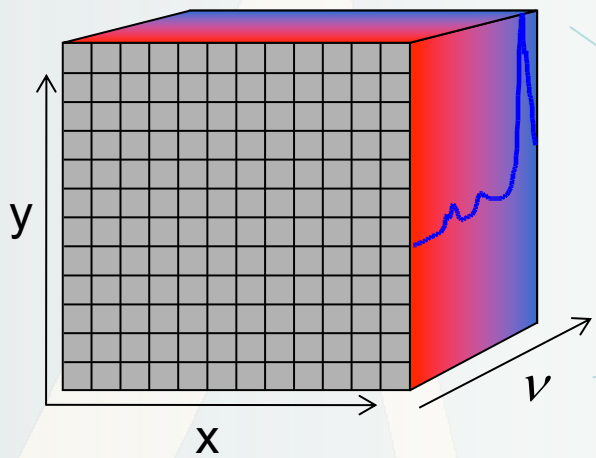
Passive Standoff Detection of Solid Explosive Residues on Soil via Infrared Hyperspectral Imaging

Neal B. Gallagher
Eigenvector Research, Inc.
James F. Kelly, Thomas A. Blake
Pacific Northwest National Laboratory
nealg@eigenvector.com

EIGENVECTOR RESEARCH INCORPORATED

Objective

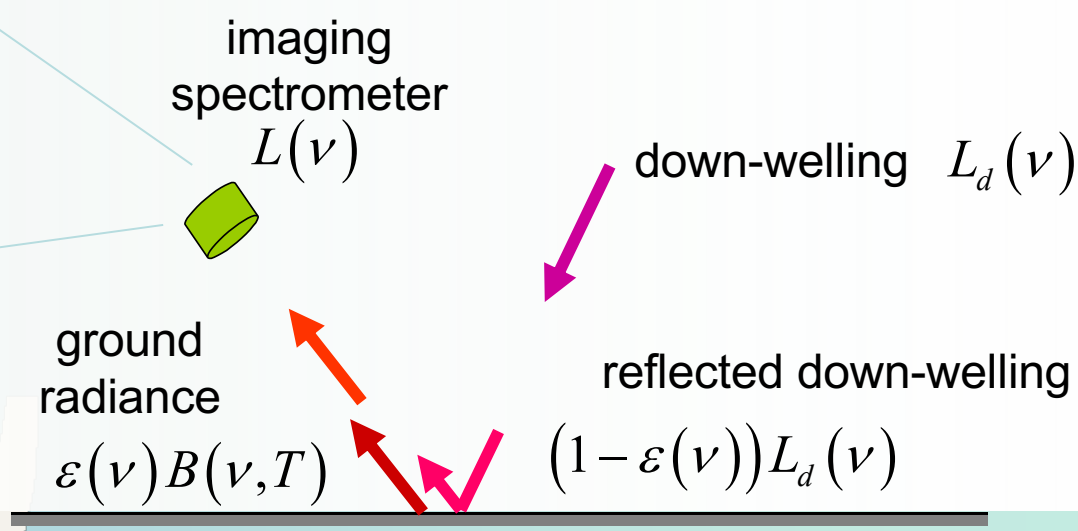
- Detection of explosive residues on, and possibly under, soil at standoff distances using hyperspectral imaging



