USEPA ASPECT Program

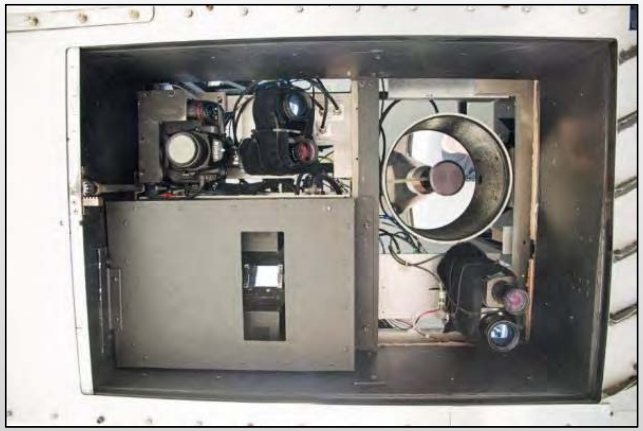
Airborne Spectral Photometric Environmental Collection Technology

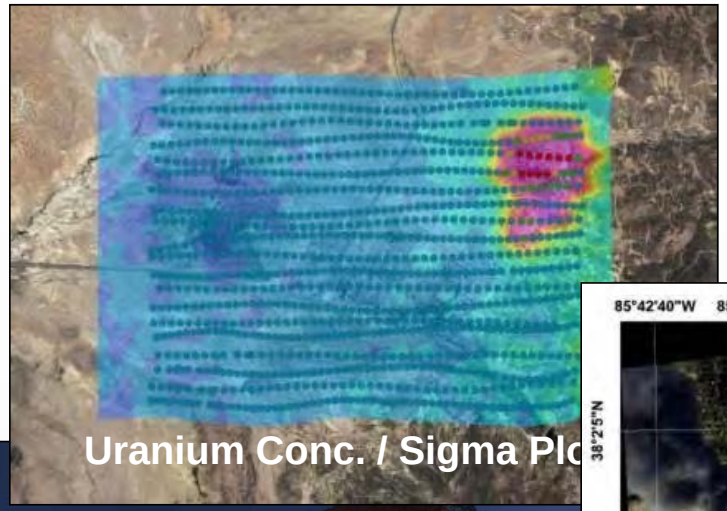
NATION'S ONLY
-Remote-Sensing & Imagery-
Chemical, Radiological & Situational Awareness

7046120

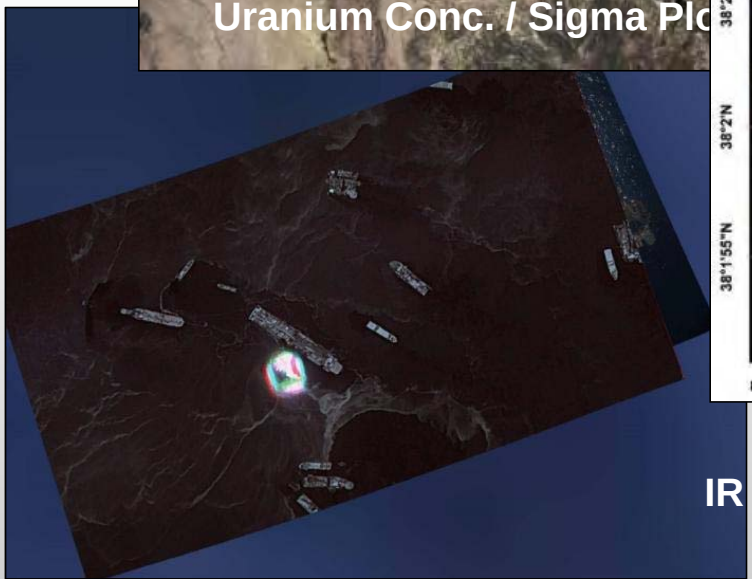
ASPECT Overview Objectives

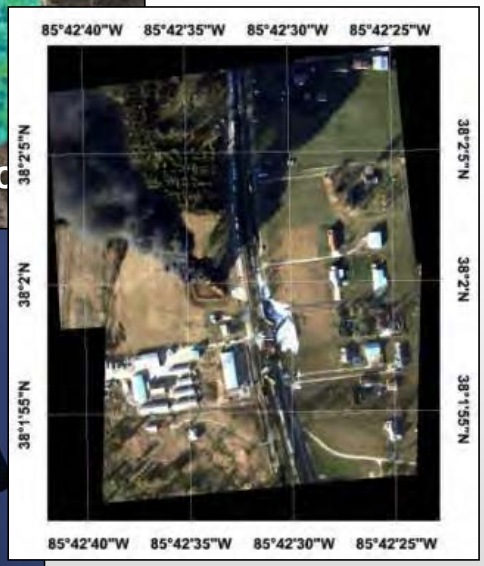
- Operational Concept
- ASPECT Systems
- ASPECT Capabilities
- Response Examples
- Detailed Pattern Recognition method
- Detailed Passive Quantification method





Uranium Conc. / Sigma Plo





IR Image @ DWH

Multi-Role Concept

- Emergency Response
- Homeland Security
- Removal/Remedial Characterization

Users/Partners include EPA, NGA, DHS, DOE, DOD, NGB, DOJ, USSS, NASA, FEMA, USCG, States

The primary role of the ASPECT program is emergency response. The system serves as a queuing device and permits a fast hazard screening to be conducted at the scene.

ASPECT - Operational Concept

- Provide a readiness level on a 24/7 basis
- Provide a simple, one phone call activation of the aircraft
- Wheels up in under 1 hour from the time of activation
- Once onsite and data is collected it takes about….

~ 5 minutes to process and turn around data to first responders

- **Deployment Simplified:**
  - Once on-scene collect chemical, radiological, or situational data (imagery) using established collection procedures
  - Process all data within the aircraft using tested automated algorithms
  - Extract the near real time data from the aircraft using a broadband satellite system and rapidly QA/QC the data by a dedicated scientific reach back team
  - Provide the qualified data to the first responder enabling them to make informed decisions in minimal time

ASPECT -CURRENT SYSTEMS

ASPECT Uses Six Primary Sensors/Systems:

- ✓ An Infrared Line Scanner* to image the plume
- ✓ A High Speed Infrared Spectrometer* to identify and quantify the composition of the plume
- ✓ Gamma-Ray Spectrometer Packs for Radiological Detection (NaI and LaBr) and two BF_3Neutron Detector arrays
- ✓ High Resolution Digital Aerial Cameras* with ability to rectify for inclusion into GIS
- ✓ Broadband Satellite Data System (SatCom)

*29 MP Mapping and 12.5 MP Nikon DX2 DSLR

Deployments & Range

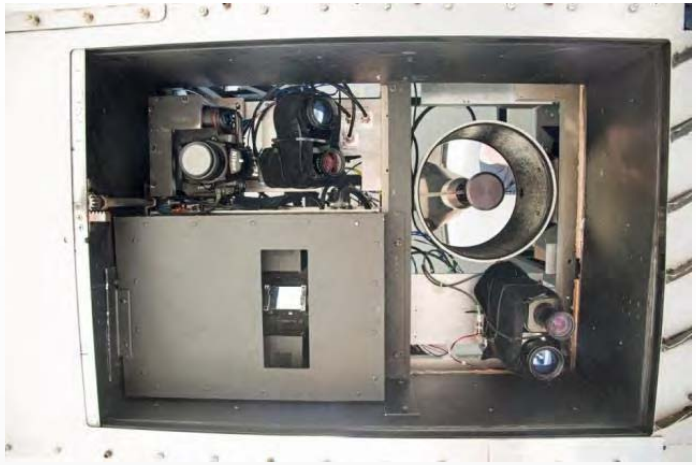
- Over 160 deployments
- ~500 Sorties (flights)
- 67 Emergency Responses
- 24+ Scientific Studies
- Numerous FTXs
- SEAR & NSSEs
- Utilized by all EPA Regions
- Federal, HRF, CST
- International Notoriety
- Terabytes of Data

Estimates Include:
1. 1 hour prep
2. Refueling stop
3. >1 hour data collection

Communications:
1. Real-time status
2. Flight parameters developed & uploaded while in-flight
3. Preliminary products in-flight

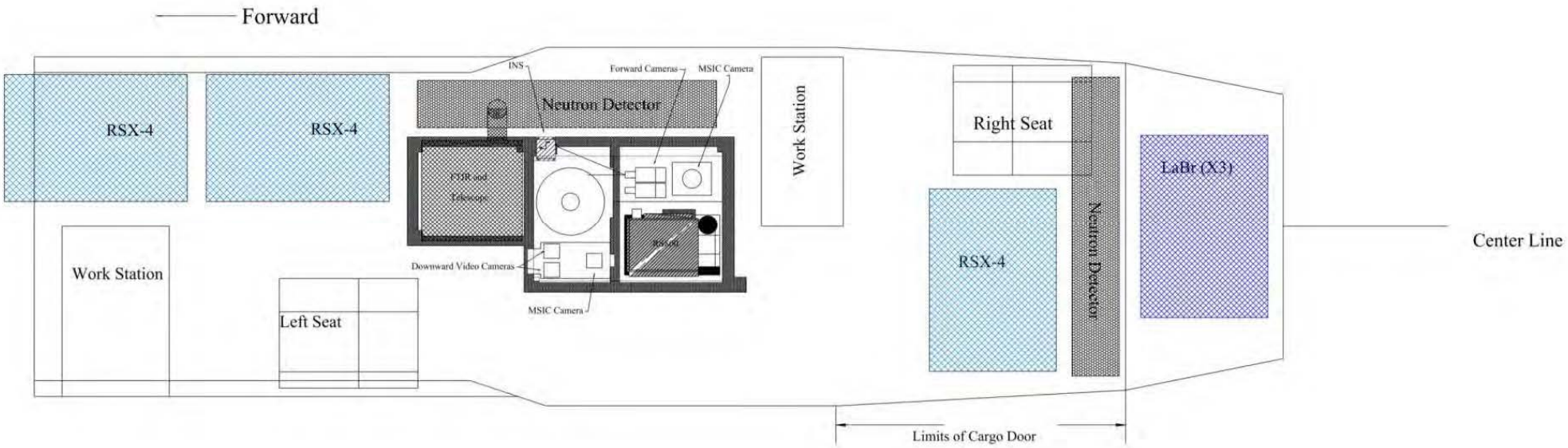
Safety/Regulation:
1. Fully FAA Certified Aircraft and Pilots
2. FAR Part 91
3. FAR Part 135

N9738B Cessna 208B Cargo master



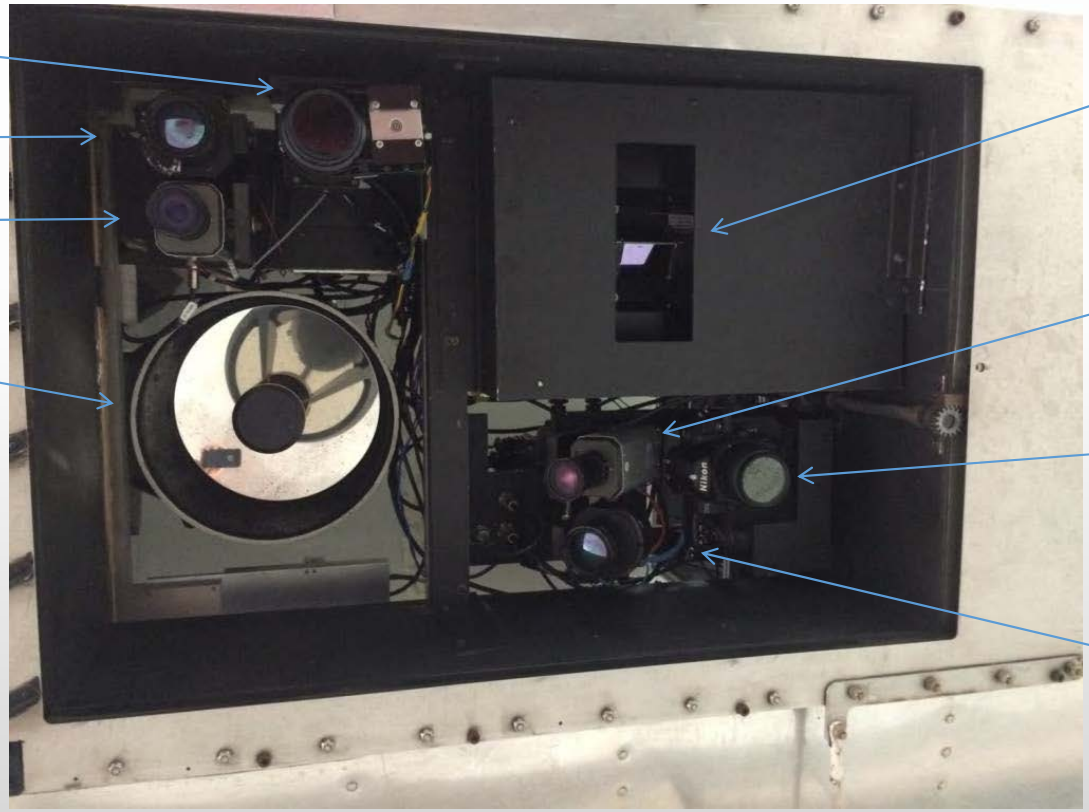
System:	Single Engine Turbo-Propeller Driven Aircraft
Make:	Cessna 208B Cargo Master, Part 91 Certification
Power Plants:	Pratt and Whitney PT-6A-114B turbine driven three blade propeller, 675 shaft HP
Empty Weight:	4458 lbs.
Useful Weight:	4604 lbs**. (2000 lbs of payload after fuel and crew!)**
Maximum Take-off Weight:	9062 lbs.
Typical Cruise Speed:	160 Kts
Typical Flight Duration:	6 Hours (65% Power) Plus 45 Minute Reserve
Service and Ceiling:	Low Altitude Waiver, 25000 Ft (MSL) max altitude
Cabin:	Un-pressurized, Crew Oxygen
Portals:	One, 20 X 30 inch DER sensor hole with Remote Door
Exhaust Mod	Full DER Exhaust Bypass
Electrical Buss:	Primary, 28 vdc @ 200 amps full load, Secondary, 28 vdc @ 90 amps full load
Data Communication:	Phased Array Satellite System, 40-60 KB/sec Data/Telephone combined, STC
Readiness Status:	24/7/365
FAA Status	Part 91, Restricted Use (Sensors Only), Full Compliance

