DEFENCE R&D DÉFENSE

LWIR hyperspectral differential imaging for gaseous and liquid contaminations sensing

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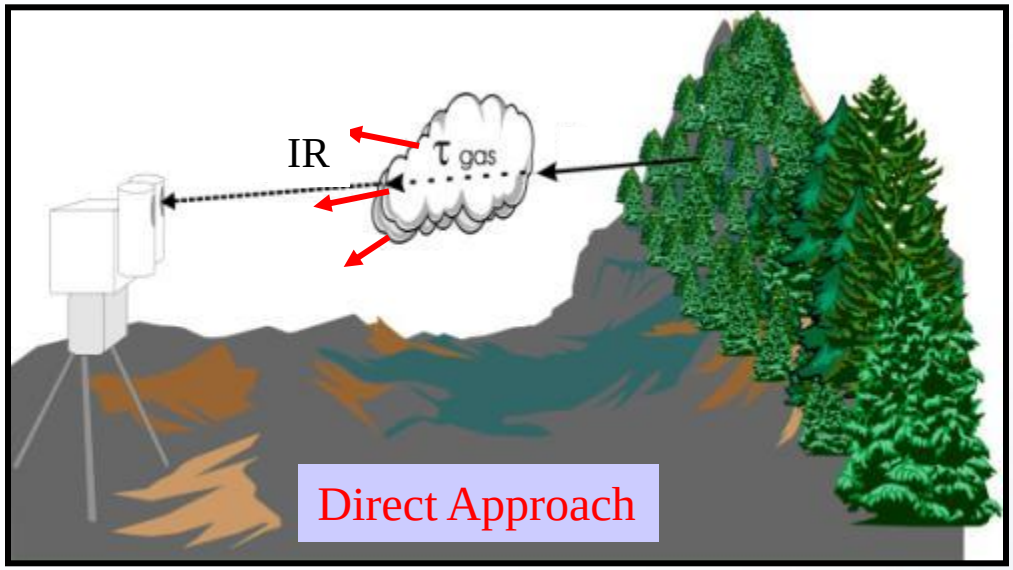
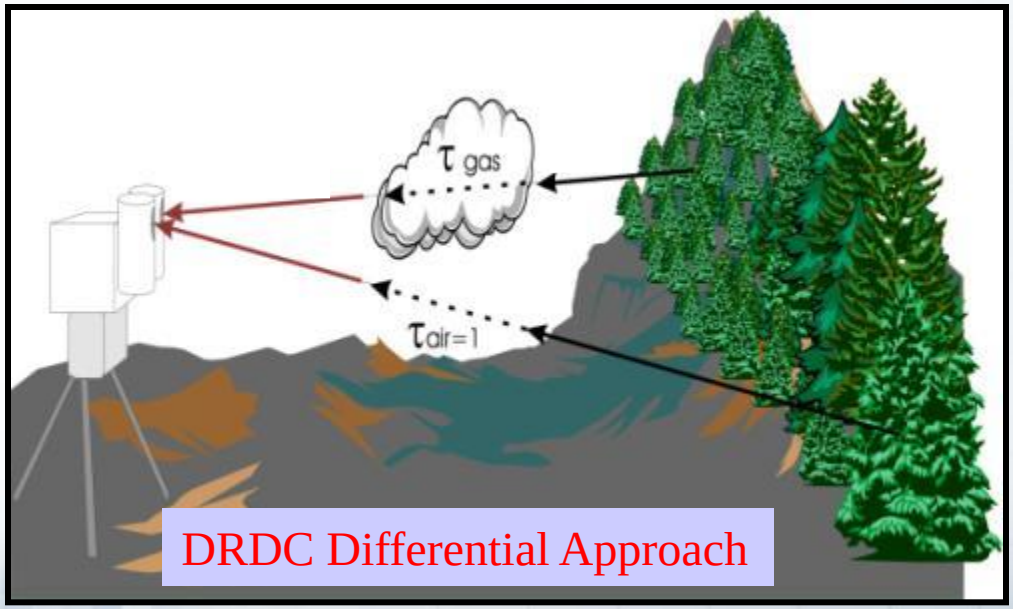
Defence Research and Development Canada
Recherche et développement pour la défense Canada
Canada

Scope of Presentation

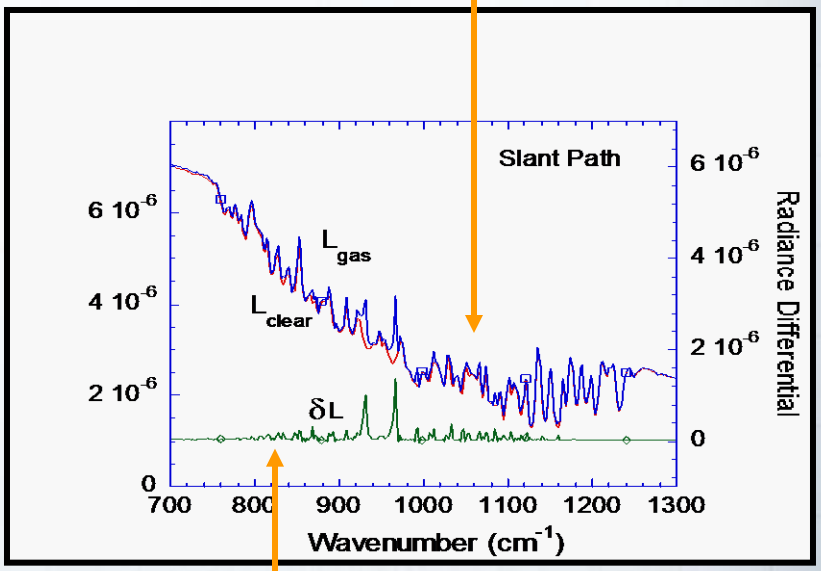
- **Differential FTIR Detection Approach**
  - Principle
  - CATSI EDM Sensor for Chemical agents and TICS
- **Differential and Imaging FTIR Approach**
  - MoDDIFS Sensor for Vapor plume Detection
  - Results
- **Differential Imaging with Polarization FTIR Approach**
  - MoDDIFS Sensor for Liquids and Solids
  - Result