Pixels → Spatial Information

Spectral → Chemical Information

$$L = \varepsilon B(T) + (1-\varepsilon) L_d$$



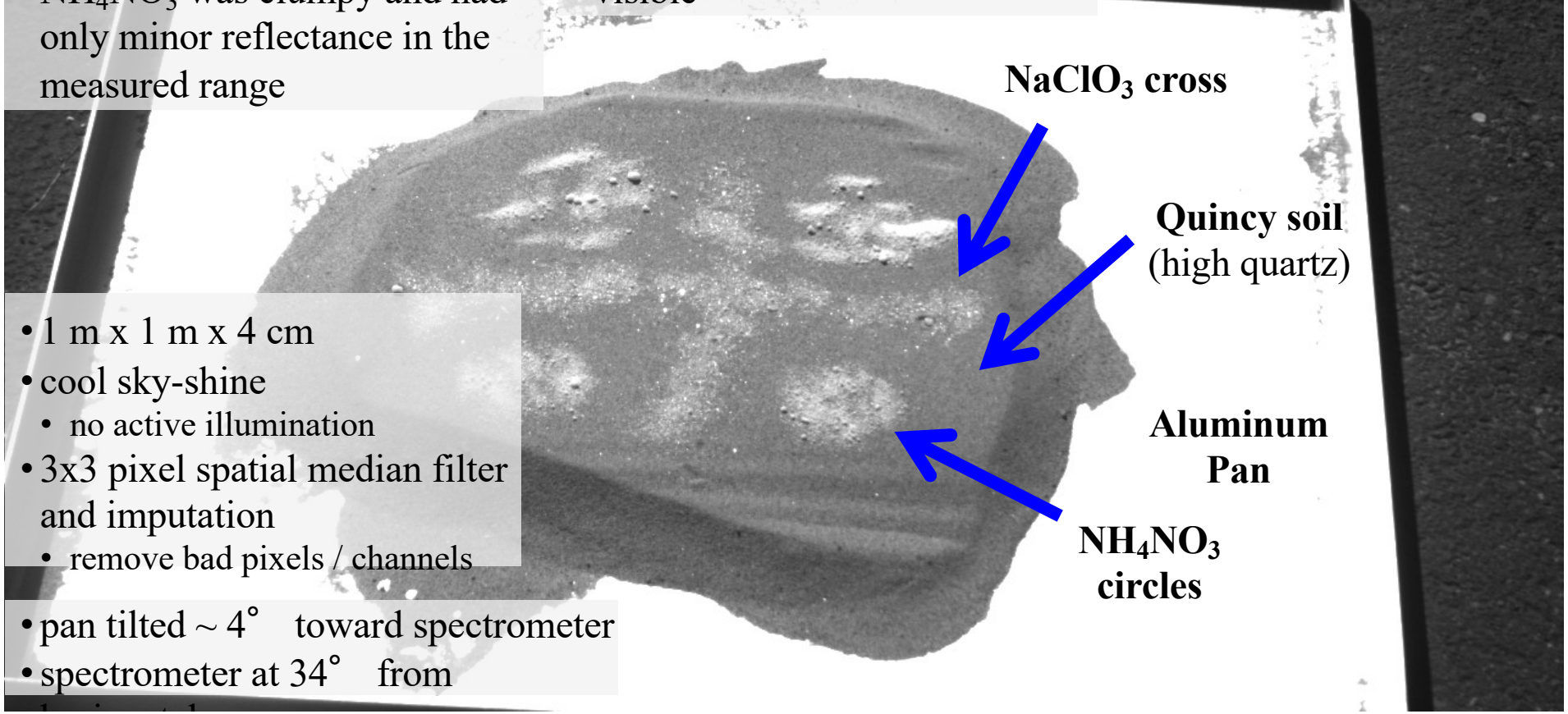
EIGENVECTOR RESEARCH INCORPORATED

Image	Acquisition Date	Acquisition Time	Temp. Amb. (K)	Target (mg/cm^2)
a	7/18/08	5:11 PM	313	blank
b	7/18/08	2:45 PM	308	$NaClO_3$ 37
c	**7/18/08**	**4:06 PM**	**310**	**$NaClO_3$ 37, NH_4NO_3 55**
d	7/18/08	4:35 PM	312	$NaClO_3$ 37, NH_4NO_3 55, 1 mm of soil deposited over targets
e	7/18/08	4:52 PM	313	$NaClO_3$ 37, NH_4NO_3 55, 3 mm of soil deposited over targets

Distance = 3.25 m
Image = 256 x 320 pixels
Freq. Range = 1297-880 cm^{-1}

- $NaClO_3$ was a very fine powder with a strong reflectance in the measured range
- NH_4NO_3 was clumpy and had only minor reflectance in the measured range

- ~3 mm of soil covered the majority of the targets
- only the largest clumps are visible