ASPECT -CURRENT SYSTEMS AND LAYOUT



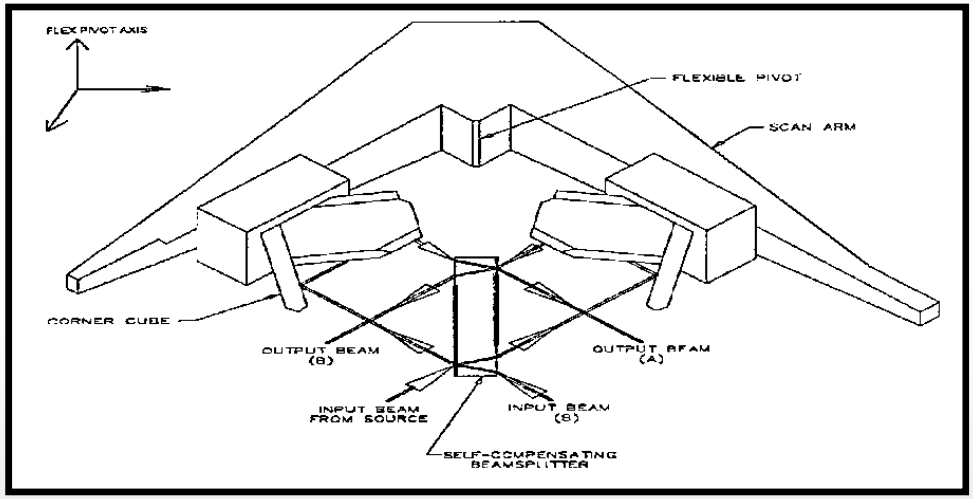
ASPECT Optical/IR Sensor Layout

Bottom View



ASPECT

FTS System

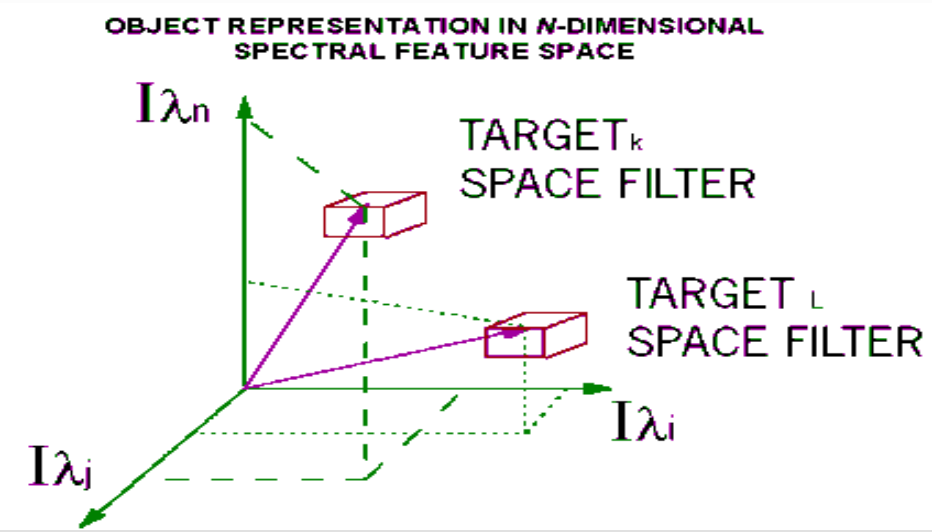


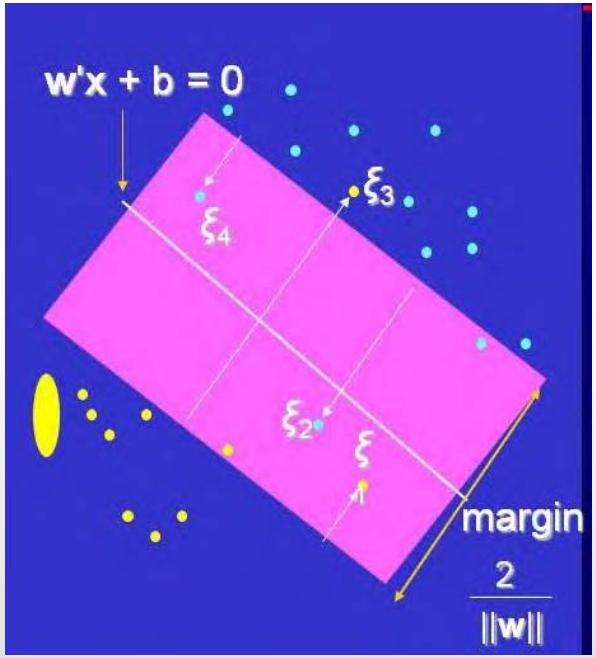
INTERFEROMETER DESIGN

- **Scan Speed - 87 scans/sec**
- **Telescope - 10" (0.2° FOV)**
- **Dual Scan Direction**
- **Throughput - 0.01 cm^2*sr**
- **Thermal Stabilization**
- **Controlled Blackbody**
- **1.0 to 32 cm^{-1} resolution**

- **Channel 1 : 3 - 5 microns $6*10^{-9}$ W/cm^2srcm^{-1}**
- **Channel 2 : 8-12 microns $1.8*10^{-8}$ W/cm^2srcm^{-1}**
- **Noise Equivalent Response**

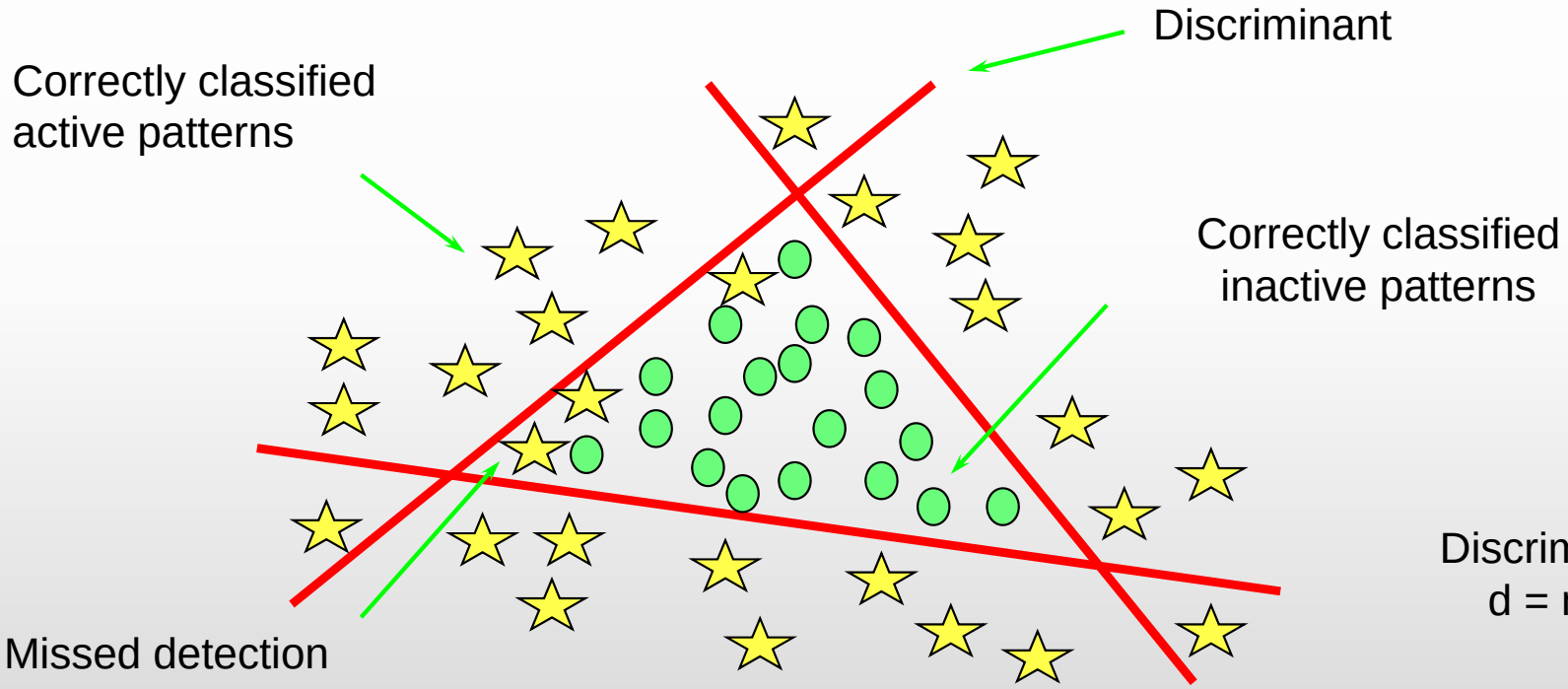
ASPECT
Multi-Dimensional Space Pattern Recognition





Output from the digital filter process is input into a n-dimensional pattern recognition routine using either a piece wise linear discriminator or a support vector machine discriminator. These routines map the vector space (patterns) into similar dimensional space.

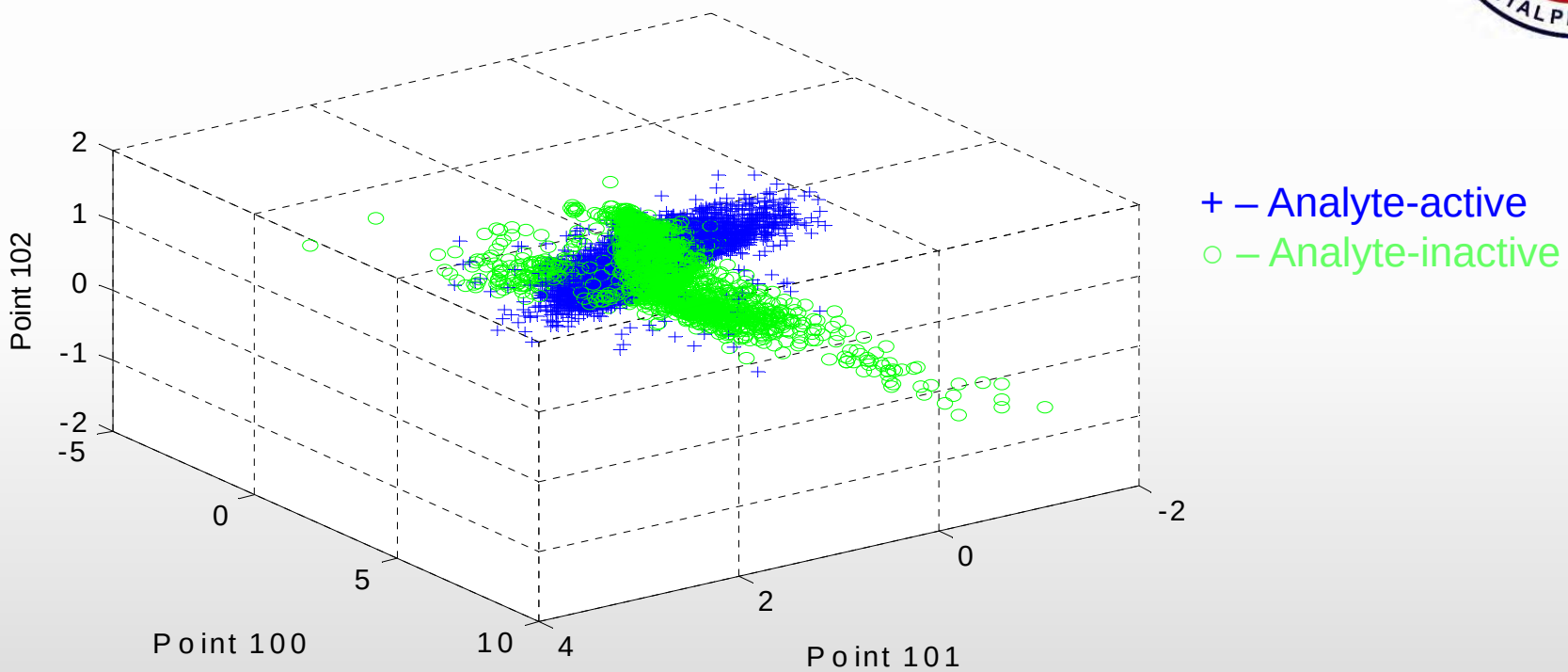
ASPECT
Piecewise Linear Discriminant Analysis



Discriminant Score
$d = \max(\mathbf{w}_j^T \mathbf{x})$

ASPECT uses about 100 dimensions of data!