Passive Infrared Spectral Sensing
Direct vs Differential Detection

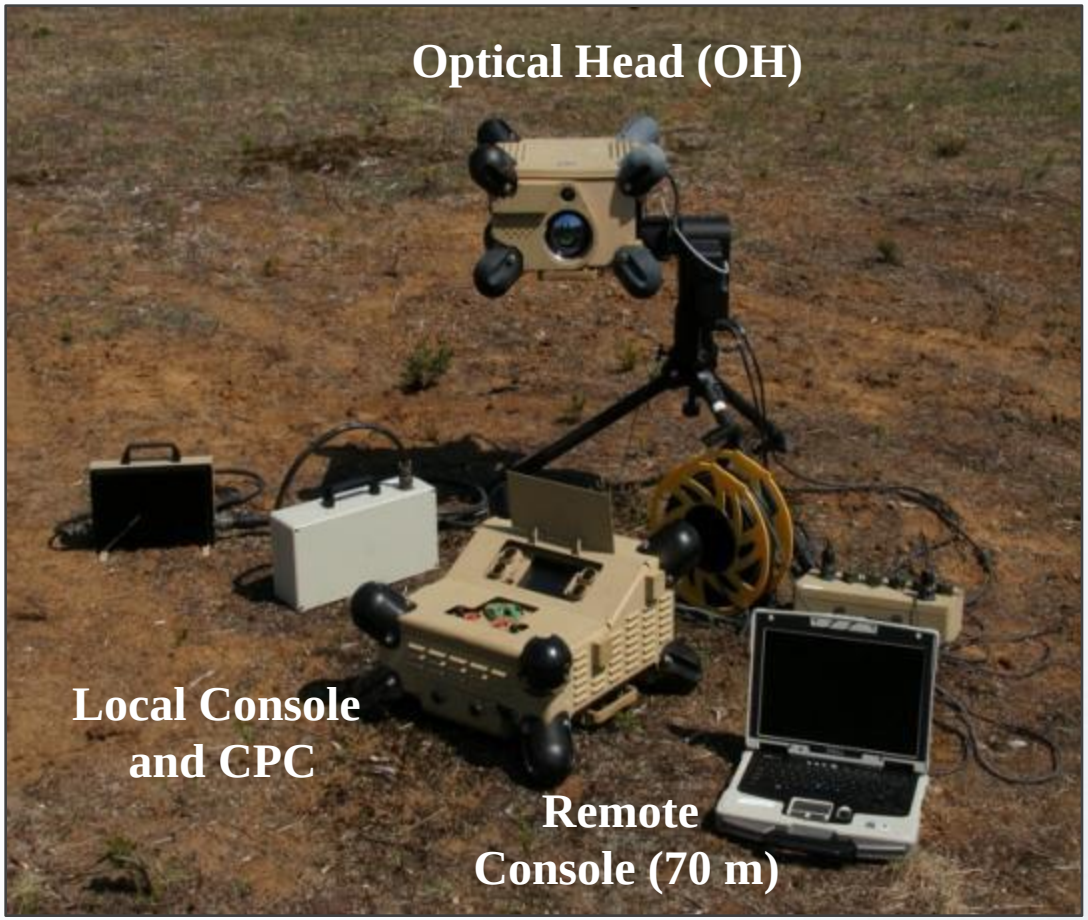




Spectroscopy



CATSI – EDM Differential Sensor Development



- CATSI Engineering Development Model (EDM)
- Development: 2005 – 2010
- Ruggedized FTIR for CAs and TICs
- Milestone: autonomous detection of chemical vapors **at 3 and 5 km ranges (2008)**

ADIS Invitational Performance Trial - Sept 2008

CATSI EDM exceeded the test requirement

3.7 km ejection point

(*300 mm lens*)

5 km ejection point

(*900 mm lens*)

3.7km	104 test events
	Probability of detection: > **80% at 95% confidence**
5 km	99 test events
	Probability of detection: > **80% at 95% confidence**

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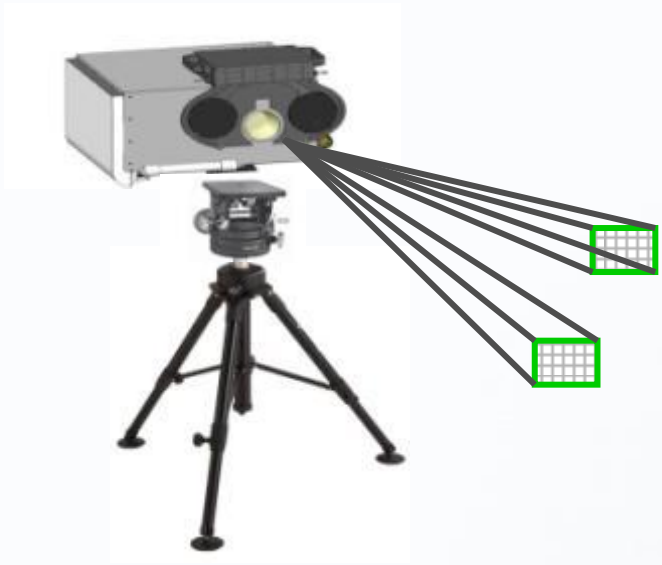
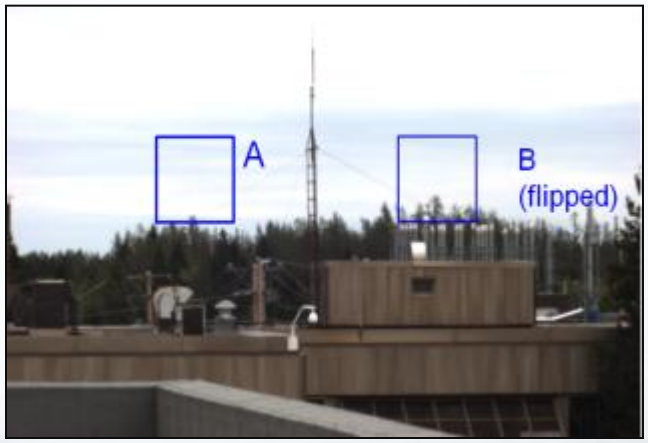
Differential and Imaging Sensor: MoDDIFS

MoDDIFS

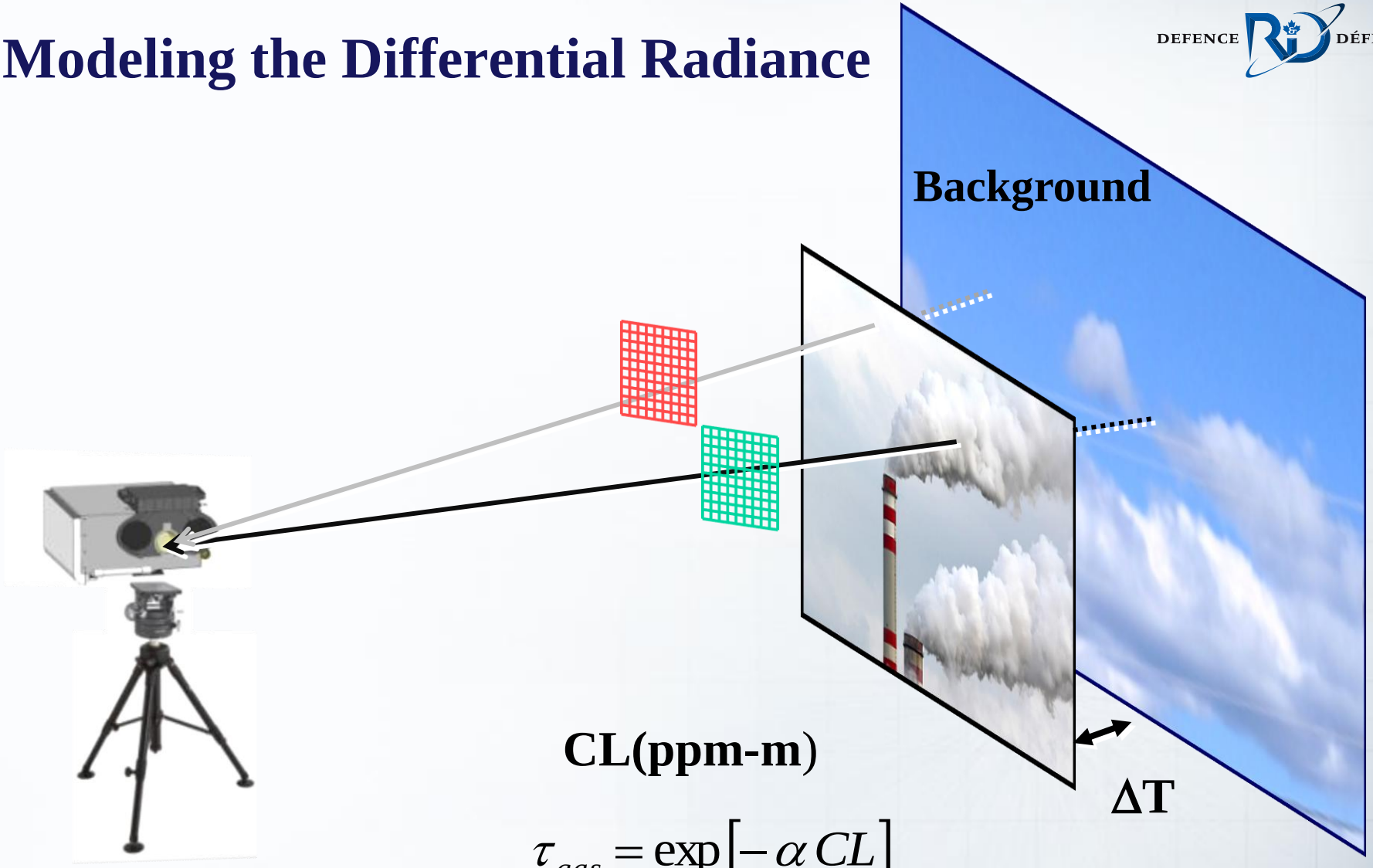




- Multi-options Differential Detection and Imaging Fourier Spectrometer (MoDDIFS)
- **Program**: CBRNE Research and Technology Initiative (CRTI)
- **Project**: CRTI 07-0179RD
- **Timeline**: 2008 to 2011
- **Objectives**: Remote detection and identification of
  - Primary: Precursor vapors and TICs
  - Parallel: Liquid and Powder Spills
- **Partners** and end-users:

- Defence R&D Canada
- Public Safety Canada
- Canadian Forces
- Montreal Port Authority
- Royal Canadian Mounted Police (RCMP)
- Montreal Advisory Comittee on Antiterrorism
- HAZMAT Division – Montreal
- Industries: Telops, AEREX

Modeling the Differential Radiance



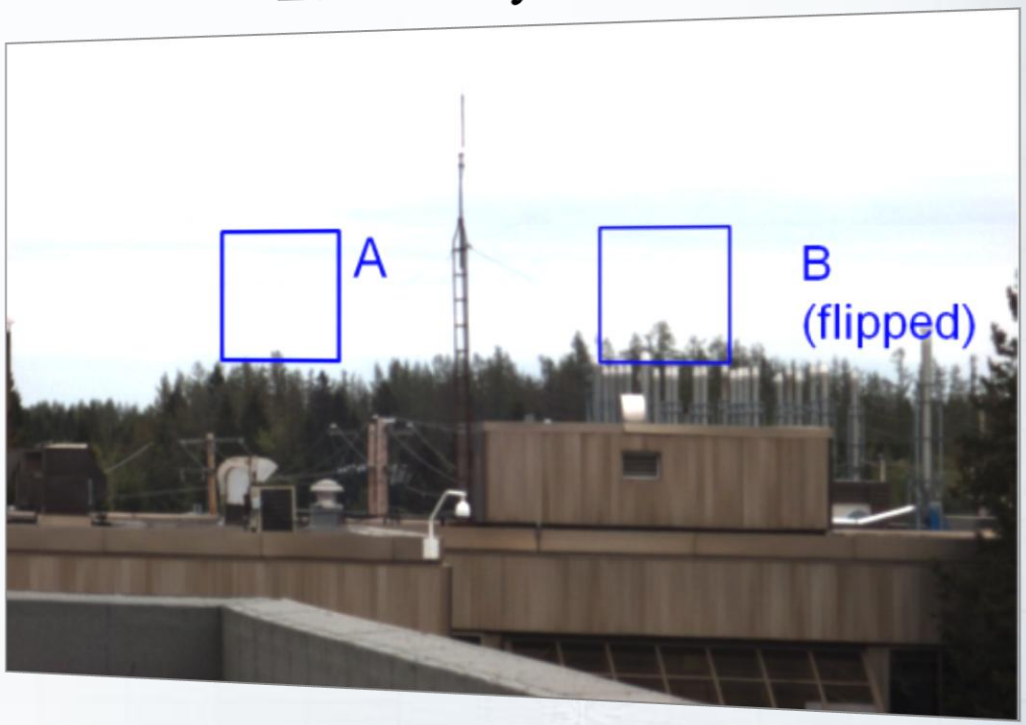
$$\tau_{gas} = \exp\left[-\alpha CL\right]$$

$$\delta L_{calc} = \Delta L_{clear} + f\left(1-\tau_{gas}\right)\left(\left(B_{gas}\tau_{near} + L_{near} - L_{clear}\right) - \Delta L_{clear}\right)$$

Gas Detection: 250 m stack

MoDDIFS

Laboratory Stacks

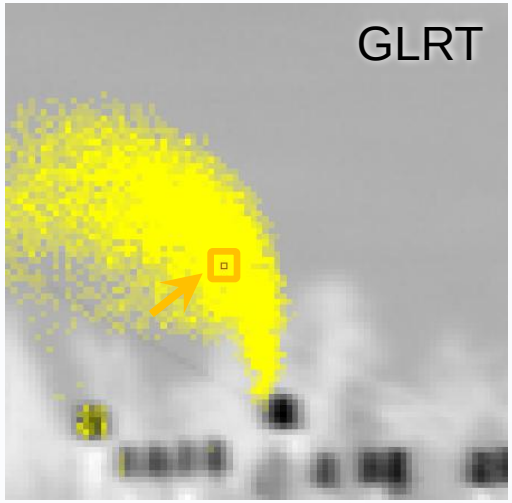


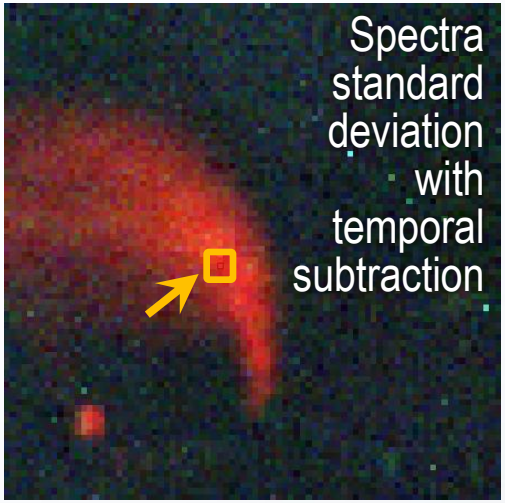
- MoDDIFS looking at stacks located at 250 meters

- Chemical vapours generated in a fumehood operating with a high volume air flow of 100 cfm

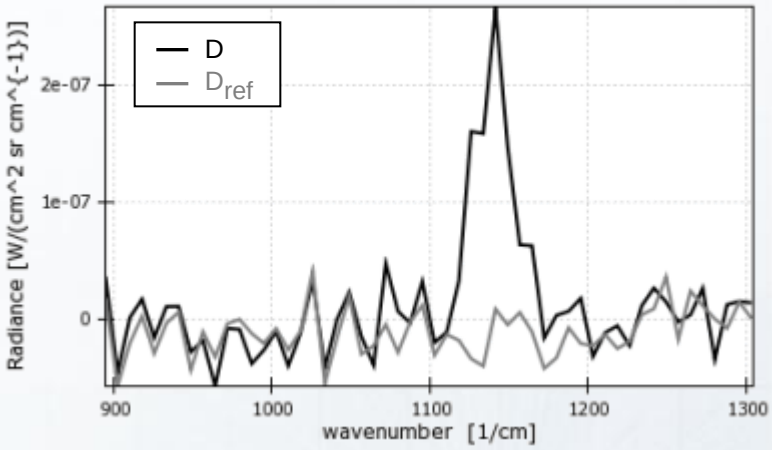
Fumehood

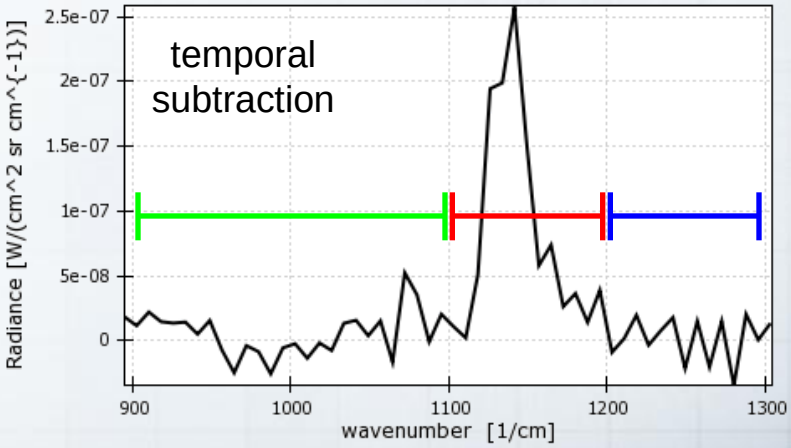
Initial Test: Chimney – Diethyl Ether





Spectrum of pixel (44,47)