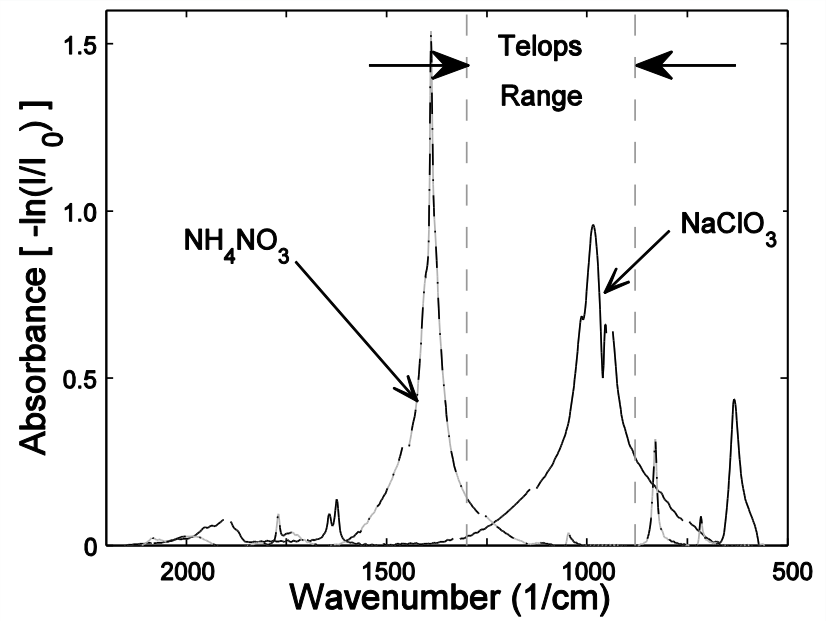


- 1 m x 1 m x 4 cm
- cool sky-shine
  - no active illumination
- 3x3 pixel spatial median filter and imputation
  - remove bad pixels / channels

- pan tilted ~ 4° toward spectrometer
- spectrometer at 34° from

Transmission Spectra of Targets

NH_4NO_3 has very little signal in the measured range: reststrahlen shoulder in the 1300 to 1250 cm^{-1} range and a minor peak at 1094 cm^{-1}