ASPECT
Training Set



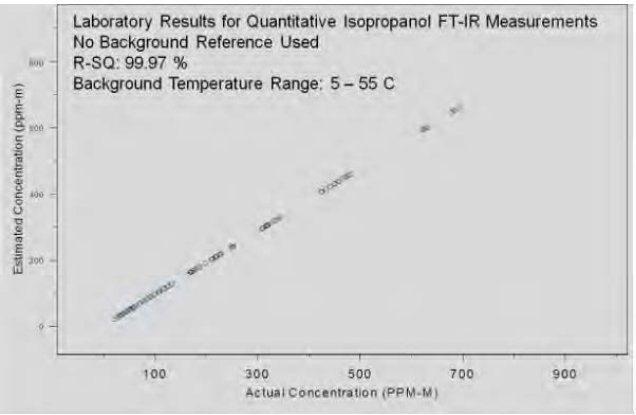
Defines the data space corresponding to active and inactive patterns

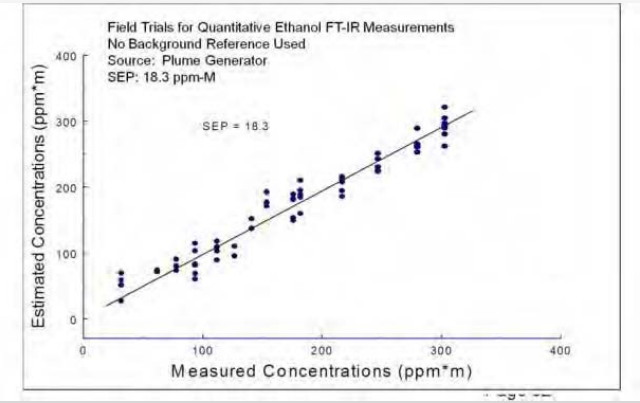
Source: University of Iowa

ASPECT
Detection Limits (in ppm*m)

Acetic Acid (20)	Cumene (200)	Isoprene (65)	Propylene Oxide (68)
Acetone (5)	Diborane (50)	Isopropanol (85)	Silicon Tetrafluoride (2)
Acrolein (88)	1,1-Dichloroethene (37)	Isopropyl Acetate (7)	Sulfur Dioxide (150)
Acrylonitrile (125)	Dichloromethane (60)	MAPP (37)	Sulfur Hexafluoride (0.7)
Acrylic Acid (33)	Dichlorodifluoromethane (7)	Methyl Acetate (10)	Sulfur Mustard (60)
Allyl Alcohol (53)	1,1-Difluoroethane (8)	Methyl Ethyl Ketone (75)	Nitrogen Mustard (25)
Ammonia (20)	Difluoromethane (8)	Methanol (54)	Phosgene (5)
Arsine (187)	Ethanol (63)	Methylbromide (600)	Phosphine (83)
Bis-Chloroethyl Ether (20)	Ethyl Acetate (8)	Methyl Methacrylate (11)	Tetrachloroethylene (100)
Boron Tribromide (2)	Ethyl Formate (10)	MTEB (30)	1,1,1-Trichloroethane (19)
Boron Triflouride (56)	Ethylene (50)	Naphthalene (38)	Trichloroethylene (27)
1,3-Butadiene (50)	Formic Acid (50)	n-Butyl Acetate (38)	Trichloromethane (7)
1-Butene (120)	Freon 134a (8)	n-Butyl Alcohol (79)	Triethylamine (62)
2-Butene (190)	GA (Tabun) (7)	Nitric Acid (50)	Triethylphosphate (3)
Carbon Tetrachloride (2)	GB (Sarin) (5)	Nitrogen Trifluoride (7)	Trimethylamine (93)
Carbonyl Fluoride (8)	Germane (15)	Phosphorus Oxychloride (20)	Trimethyl Phosphite (4)
Carbon Tetrafluoride (1)	Hexafluoroacetone (4)	Propyl Acetate (7)	Vinyl Acetate (6)
Chlorodifluoromethane (6)	Isobutylene (150)	Propylene (37)	

ASPECT
Detection Limits





- Detection limits are referenced to methanol
  - Methanol DL based on both laboratory and field observations
  - DL is defined as a signal to noise ratio of 3
  - Passive laboratory measurements are referenced to an active bench top FTIR
  - All data is collected at 16 cm-1 resolution
  - A 5° C temperature difference is used
- Spectra from published libraries are used to develop detection limits for other compounds
- Library spectra is either decimated or smoothed to 16 cm-1 resolution and the appropriate absorbance is obtained.
- A ratio is used between the absorbance and detection limit of methanol to the other compound:

Chemical X DL = (Methanol DL)(Chemical X Absorbance)/(Methanol Absorbance)

ASPECT
Rapid Assessment of Field Data using an Empirical Sensor Model Verified Against Lab and Field Data

- Typical Laboratory Spectroscopy: where: A = Absorbance

  $A = \mathrm{Log}_{10}(P/P_o)$ P/P_o = Ratio of Signal to Background
- Beer's Law: where A = Absorbance

  $A = E*b*C$ where: E = Emissivity

  b = Path length
- With Substitution:

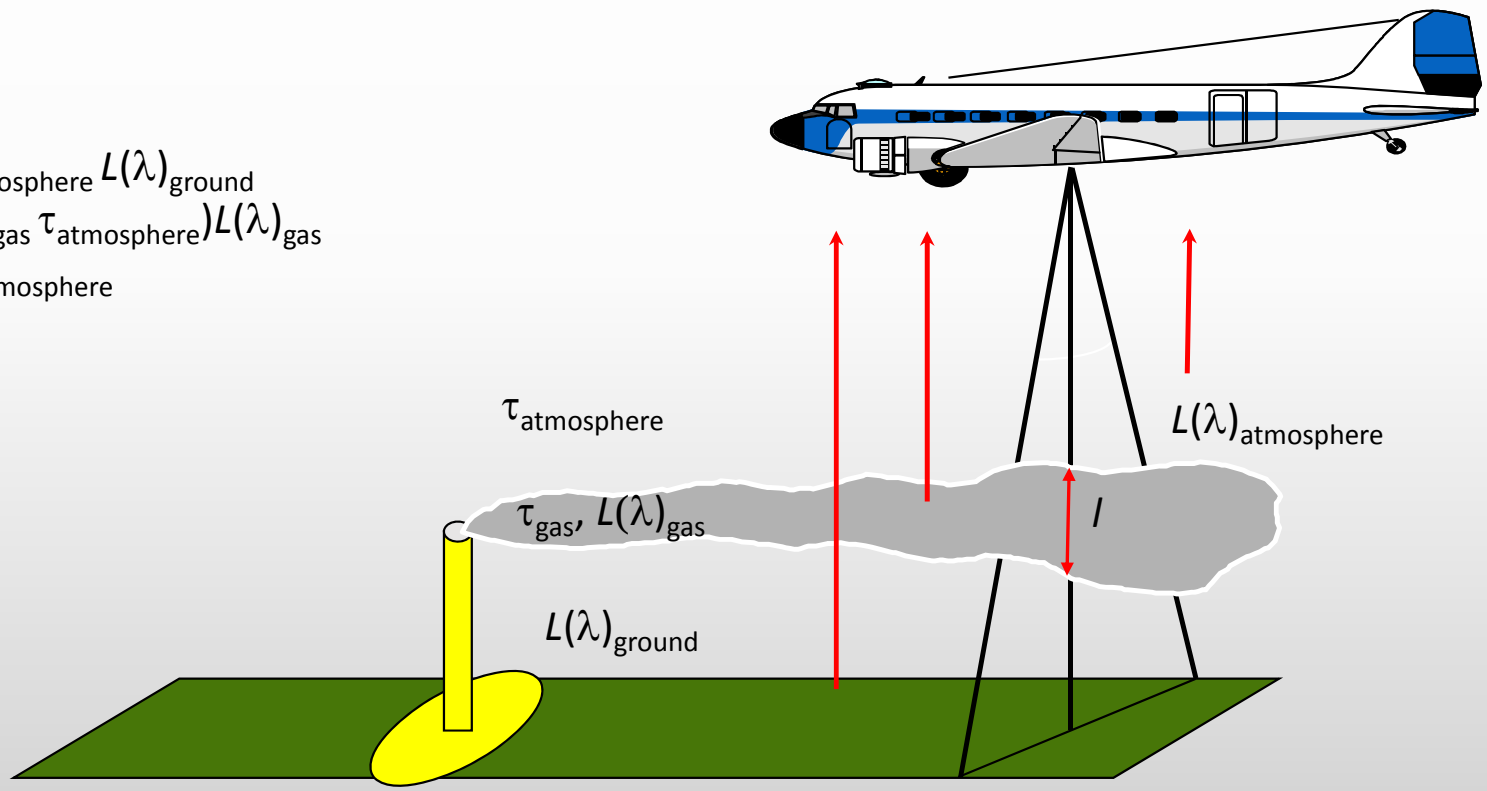
  $E*b*C = \mathrm{Log}_{10}(P/P_o) \rightarrow C = (\mathrm{Log}_{10}(P/P_o))/(E*b)$
- Assumptions:
  - The Kalman score output from the pattern recognition provides a rough first order estimator of the signal intensity in a spectrum for a gaseous species detected against the background effects
  - A score = 0 defines the system detection limit
  - A score = $1.0X10^{-13}$ defines the background score
  - For a large release a path of 50 meters is used, for a small release a path of 10 meters is used.
  - The absorbance, A, is a scaling factor and is adjusted to fit the data
  - A constant instrument and vapor/background temperature is assumed
  - Errors tend to be large (100%) so the method provides a screening result of low, medium, and high
- With Substitution of the Kalman Score:

  $C = (1/E*b)(\mathrm{Log}_{10}\,(\text{Kalman Score})/(\text{Kalman Background}))$
- Referenced to the Detection Limit, DL:

  $C = DL/b + (1/E*b)(\mathrm{Log}_{10}\,(\text{Kalman Score})/(\text{Kalman Background}))$

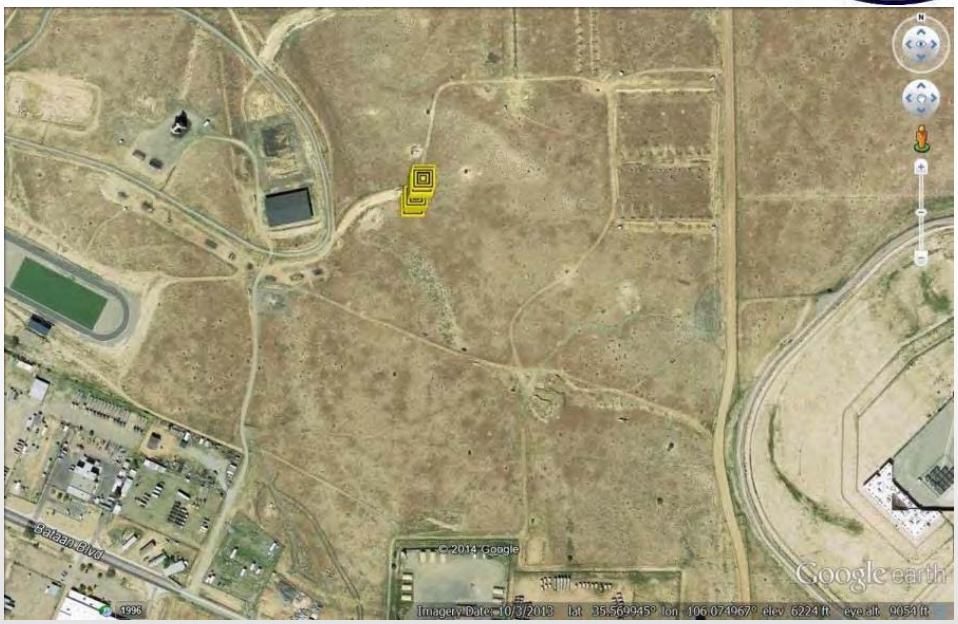
ASPECT
Radiometric Model

$$L(\lambda)_s = \tau_{gas}\,\tau_{atmosphere}\,L(\lambda)_{ground} + (1 - \tau_{gas}\,\tau_{atmosphere})L(\lambda)_{gas} + L(\lambda)_{atmosphere}$$



US EPA ASPECT

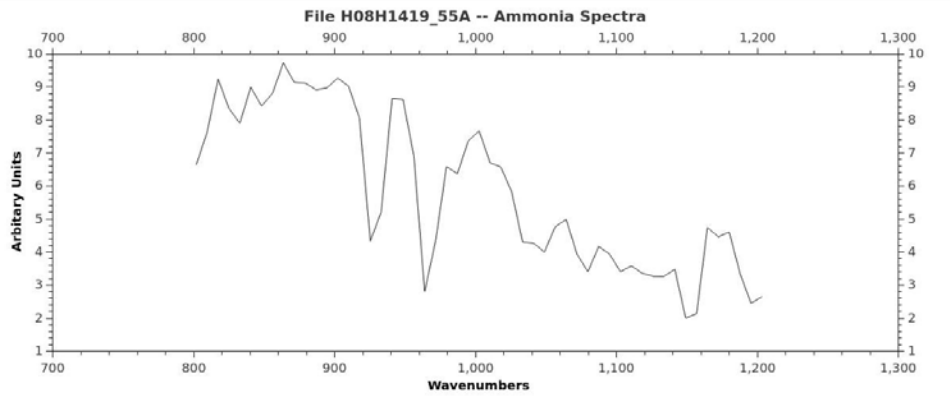
Rapid Assessment of Field Data using an Empirical Sensor Model Verified Against Lab and Field Data

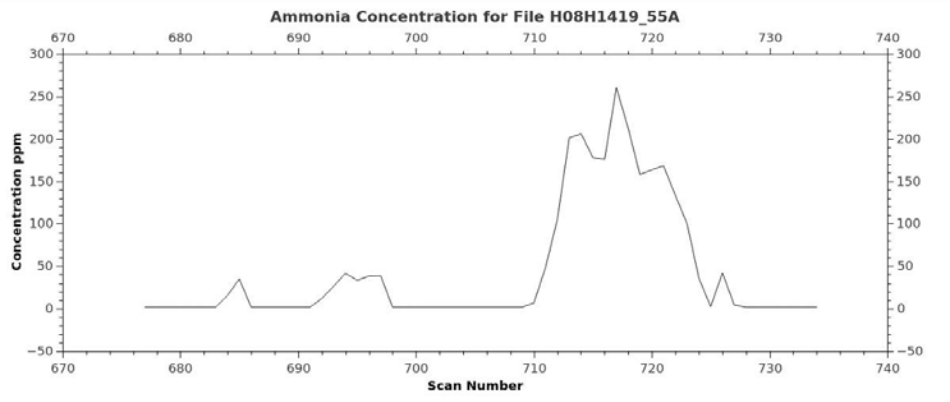


Ammonia Detection for File H08H14190_55A and Close-up
2014 New Mexico 64th CST Exercise – one FTIR sample path by the aircraft over the target

US EPA ASPECT

Rapid Assessment of Field Data using an Empirical Sensor Model Verified Against Lab and Field Data





Confirmation Ammonia Spectra and Rapid Assessment Data for an Estimated Plume (11.5 meter Plume Thickness)