Detection Algorithm: GLRT (Generalized Likelihood Ratio Test)

$$GLRT = \frac{\left\| P_B^{\perp} m \right\|^2}{\left\| P_{BS}^{\perp} m \right\|^2}$$

- **Numerator:** squared norm of measurement projected **out of the background space** (background suppression)
- **Denominator:** squared norm of measurement projected **out of the background + signature space** (background and signature suppression)
- **Around 1** if no signature is present in measurement; strictly positive

Detection Summary (Chimneys)

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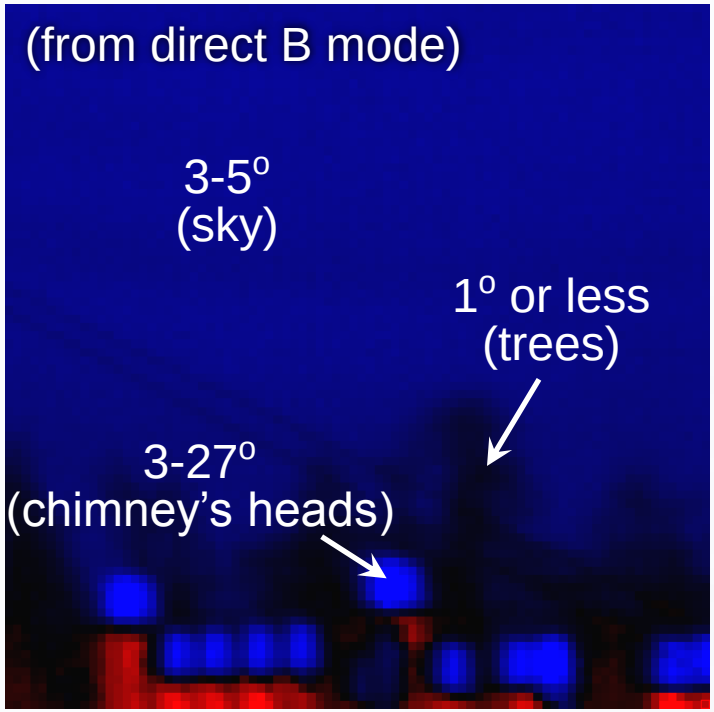
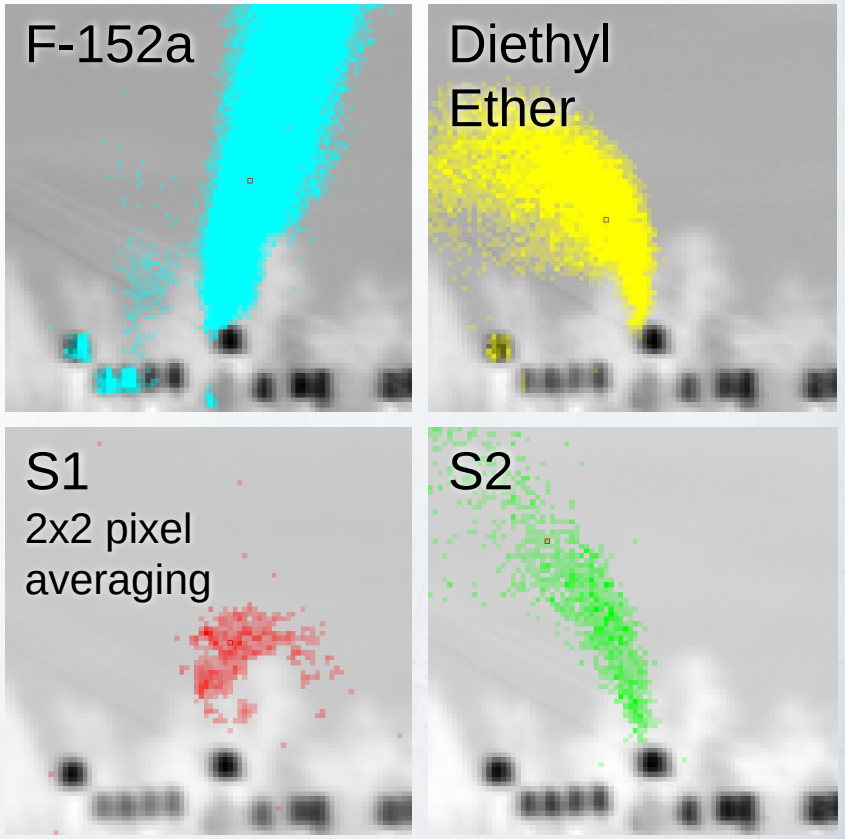
Temperature difference ΔT



blue: background colder than air
red: background hotter than air
dark: small ΔT

GLRT

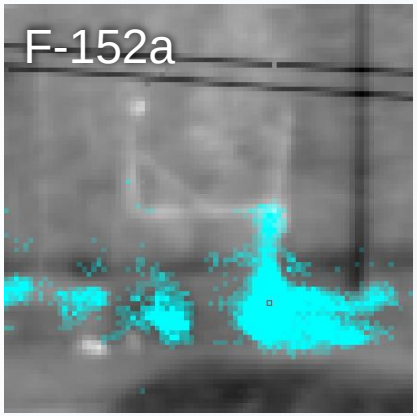


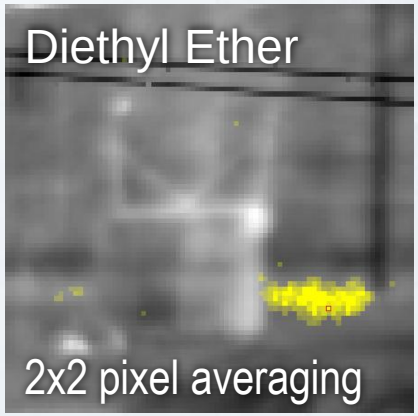
Detection is higher towards the sky than towards the trees

SNR vs Detection

Solvents	PPM	SNR Simulation	MoDDIFS Detection
S1	8200	1.6	YES
S2	1850	0.2	NO
Diethyl Ether	2150	2.2	YES
Difluroethane (F152a)	18000	6.3	YES
S5	3600	2.5	YES
S6	260	0.01	NO

Other detection results: 450 m





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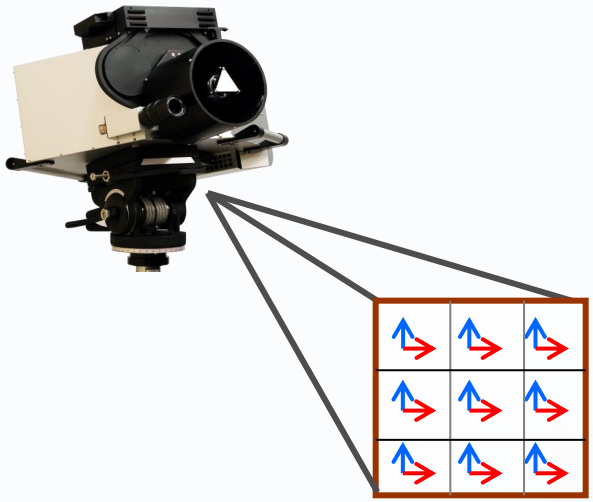
Differential and Imaging Sensor: MoDDIFS