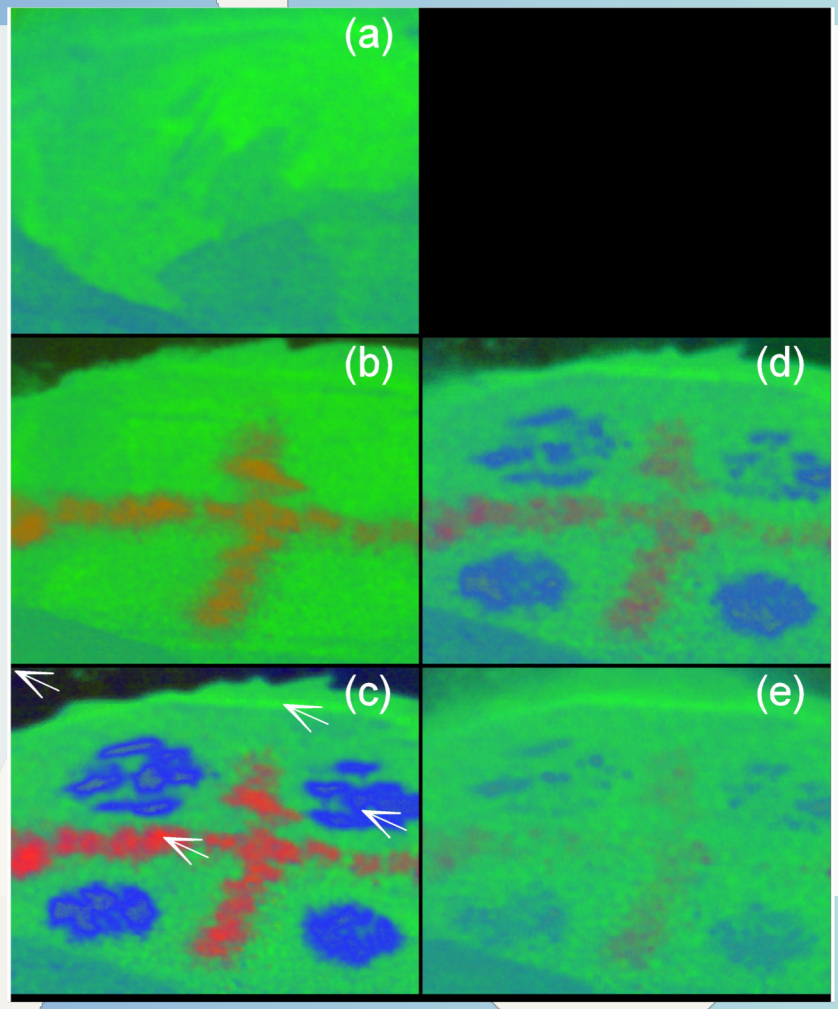


$NaClO_3$ has strong reststrahlen feature over the entire measured range. Peaks observed at 972, 939 and 1005 cm^{-1}