2014 New Mexico 64th CST Exercise

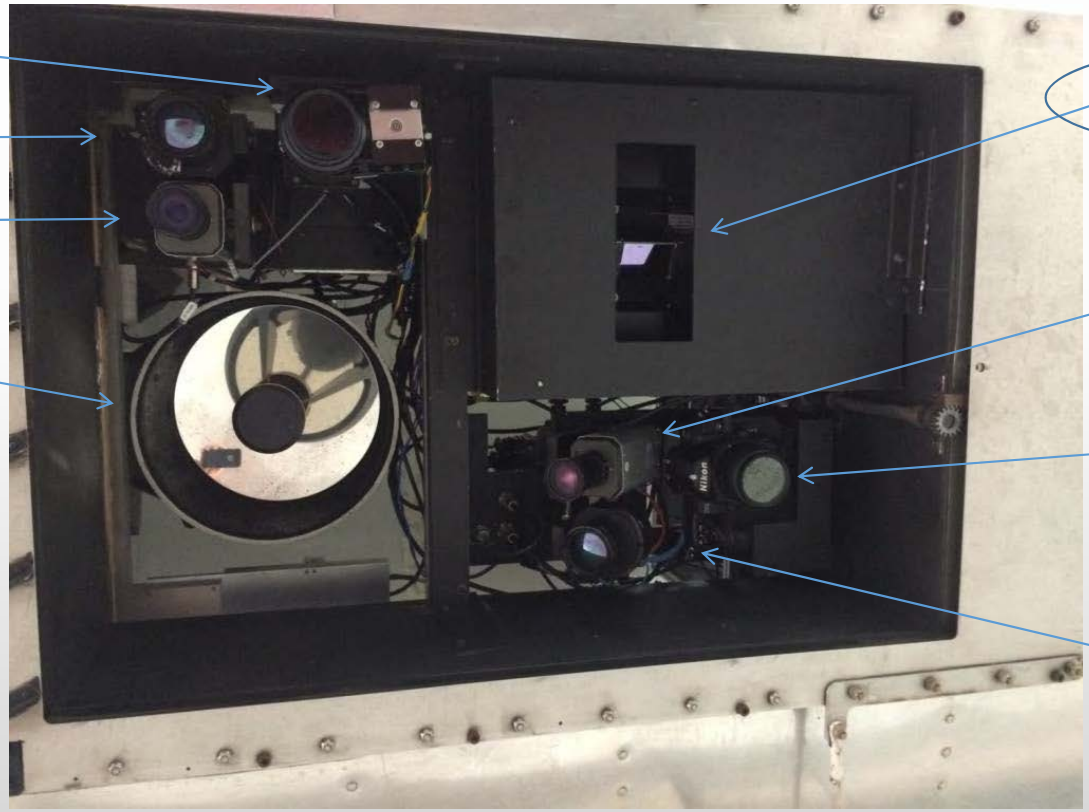
US EPA ASPECT

Rapid Assessment of Field Data using an Empirical Sensor Model Verified Against Lab and Field Data

Locations of All Ammonia Detections
2014 New Mexico 64th CST Exercise

ASPECT Optical/IR Sensor Layout

Bottom View

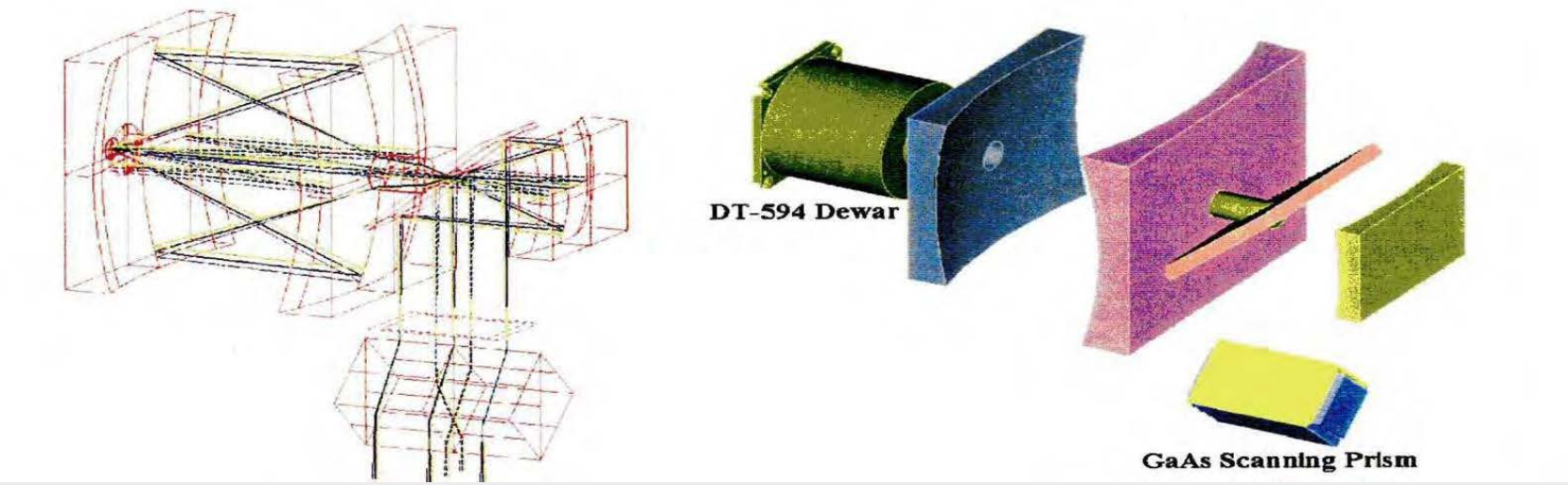


ASPECT
Line Scanner RS-800MSIRLS

- Using a scanner speed of about 60 Hz and a field of view of 60º results in a linear infrared image approx ½ mile wide.
- Approx 2.0 square miles can be imaged per minute.
- Chemical Discrimination is accomplished using a matrix of 16 cold optical filters having a bandwidth of approx 5 – 10 wavenumbers
- Data Collection Status in approximately 12 minutes from Start-up

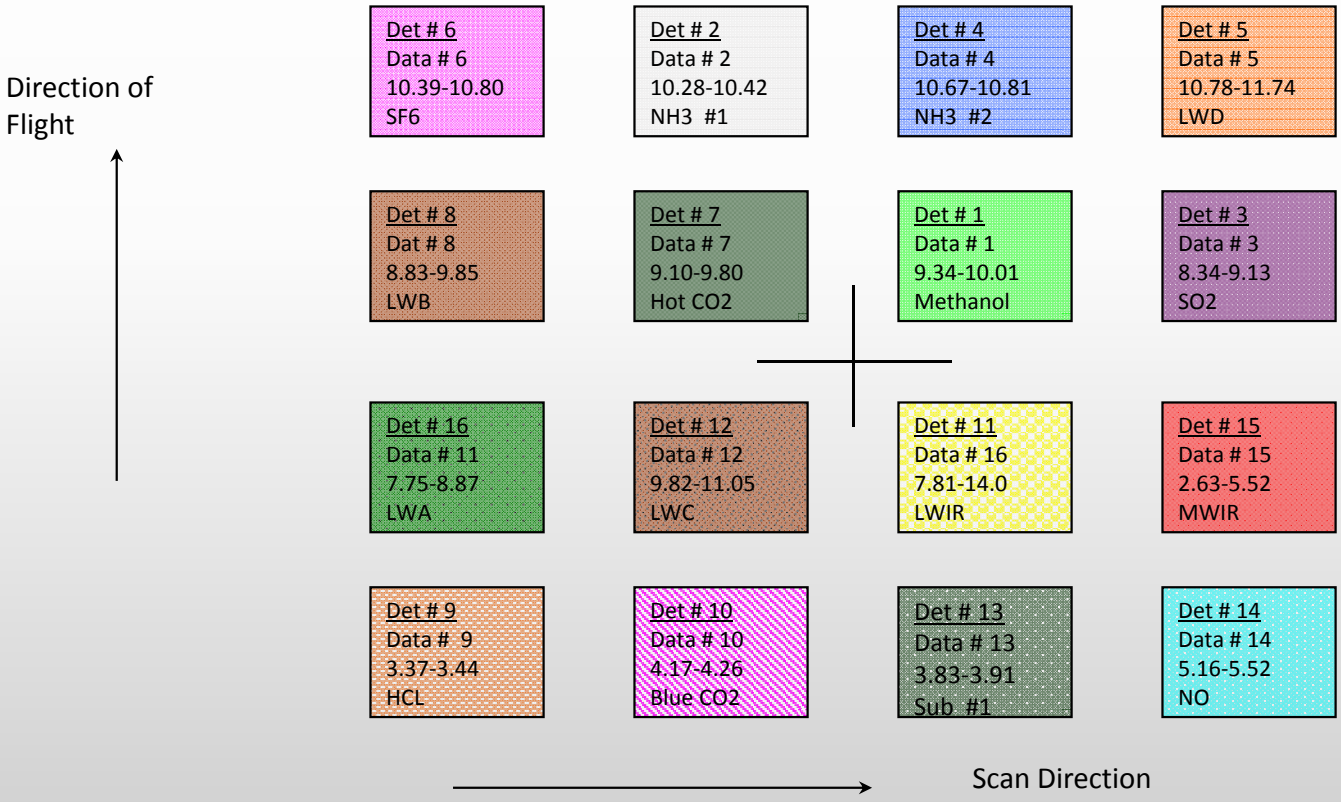
ASPECT
RS-800MSIRLS Line Scanner Detail

RS-800MSIRLS Line Scanner Design

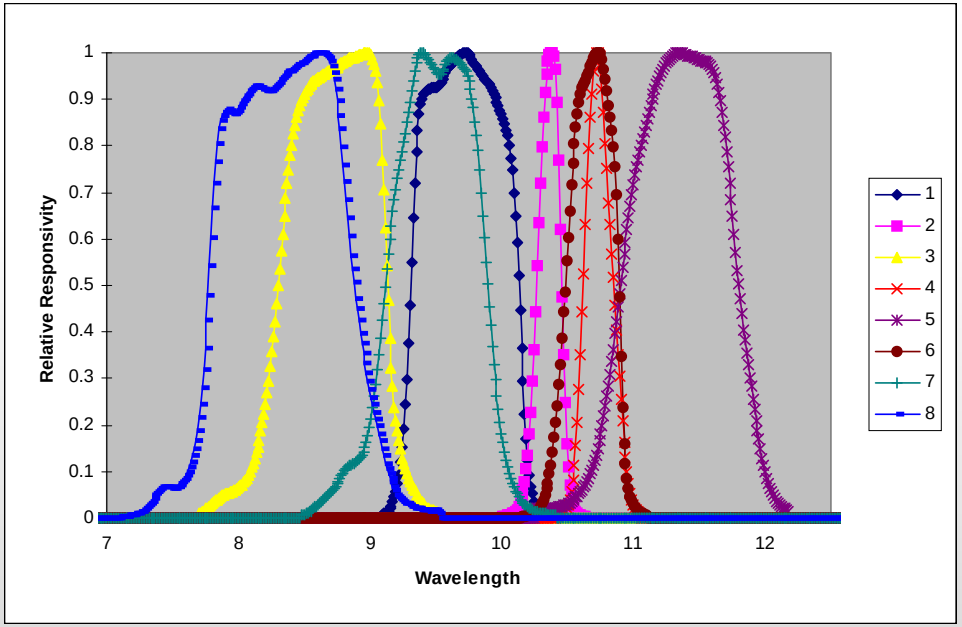


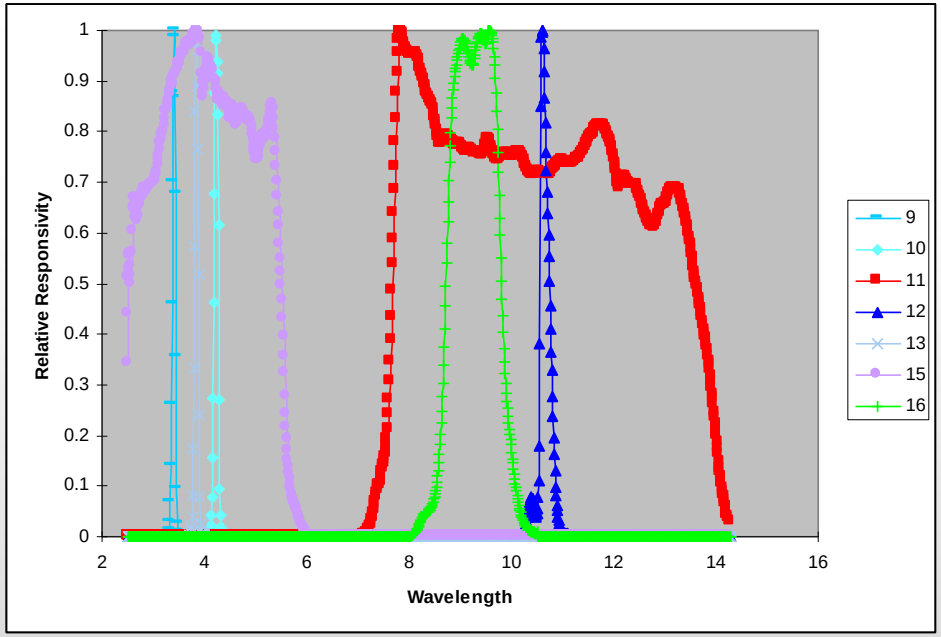
The RS800 consist of a rotating scanning prism with focusing reflective optics. The RS800 is very efficient in both optical throughput and f-number.