MoDDIFS-Polarization



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- **Program**: CBRNE Research and Technology Initiative (CRTI)
- **Project**: CRTI 07-0179RD
- **Timeline**: 2008 to 2011
- **Objectives**: Remote Sensing
  - Application-1: Precursors and TICs
  - Application-2: Liquids and Solids
- **Partners** and end-users:

- Defence R&D Canada
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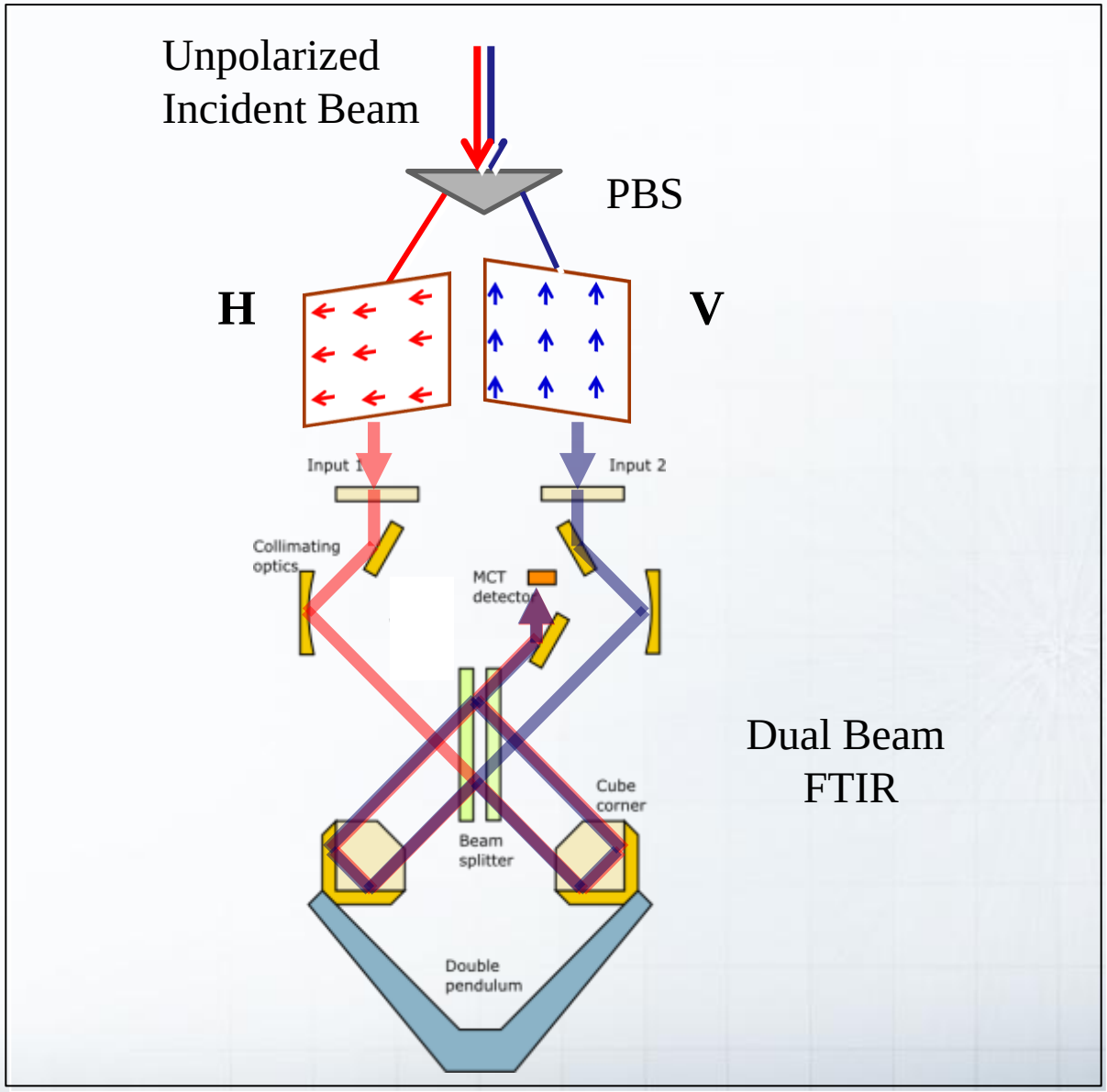
MoDDIFS Polarization



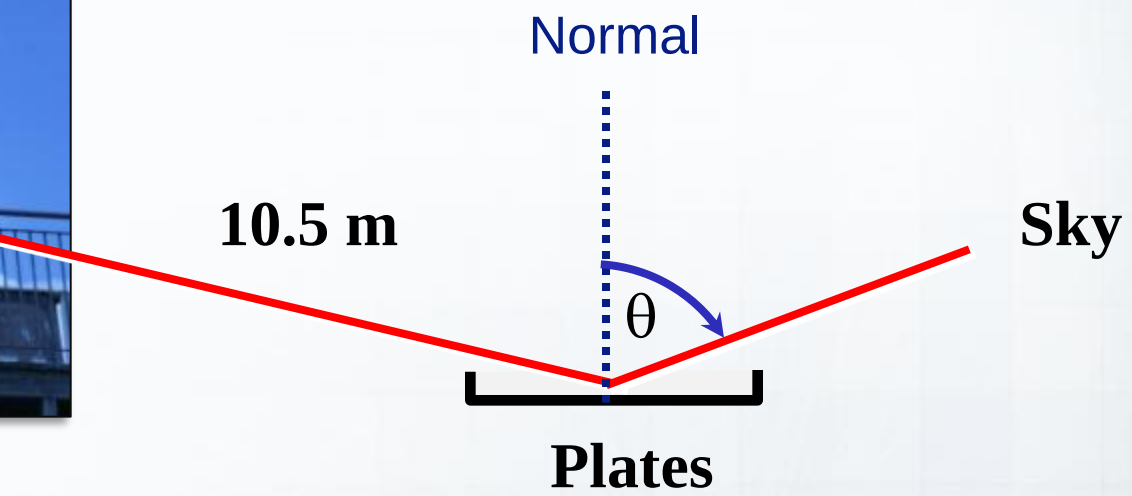
MoDDIFS Option 2: Short Range Polarization Sensing

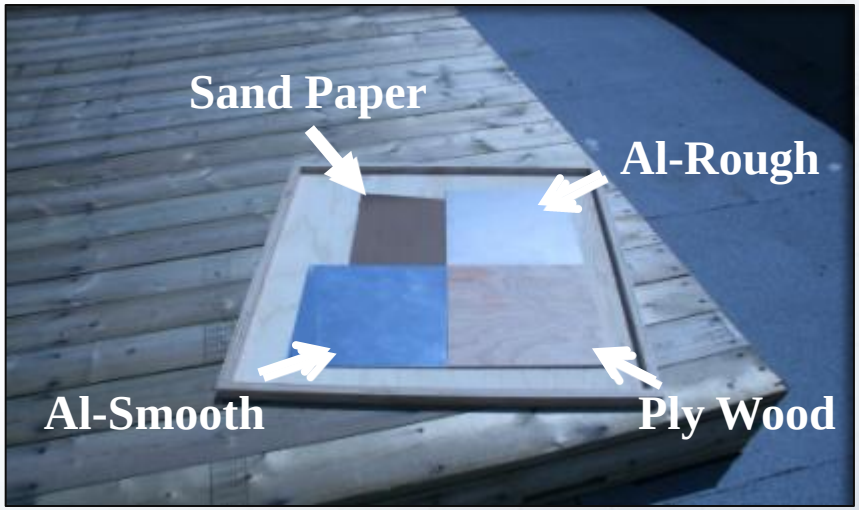
Parameter	Units	Value
Working distance	m	5 to ≥ 20
FPA Window Size	pixel x pixel	84 x 84
iFOV	mrad	0.1
FOVs (horiz. x vert.)	mrad x mrad	8.4 x 8.4
$\Delta FOV_{center\text{-}center}$	mrad	0 (none)
Vignetting/Obscuration	%	~20%