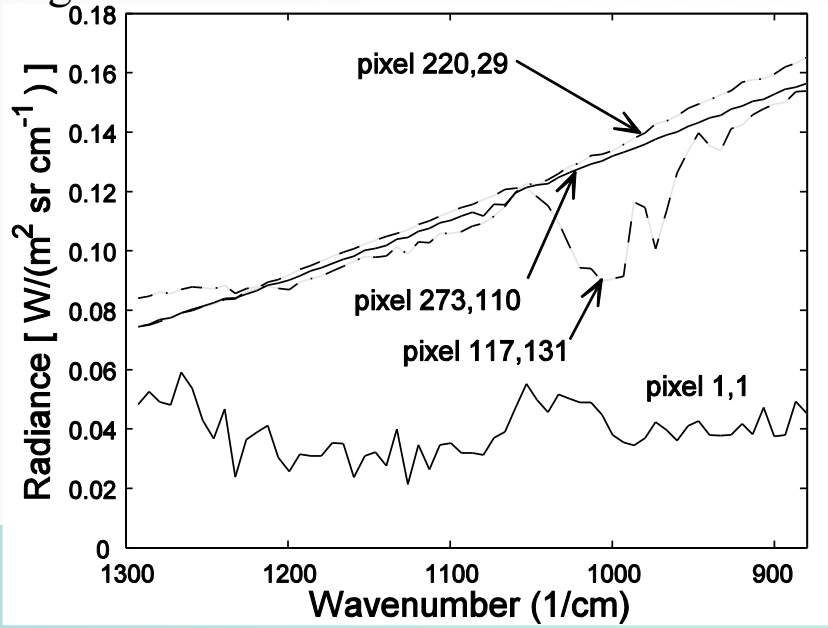
Water is present for >1300 cm^{-1}

EIGENVECTOR RESEARCH INCORPORATED

End-Member Extraction

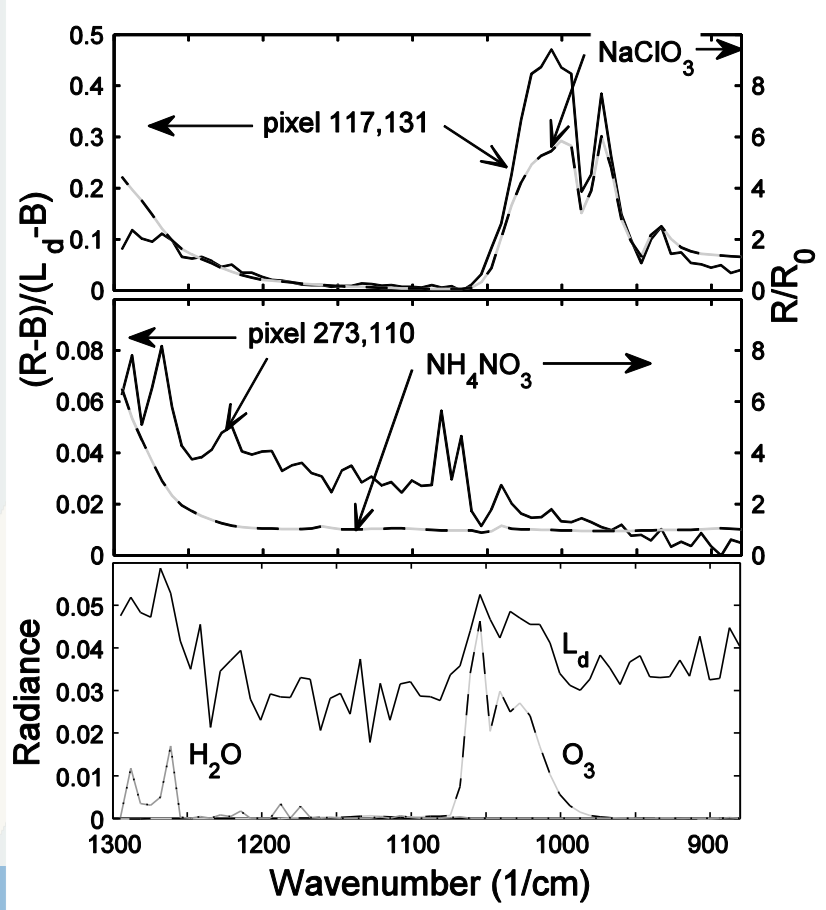


- Four end-members were selected from Image *c* using the DISTSLCT geometric-based method.
- Data from all images were fit in a least-squares sense to the normalized end-members (classical least squares for target detection).
- Images have *not* been contrasted.



EIGENVECTOR RESEARCH INCORPORATED

Comparison of End-Members to Laboratory Spectra



$$L = \varepsilon B(T) + (1-\varepsilon) L_d$$

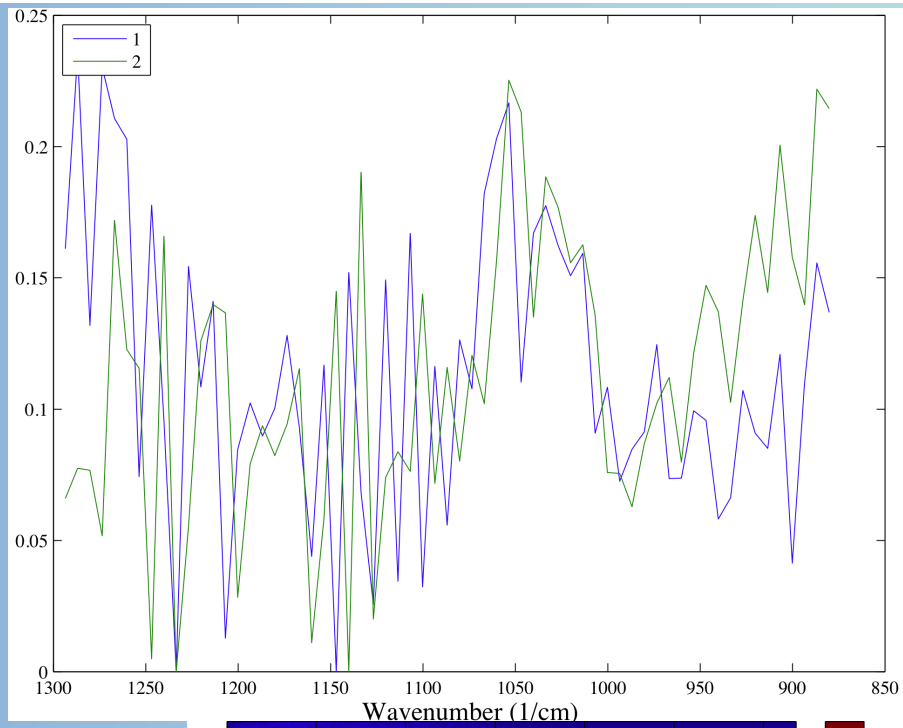
$$(1-\varepsilon) = \left(L - B(T)\right) / \left(L_d - B(T)\right)$$

$$\approx \left(L_{x,y} - B\left(T_{b,\max}\right)\right) / \left(L_d - B\left(T_{b,\max}\right)\right)$$