ASPECT
RS-800 Detector Layout



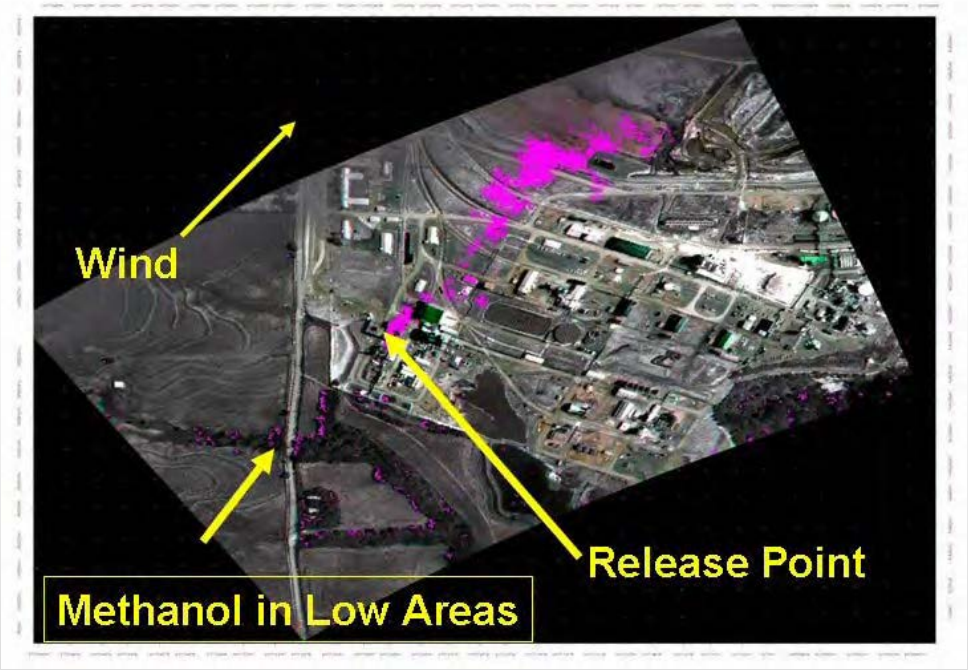
ASPECT
RS800 Bandpass Filter Response

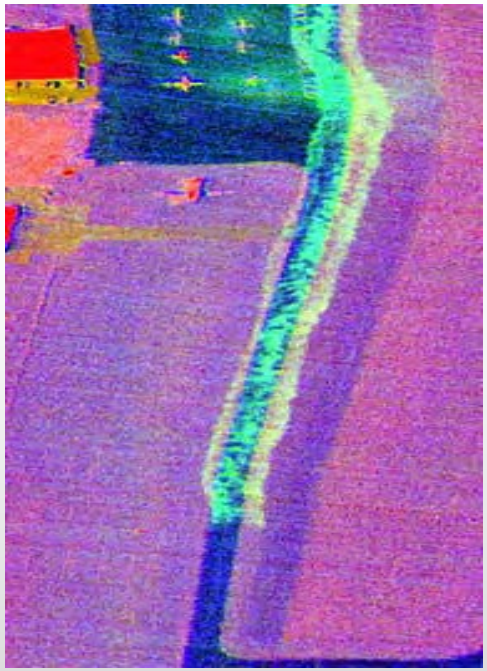




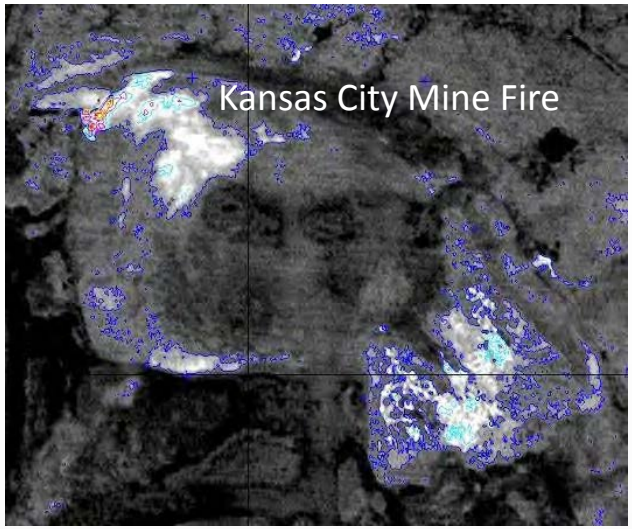
ASPECT

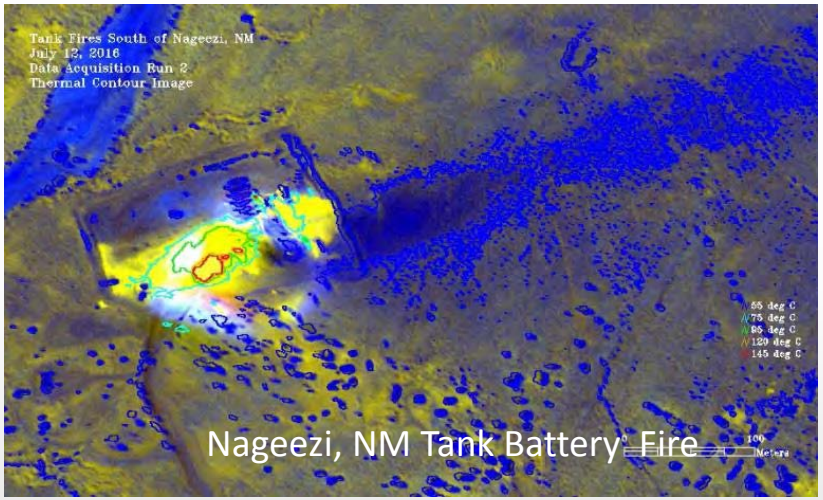
Methanol and Ethanol Imagery

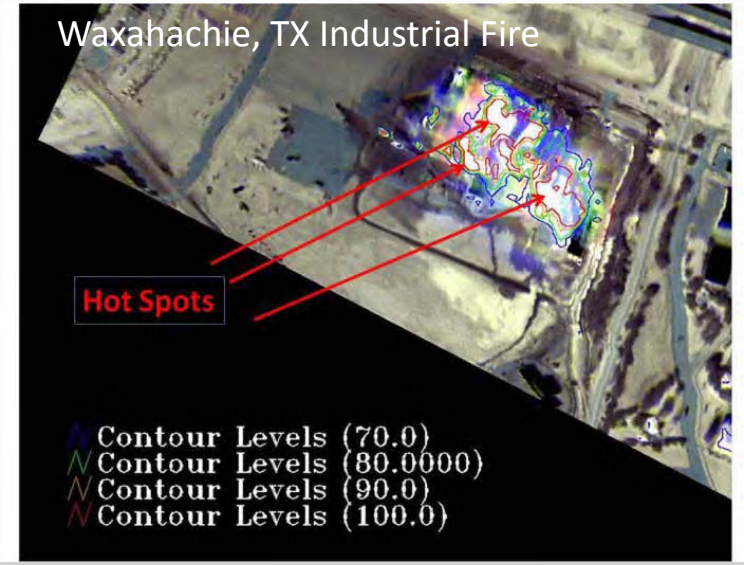




ASPECT
Thermal Products





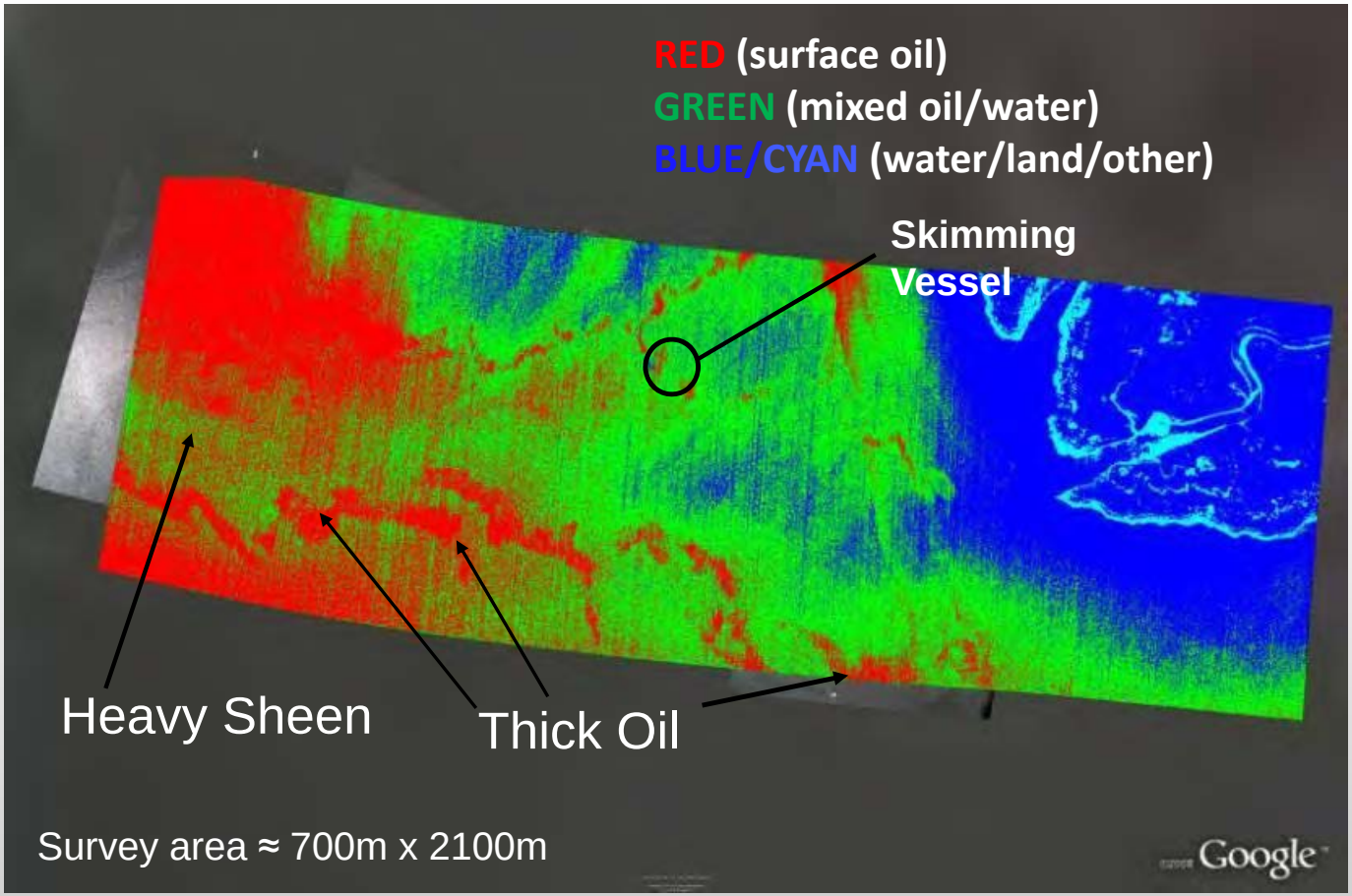


Long wave Thermal Specifications:

- Pixel Size = 0.5 M
- Linear Range = Up to 200 C
- Resolution = 0.05 C

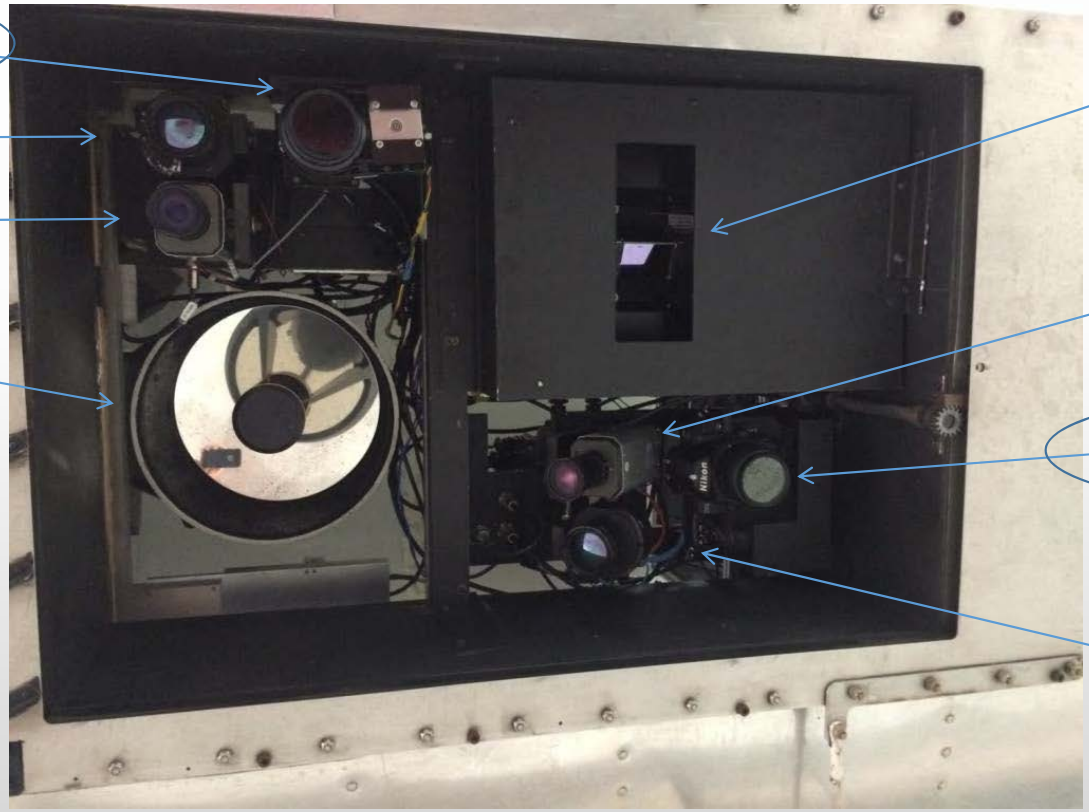
ASPECT

Supervised Classification Of Oil on Water



ASPECT Optical/IR Sensor Layout

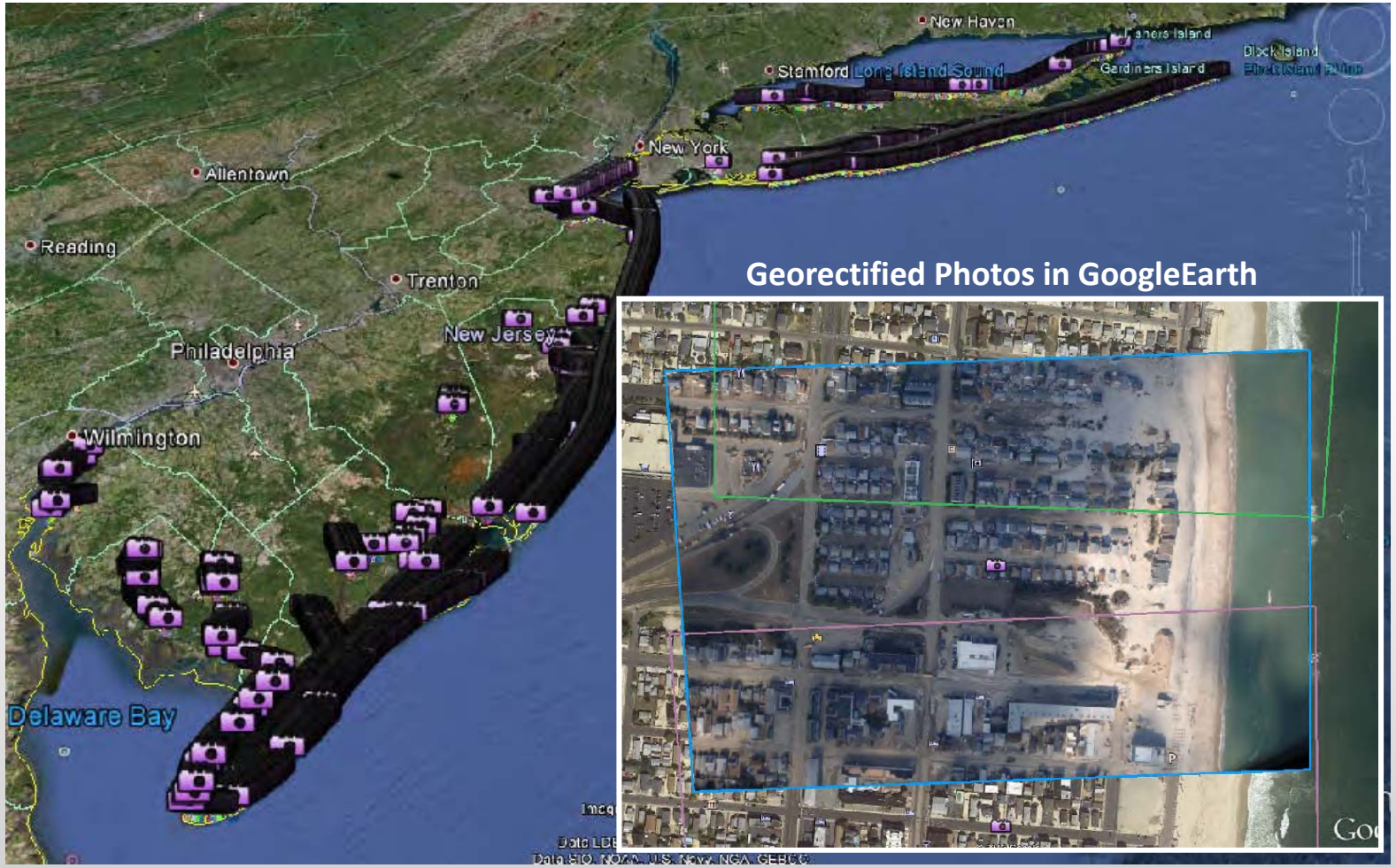
Bottom View



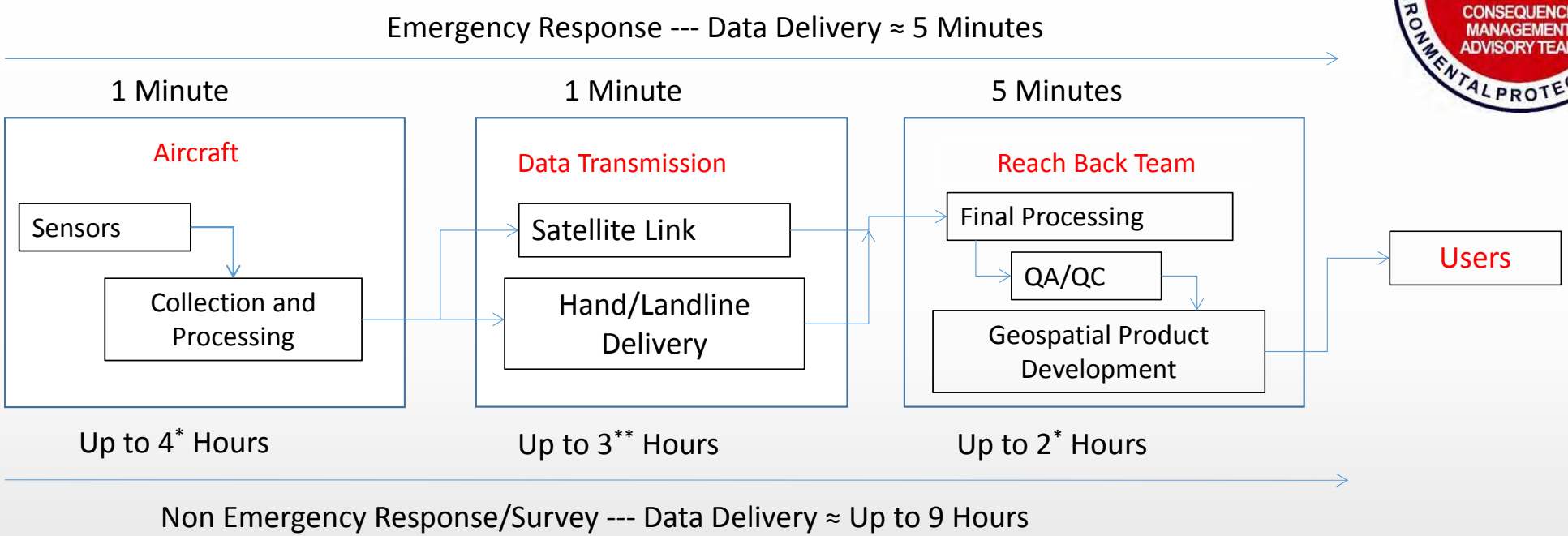
ASPECT
Aerial Photography

- 29 MP High Resolution Mapping Camera and a secondary 12.5 MP DSLR Camera.
- Automatically slaved to the IR sensors
- Automated Geo-Rectification/GIS Coded Images
- Full Ortho-Rectification (Terrain and Camera Model) Correction
- Ability to Process in the Air-Approx. 3 Minute Turn-Around
- Compressed Transmission of Data Via SatCom
- Fast Turn Around on Images – Approx. 1000 processed images per Mission
- All Products can be imported into:
  - ✓ Google Earth,
  - ✓ ESRI
  - ✓ Generic Geospatial software packages
  - ✓ *Respective Packages Easily Selectable*

Hurricane Sandy Response



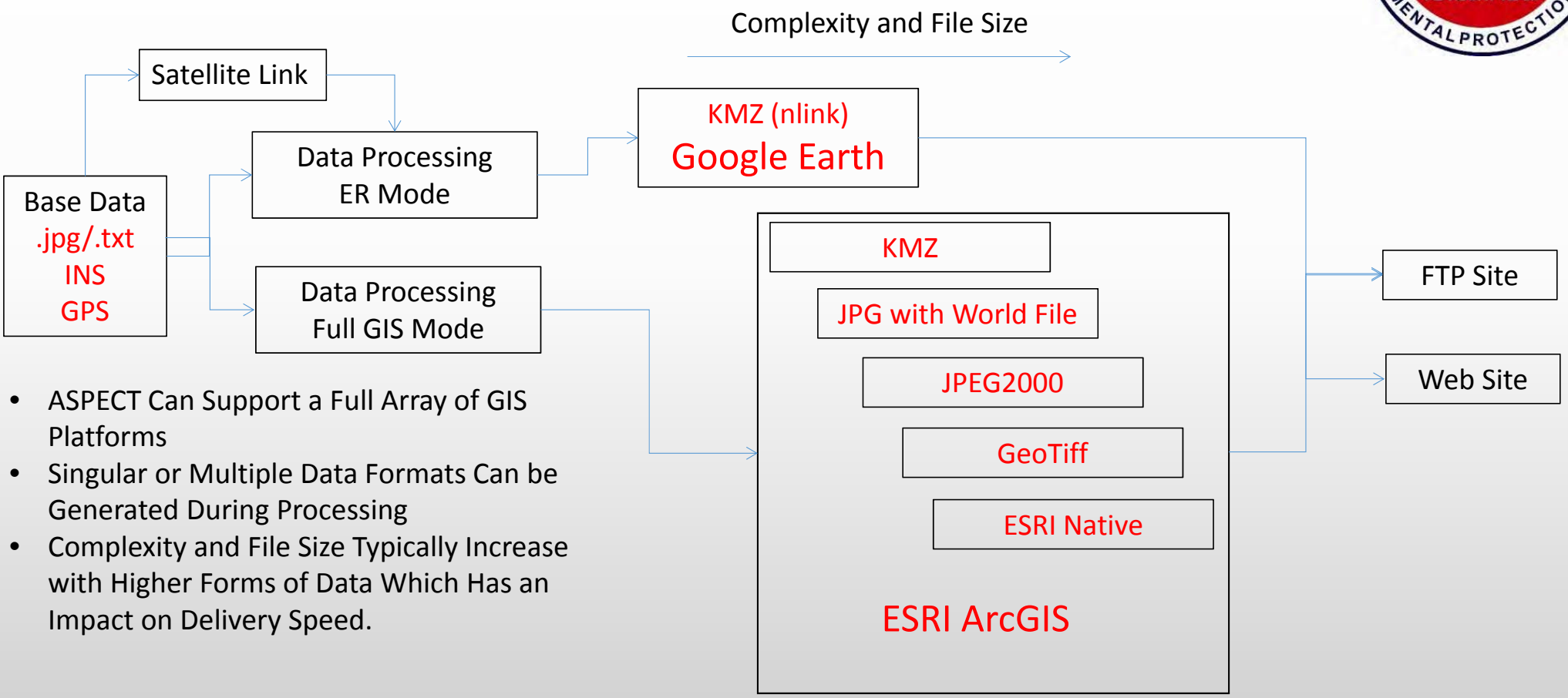
DATA PROCESSING AND DELIVERY TIME



* Dependent on the size and complexity of the survey area. 5 hours represents the maximum on-station capability of the aircraft.

** Dependent on the available bandwidth for data transmission. A high speed connection will minimize this time estimate.

ASPECT
GEOSPACIAL PRODUCT DEVELOPMENT



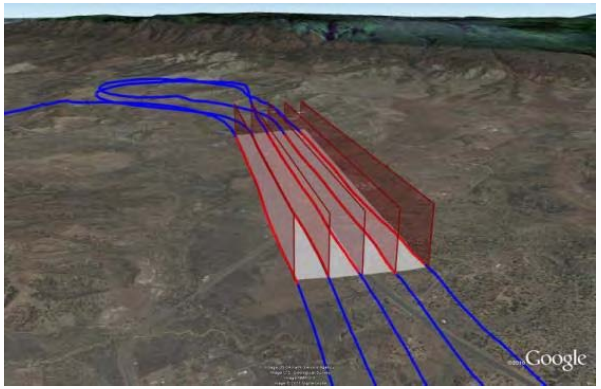
- ASPECT Can Support a Full Array of GIS Platforms
- Singular or Multiple Data Formats Can be Generated During Processing
- Complexity and File Size Typically Increase with Higher Forms of Data Which Has an Impact on Delivery Speed.

ASPECT
Mission Design

- **Initial Flight Design using Flight Profiles and/or Flight Lines**
- **Generation of a Mission Order**
- **Analysis of Flight Hazards**
- **Constant Review of Weather**
- **ASPECT real-time quality checks on flight paths and altitudes**

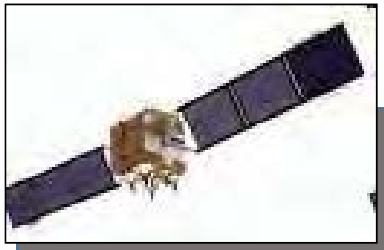
- **For Emergency Response Actions, Sections of Mission Planning are Conducted in the Air.**

- **Nav/Flight Line Data is Generated Using Custom Software and Can be Uploaded While the Aircraft is in Flight.**



ASPECT – Data QA/QC & Dissemination

Performed in about 5 minutes

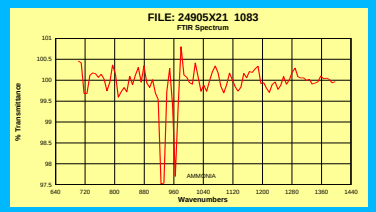


Data package unzipped by scientific reach back team

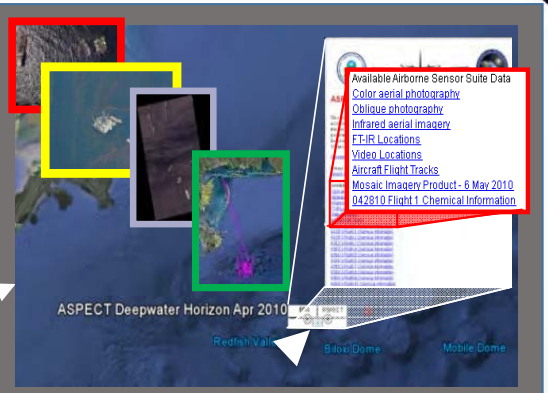
Compressed data package sent via satellite