1 mm @ 10 m

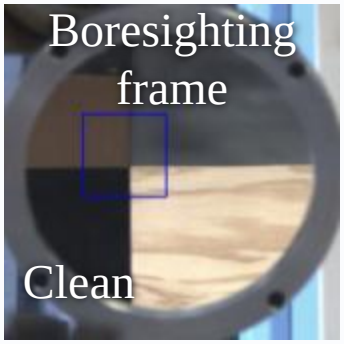
Differential polarization

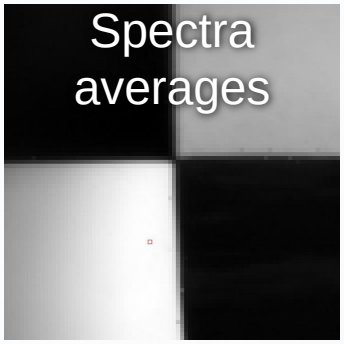
Lab. and Outdoor Measurements

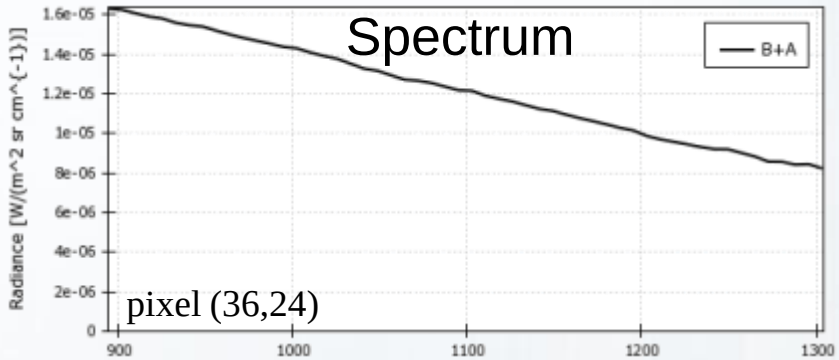


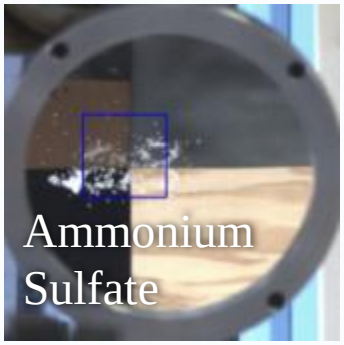


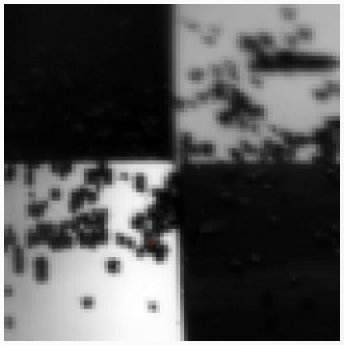
Lab. Measurement: Ammonium Sulfate

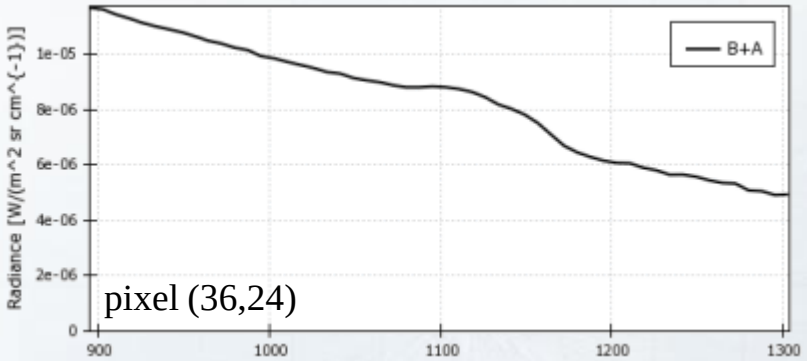


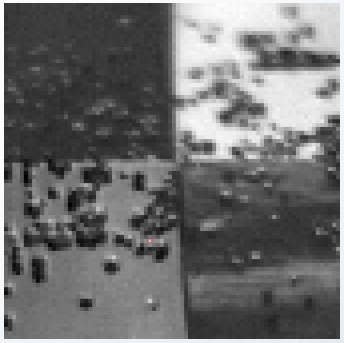


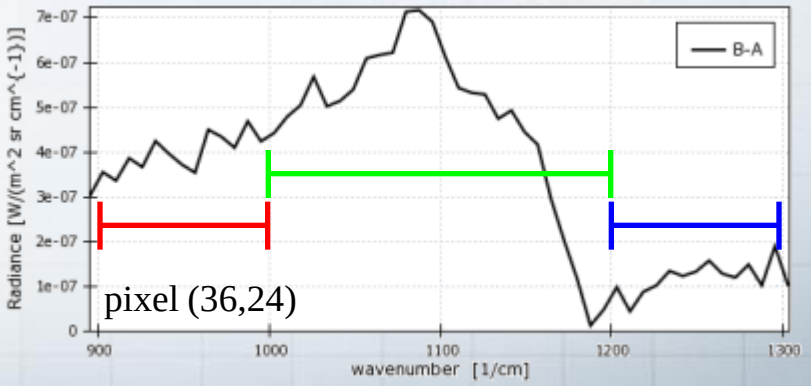






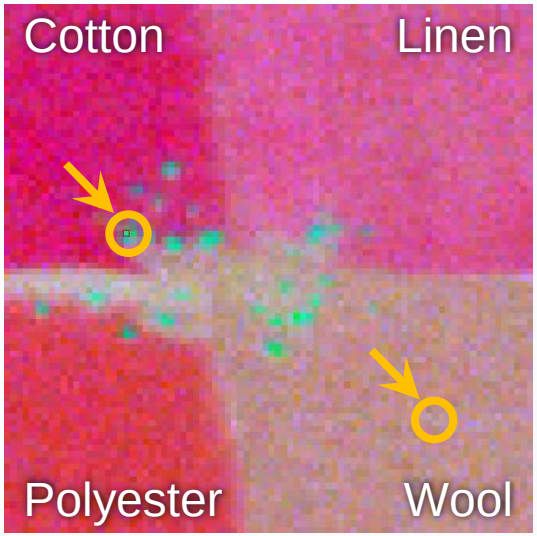






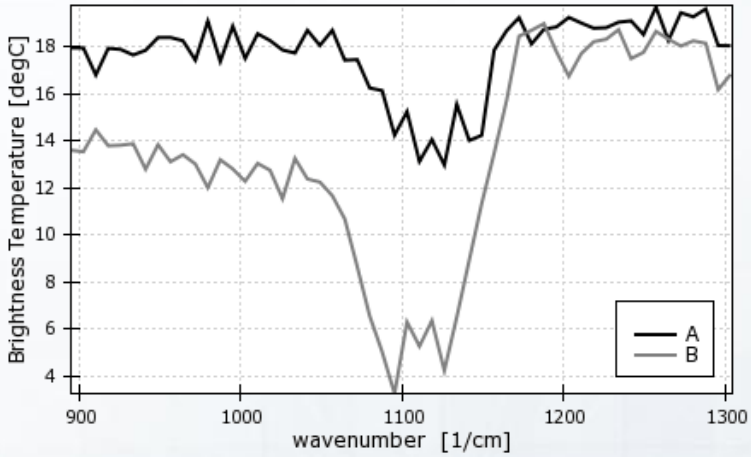
Ammonium Sulfate – Outdoors

spectra
standard deviation

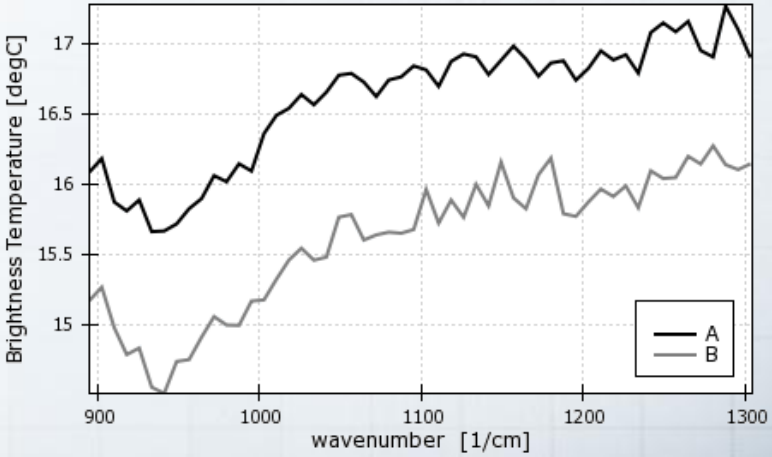


red: 1100-1200 cm^{-1}
green: 900-1100 cm^{-1}
blue: 1200-1300 cm^{-1}

Ammonium Sulfate

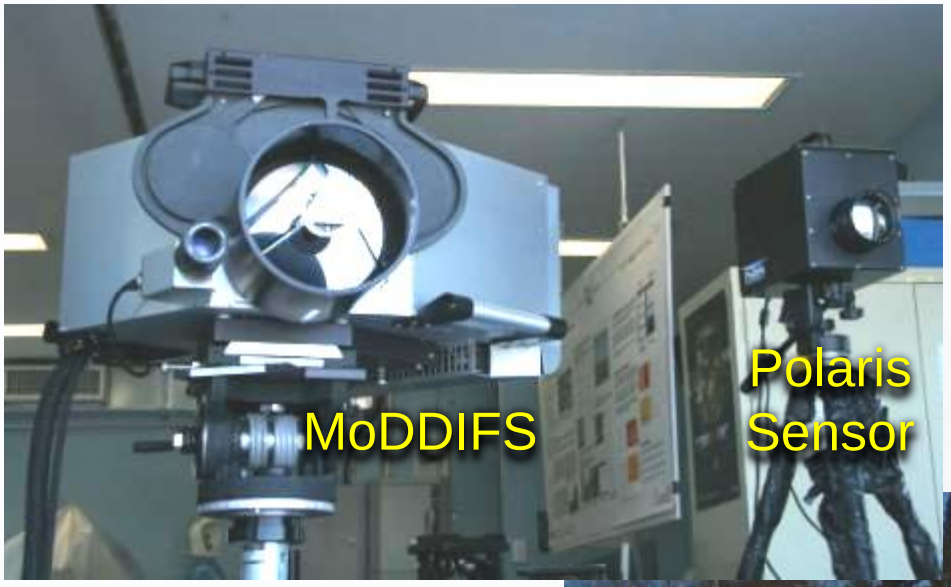


Wool

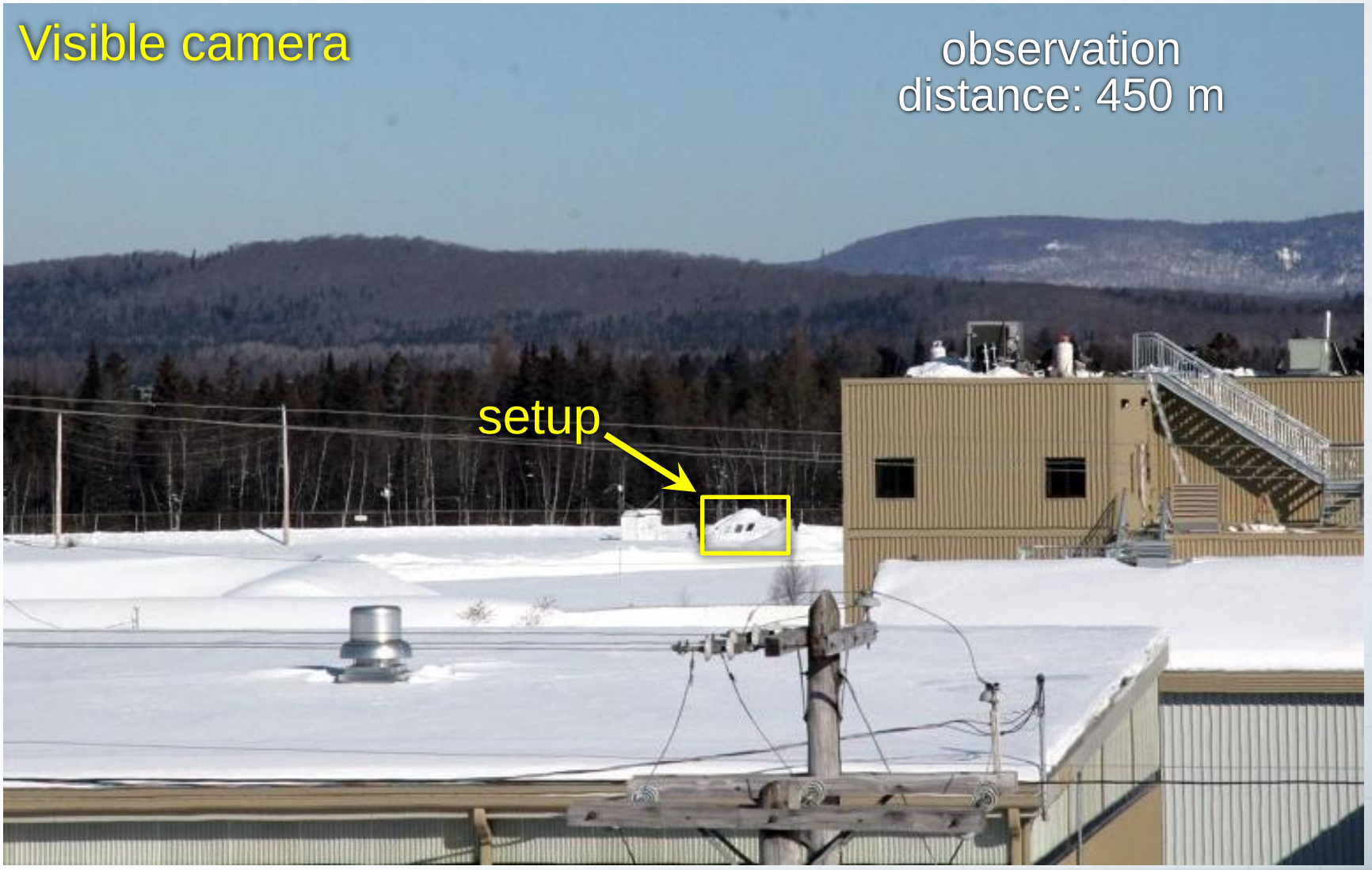


Polarization Sensing in the Field

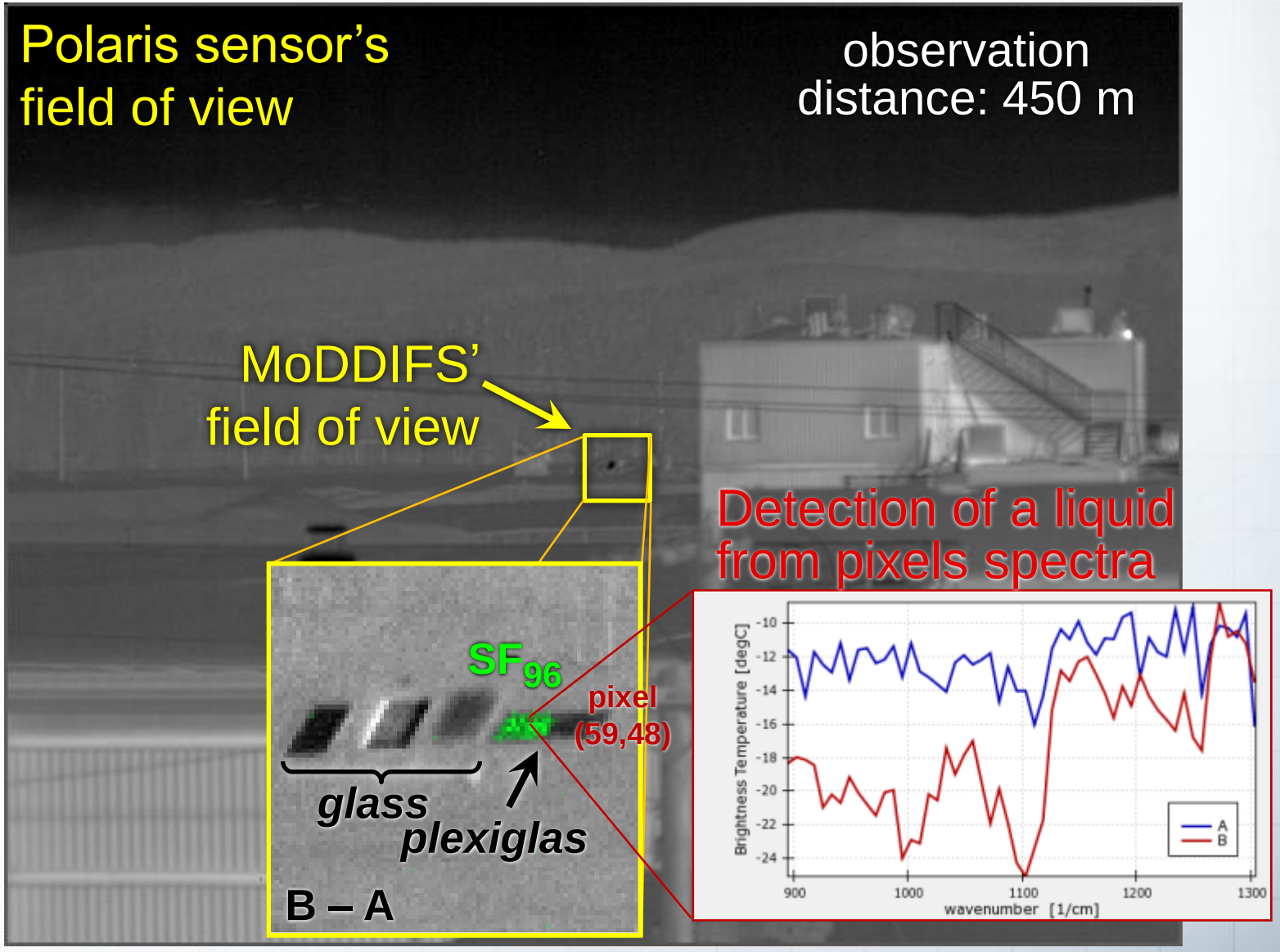
Mound of snow – Sensors and Setup