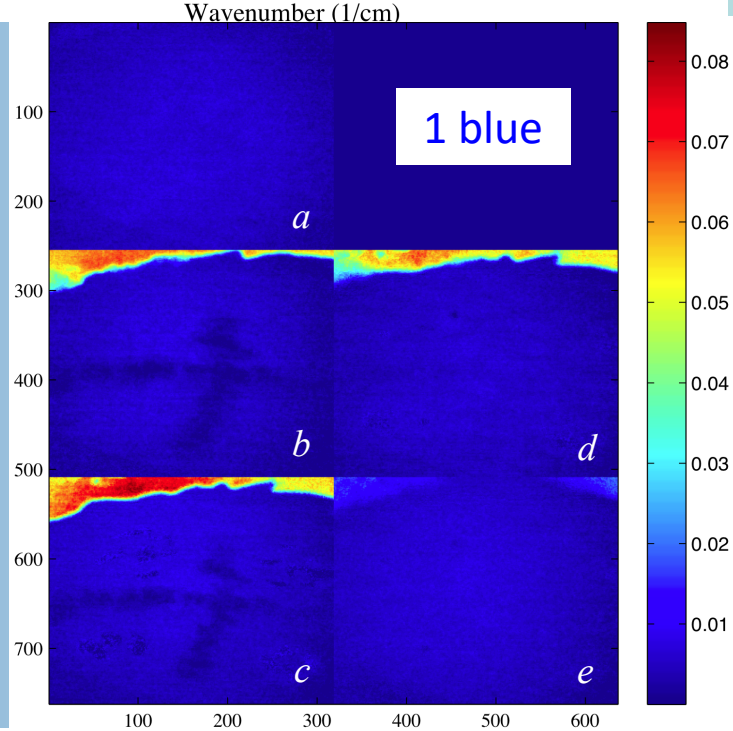
$$L_d = \left(L_{1,1} - \varepsilon_{Al} B(T)\right) / \left(1 - \varepsilon_{Al}\right)$$

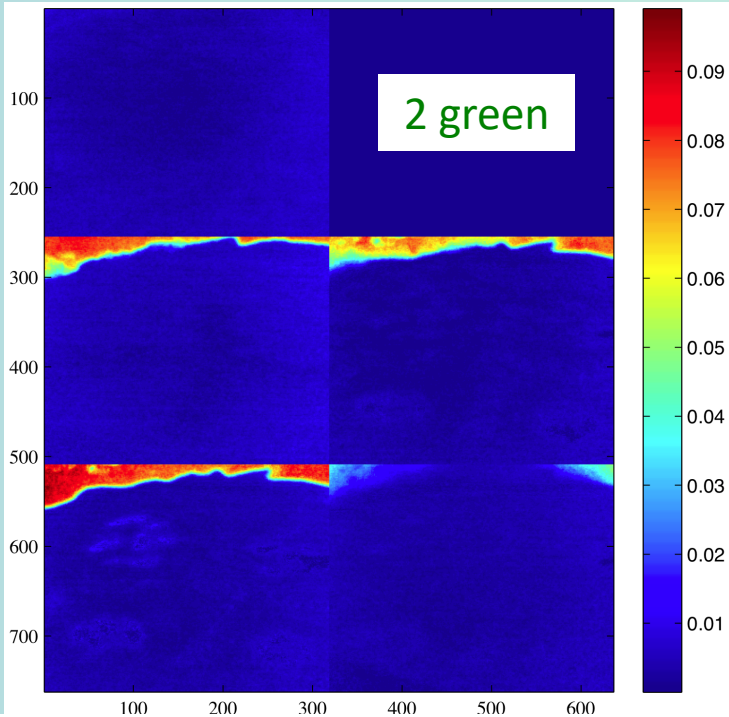
$$\approx \left(L_{1,1} - 0.05 B(310K)\right) / (1 - 0.05)$$