Automated airborne processing and packaging

Chem/Rad/Situational data collected

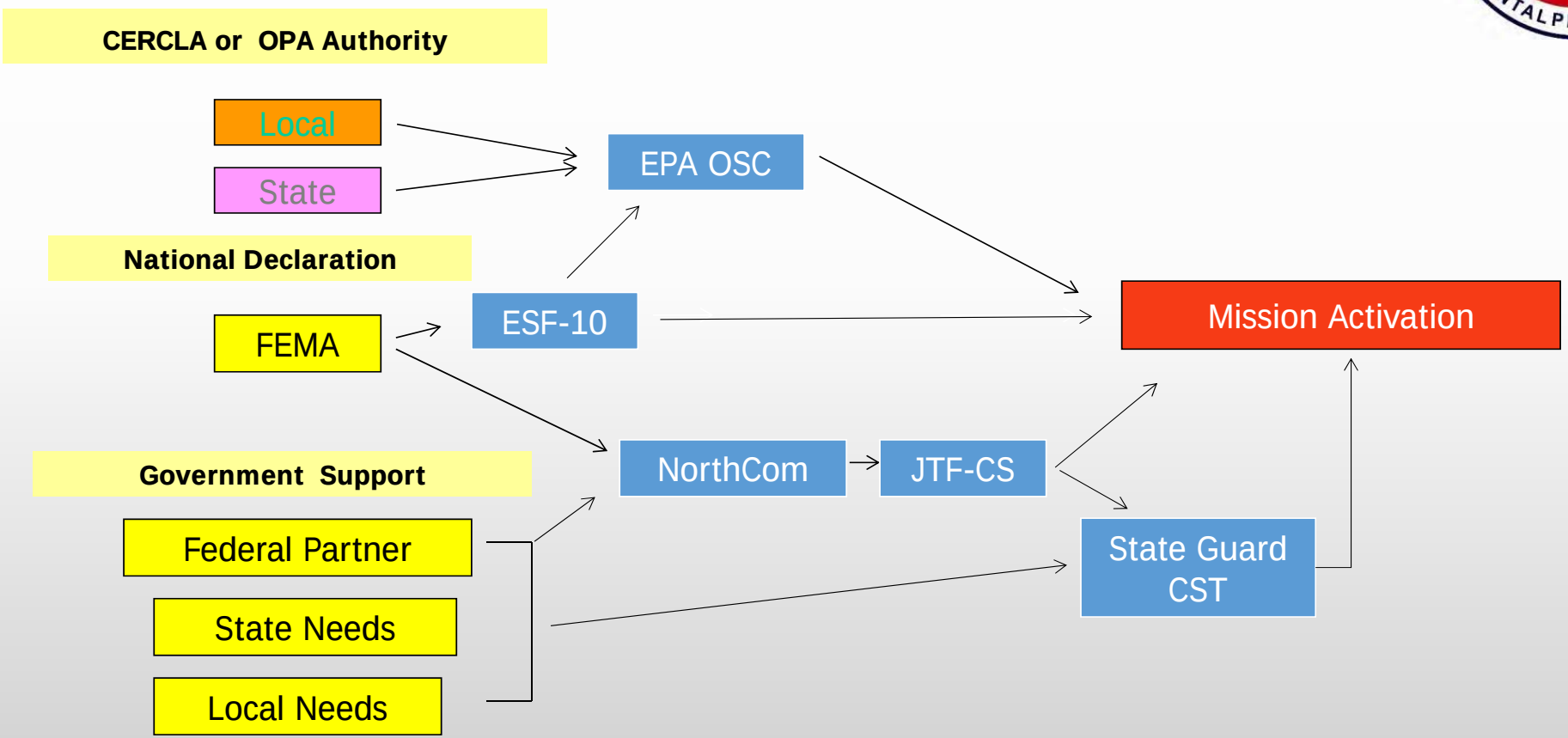


Reach Back Analysis and Confirmation

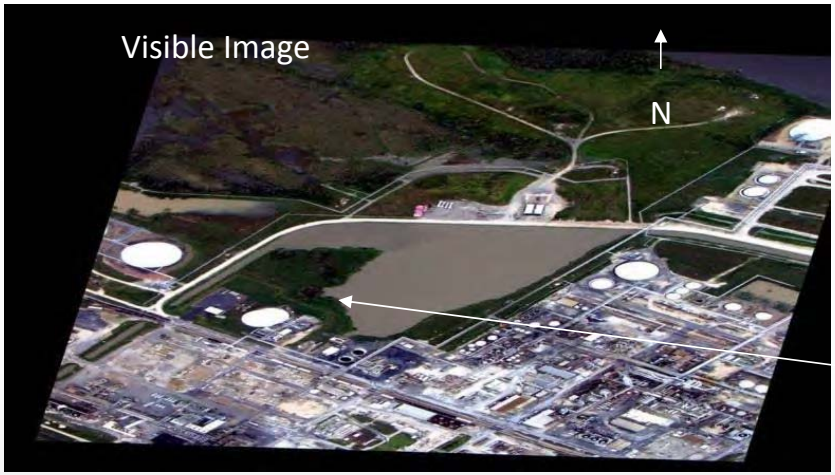


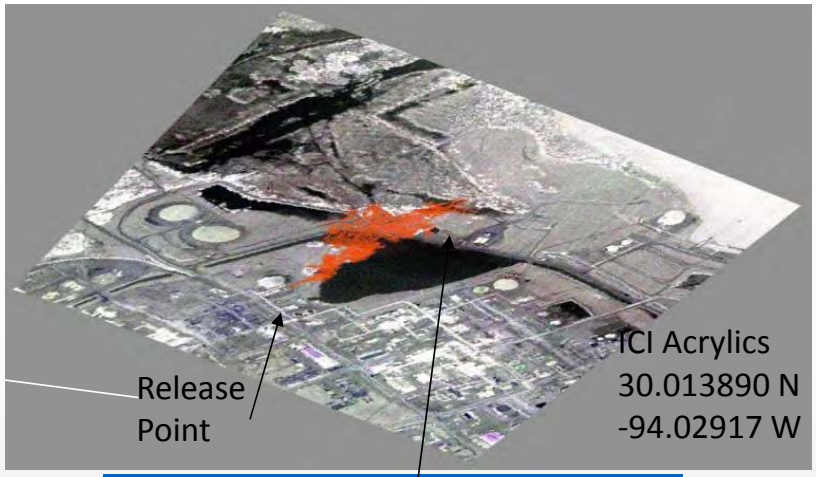
Data dissemination using Google Earth/ESRI

ASPECT
Methods of Activation

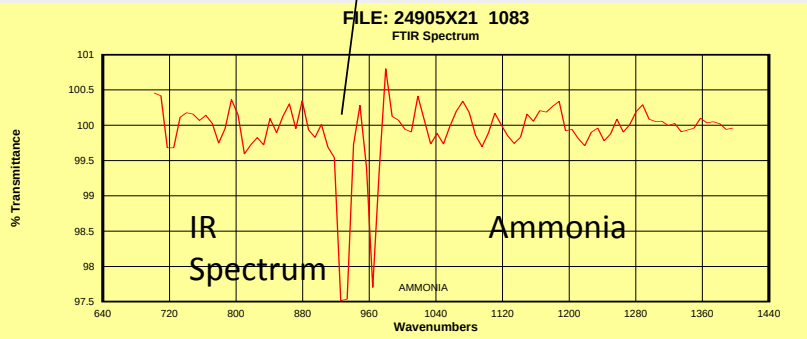


ASPECT – Hurricane RITA Response 9/24/2005

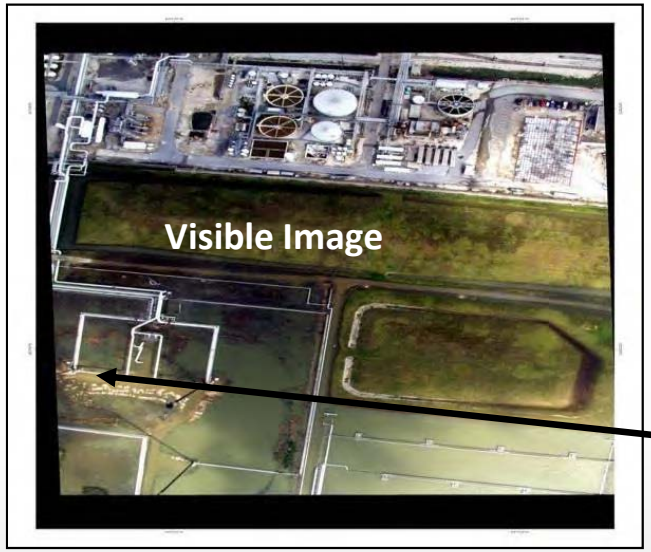




Plume Identification and Classification



ASPECT – Hurricane RITA Response 9/25/2005

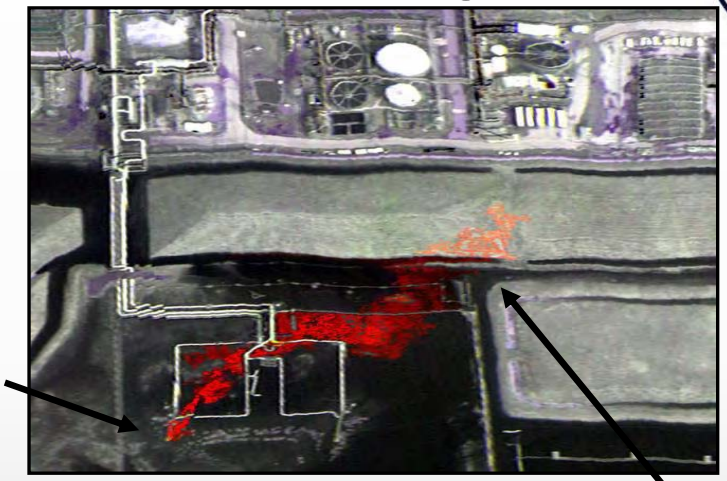


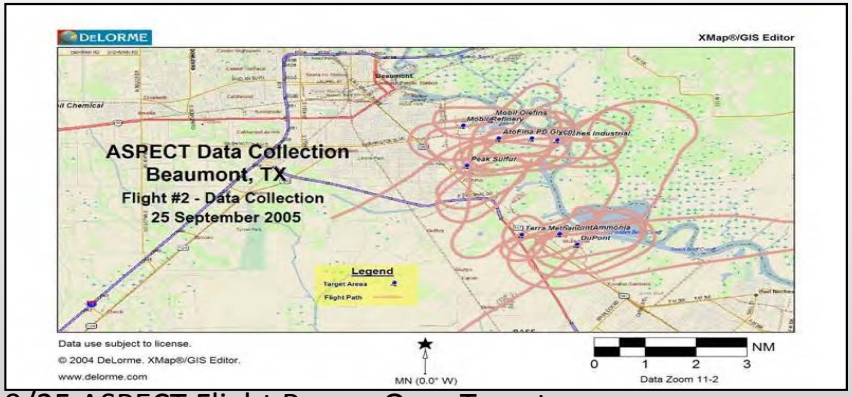
Beaumont, Texas

30.06537 N
-94.0633 W

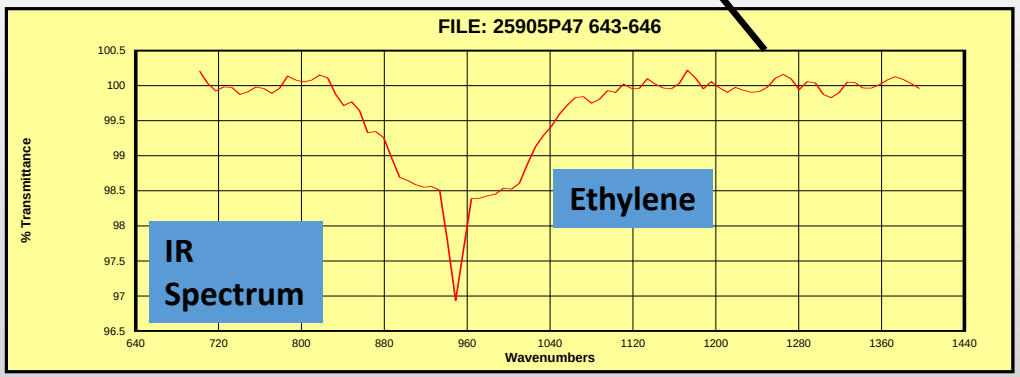
Release Point

IR Image



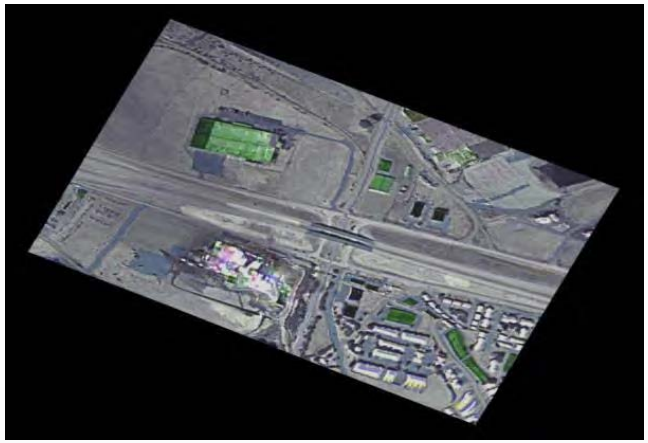


9/25 ASPECT Flight Passes Over Targets

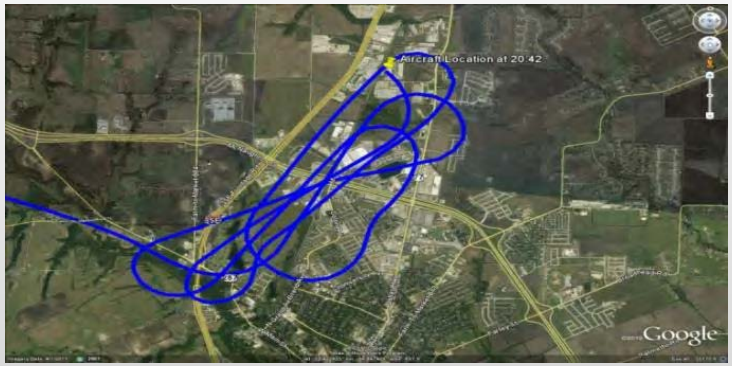


ASPECT – **Magnablend Fire – 3 Oct 2011**

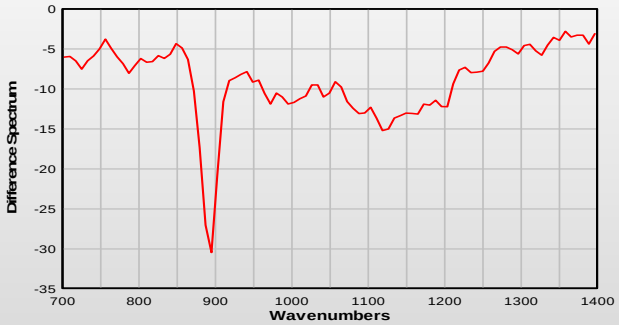
Visible Image



IR Image



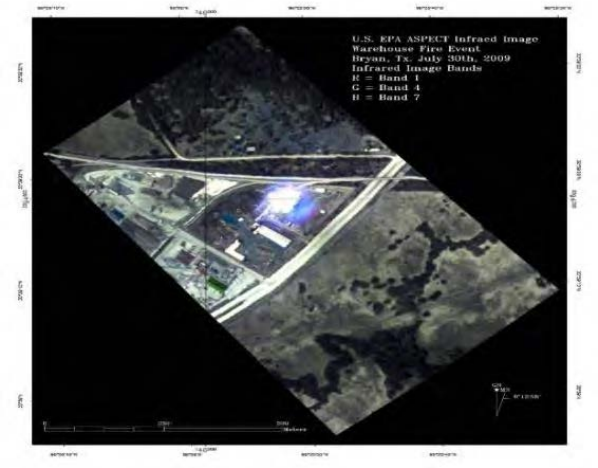
Flight Path



Isopropylene Spectrum

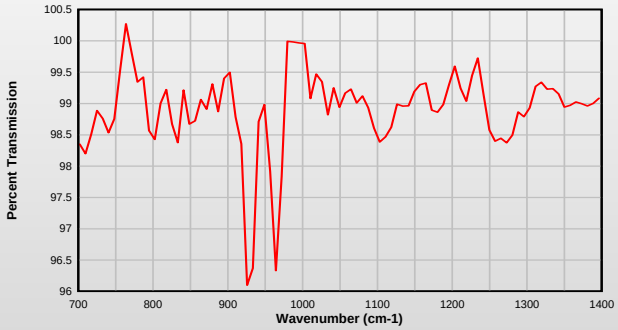
ASPECT – El Dorado Chemical Fire – 30 July 2009