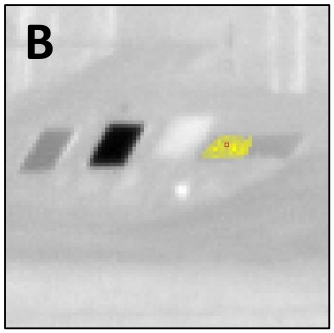
Mound of snow – Visible view

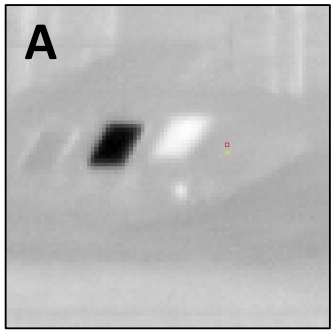


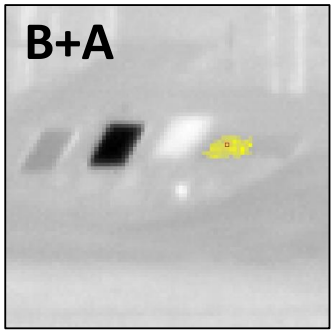
Mound of snow – Infrared radiance

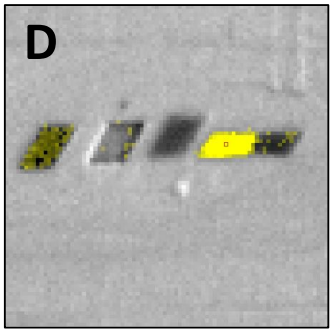


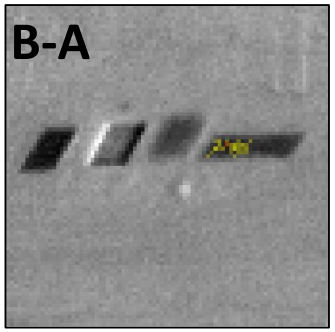
Detection of SF96 on Plexiglas

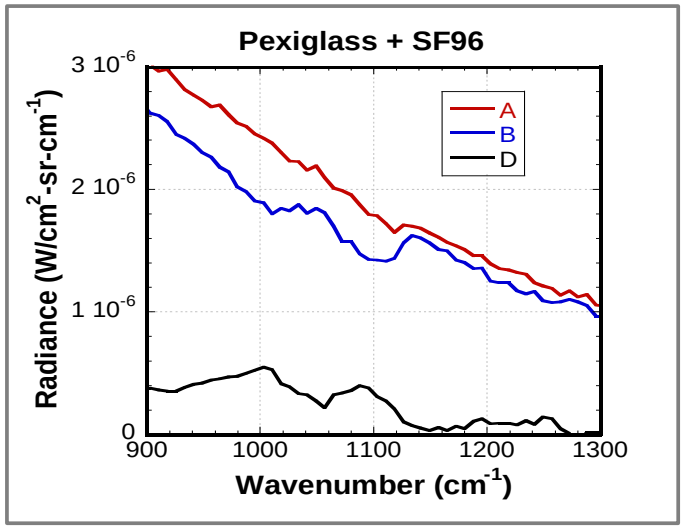












Sensing mode	GLRT score [σ] (snow)	GLRT score [σ] (snow / sky)	Signature Angle [°]
A	10	11	55
B	36	120	55
B+A	36	77	55
D	176	134	55
B-A	21	23	55

LWIR hyperspectral differential imaging for gaseous and liquid contaminations sensing

Summary and Conclusion

- MoDDIFS is a unique Imaging FTS for plume and polarisation sensing
- Capability includes
  - Real-time calibration
  - Real-time GLRT detection/imaging
- Measurements of CL for solvents agree well with calculations
- Measurements on various substrates, liquids and powders show potential for D and DoLP

Collaborators

DRDC Valcartier

- ***Jean-Marc Thériault***
- *Hugo Lavoie*
- *Francois Bouffard*
- Eldon Puckrin
- Denis Dubé
- Sylvain Désilets
- Daniel Chamberland
- Eric Bergeron
- Gaston Nadeau

AEREX

- *Paul Lacasse (DPM)*
- ***Gilles Fortin***
- Nicolas Bédard-Maltais
- [1],

Telops

- Alexandre Vallieres
- Yan Montembeault
- Marc Duval
- Martin Chamberland

QUESTIONS

?

J.-M. Thériault et al., " *CATSI EDM – A New Sensor for the Real-Time Passive Stand-off Detection and Identification of Chemicals*'', SPIE Conference Proceedings SPIE 7665-38, April 2010

J.-M. Thériault et al., " *A Novel Sensor for Passive Standoff Detection of Explosives and Explosive Precursors*'', SPIE Conference Proceedings, SPIE 8018-59, April 2011

" *CAT on a hot TICs roof: Dr. Jean-Marc Theriault Leader Passive CBRNE Threat Detection Group for DRDC Valcartier, tells Gwyn Winfield about the latest litter of Stand-off detectors*", CBRNe World Magazine, UK, pg. 84-87, Autumn 2010