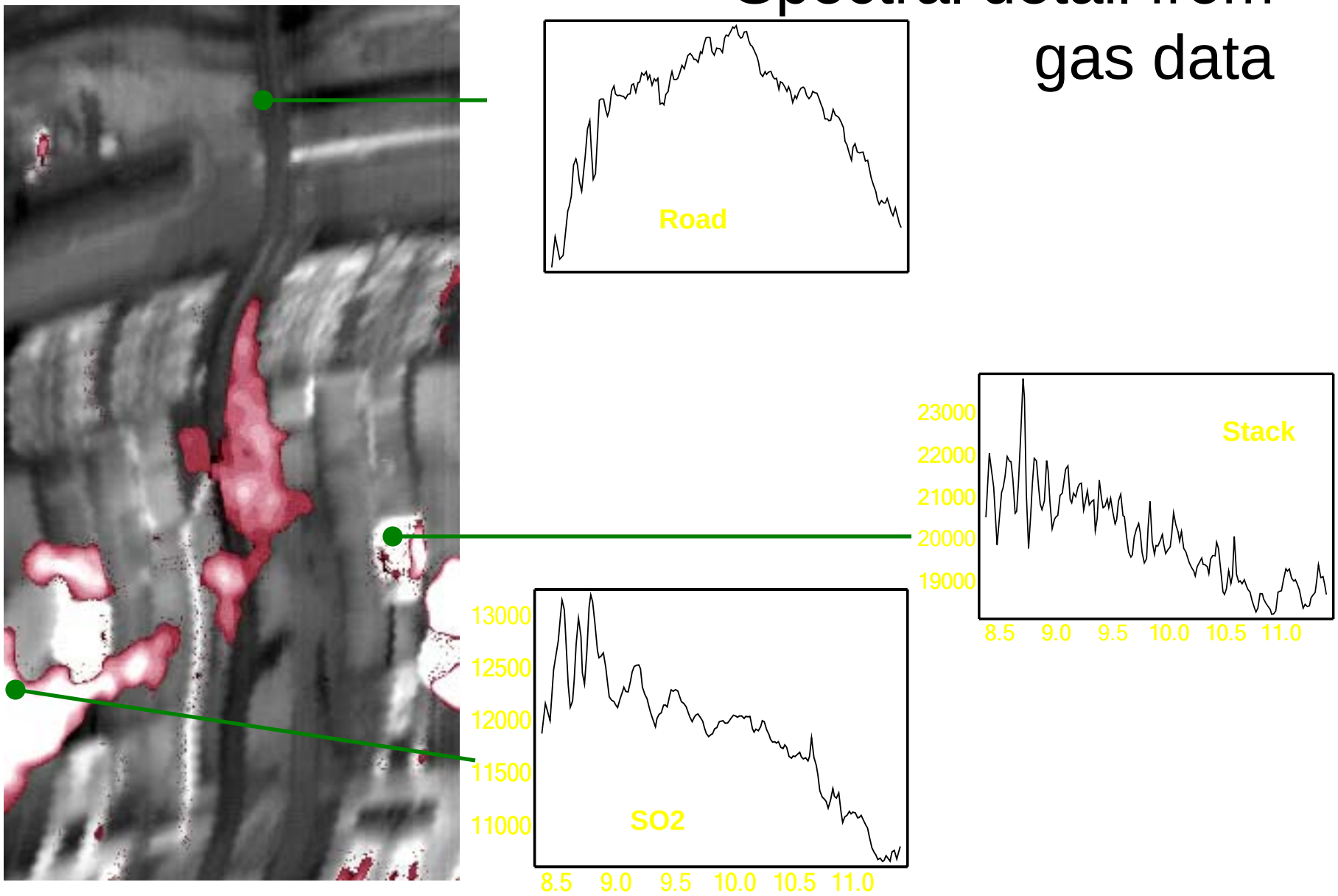
AHI 10μm Thermal Image



SO_2 detection overlay

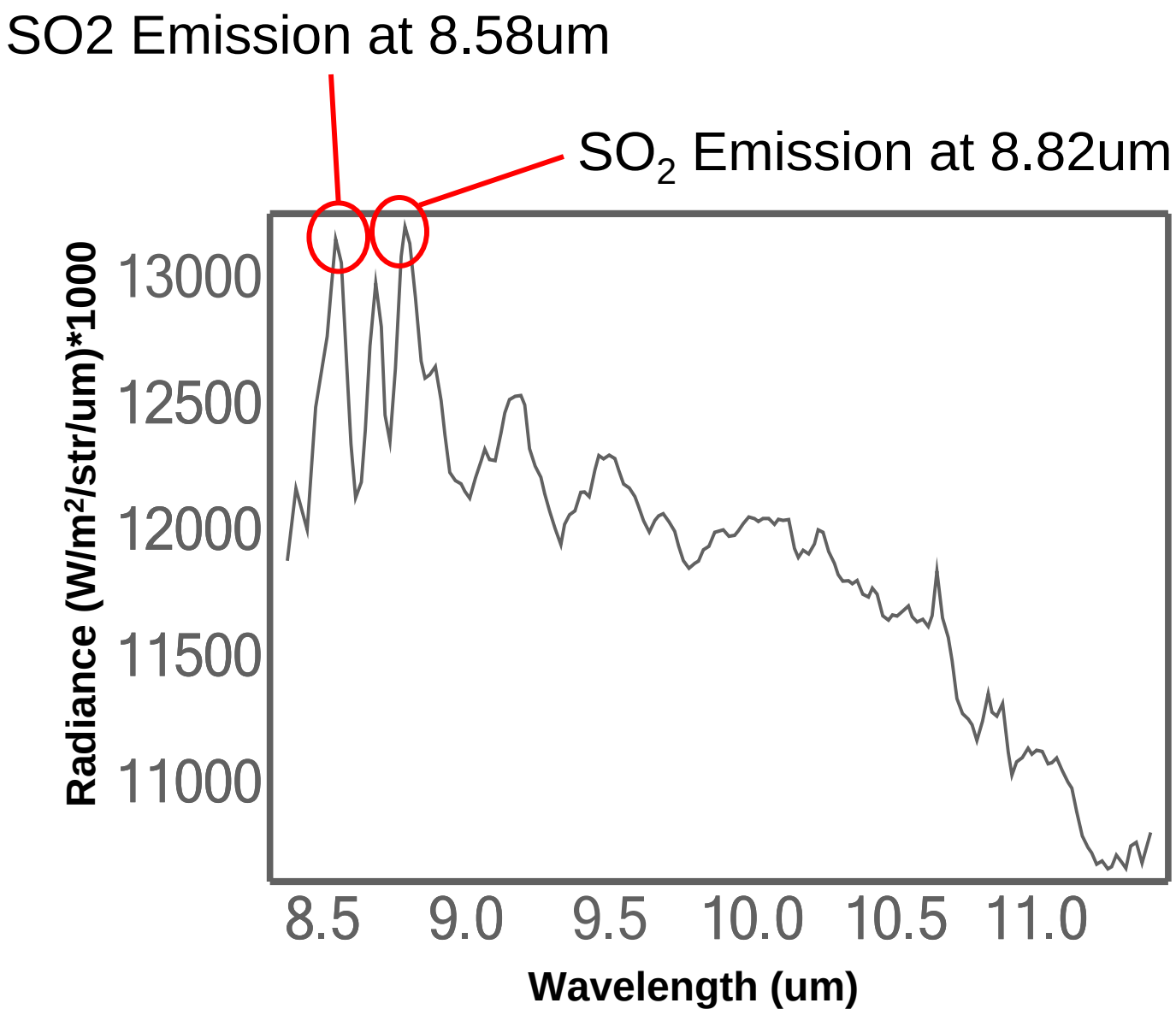
Line Scanner

Spectral detail from gas data



Note: Y-axis units in W/m^2/str/um*1000

LWIR Gas Detection



Validation

- Compared data analysis results to facility emission inventory (EI)
  - EI contains geolocated sample points for permitted emissions and discovered fugitives (leaks)
- Benzene plume occurred at a fugitive emission point in the EI
- EthylGPE plume was found but turned out to be a false detect.

Future work

- More in-depth analysis for this dataset
  - Chemical concentration determination is next step
- Investigate utility of this technology for other applications
  - Forest fire emissions
- New sensor development and testing
  - AHI follow-on (AHI-2)

AHI-2 demonstration project

- Next generation AHI sensor will have 10x sensitivity at a third the size
- Sensor testing will be done in Hawaii in late summer
- Controlled test at an industrial park
- See poster for more details

Campbell Industrial Park, Kapolei, Hawai'i

Acknowledgments

- EPA Office of Research and Development
- University of Hawai'i at Manoa
- EPA Region 6 and Houston lab
- Collaborators including Air Force Research Lab – Rome, NY

Further information and Contact

David Williams

Phone: 919-541-2573

williams.davidj@epa.gov

AHI contacts:

Paul Lucey and Tim Williams

http://www.higp.hawaii.edu/ahi/