Visible Image



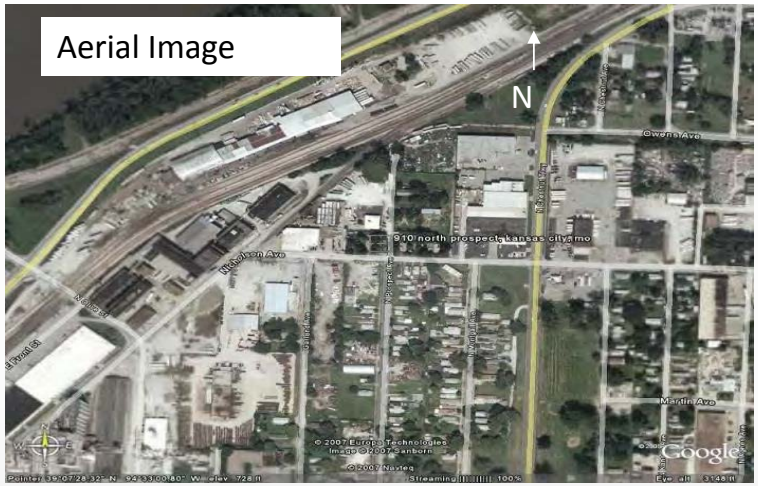
IR Image

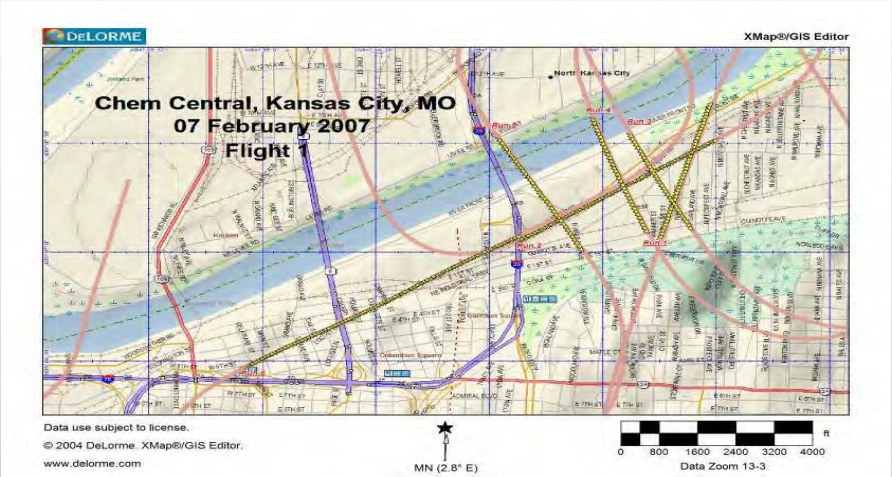
Flight Path

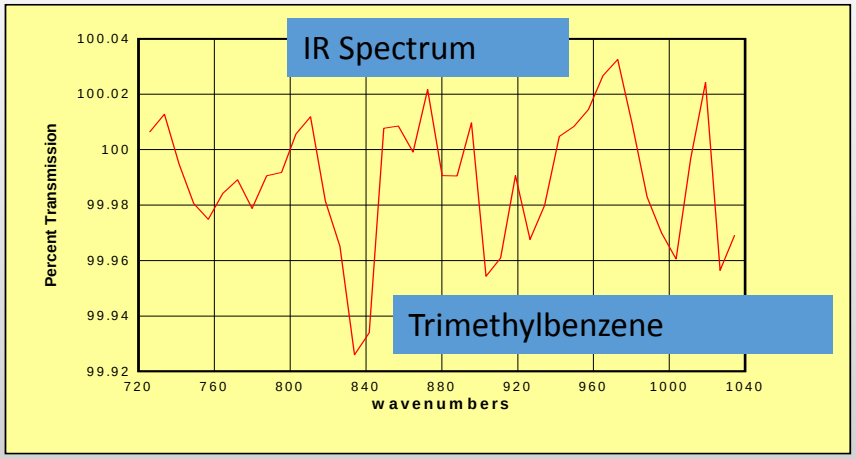


IR Spectrum

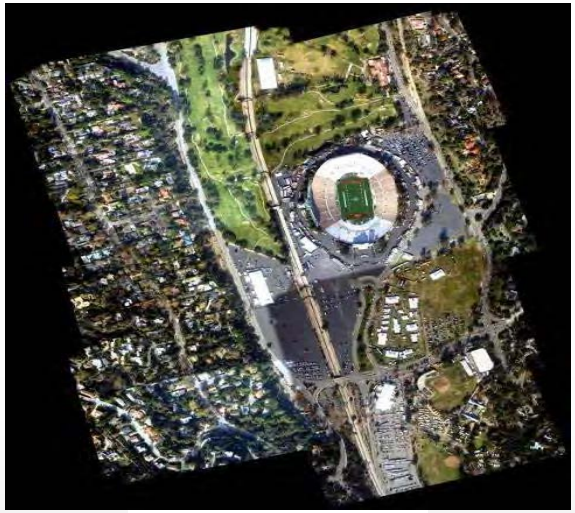
ASPECT – Chem Central, Kansas City, MO--7 February 2007





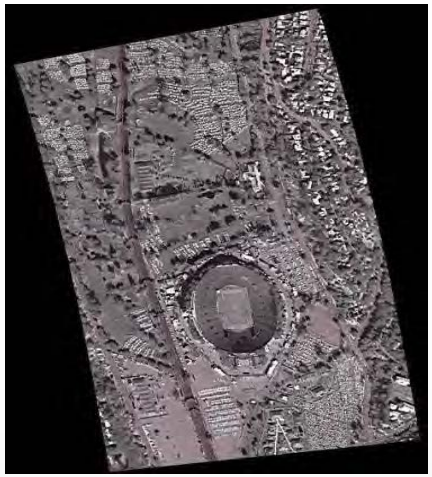


ASPECT – Rose Bowl Pasadena CA –1 January 2008

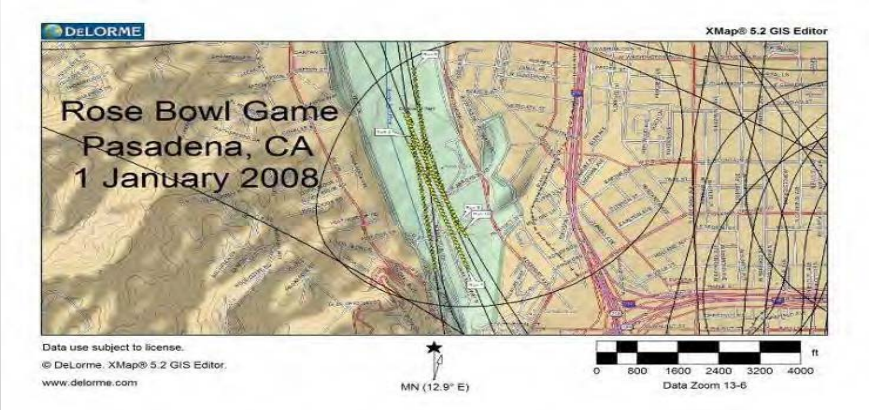


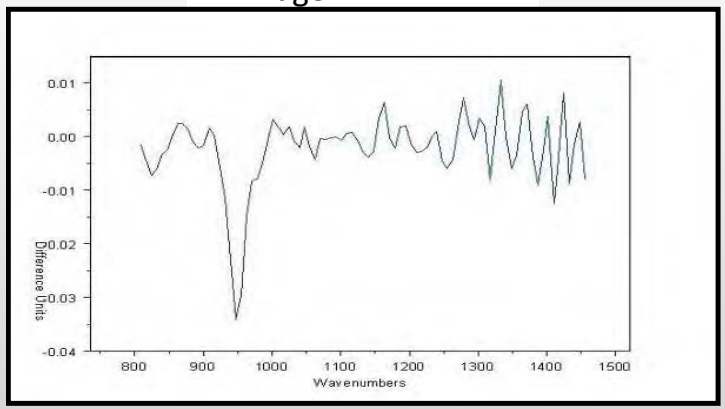
Aerial Image

N



IR Image



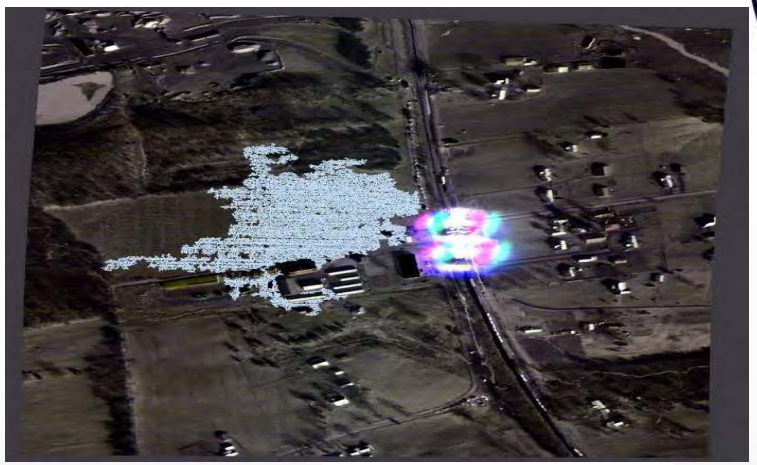


Ethylene Spectrum

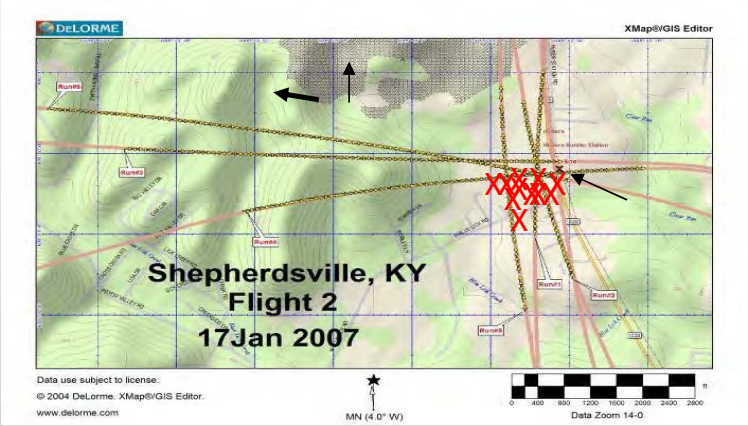
ASPECT – Shepherdsville Train Derailment -- 17 January 2008

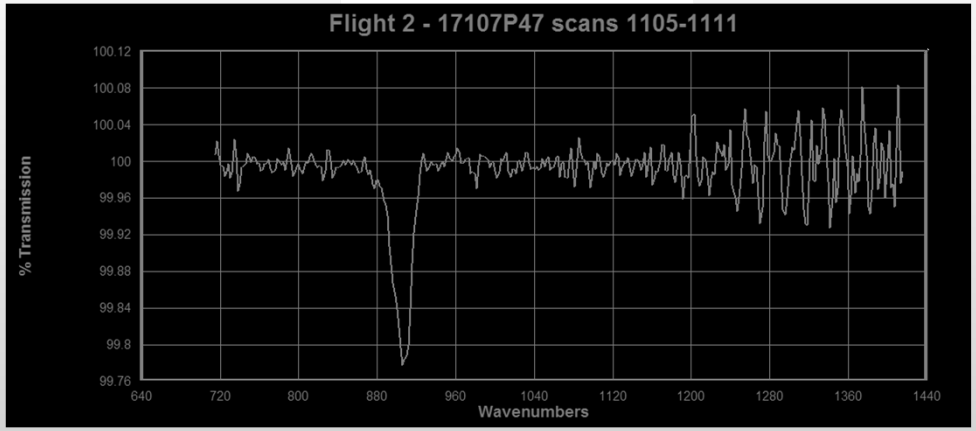
Aerial Image

N



IR Image

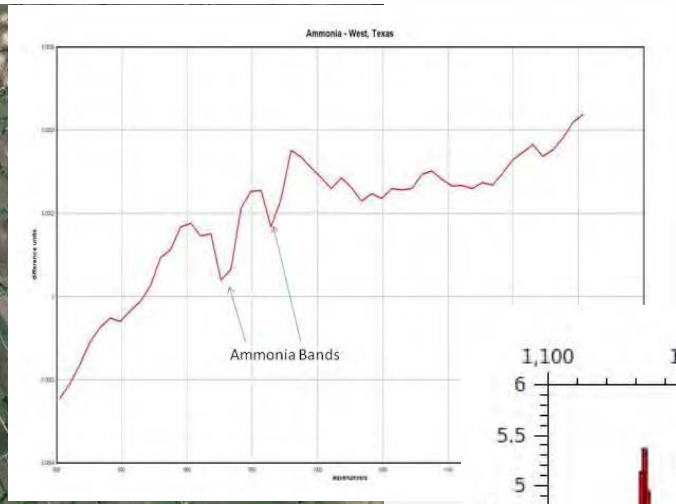


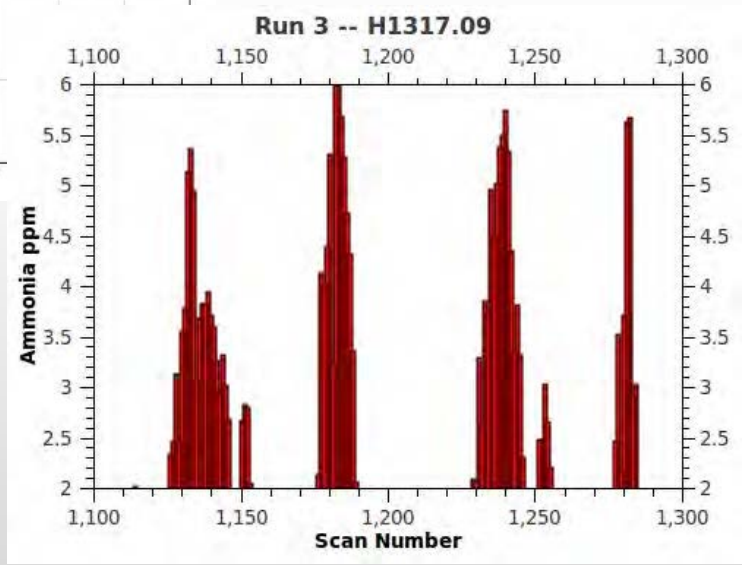


1,3-Butadiene Spectrum

ASPECT -- West, TX Explosion Response – 18 April 2013

ASPECT -- West, TX Explosion Response – 18 April 2013





18 April 2013 – 0000 Local

Contact and Readiness

Dr. Mark J. Thomas - ASPECT Program Manager

Thomas.Markj@epa.gov

CAPT John Cardarelli, PhD - ASPECT Radiological Lead

Cardarelli.John@epa.gov

Tim Curry - ASPECT Contract Management

Paul G. Kudarauskas – Chief, FOB Branch

Readiness - 24/7/365 On-Call

1 Hour Wheels-up!