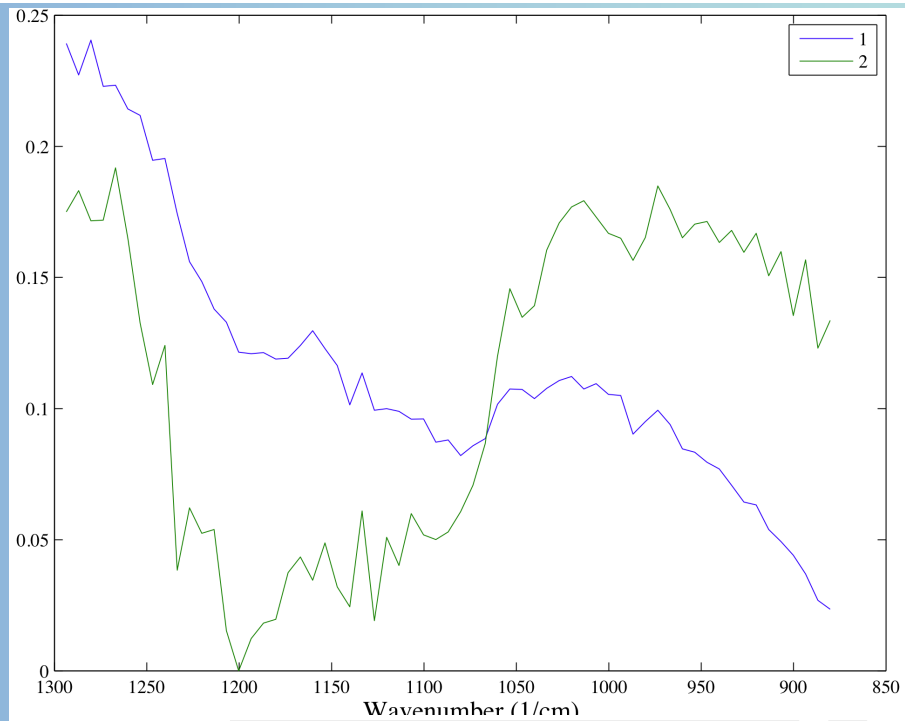
EIGENVECTOR RESEARCH INCORPORATED



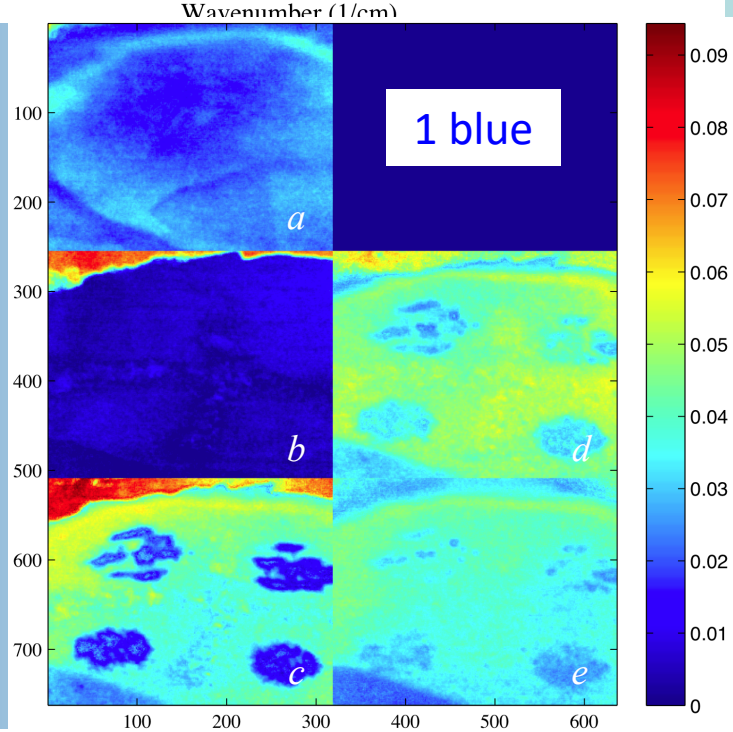
- PCA suggested 5 major factors and perhaps 2 very minor factors.
  - no centering or scaling was used.
- MCR (least squares) with 7 factors and non-negativity constraints on both **C** and **S**.
  - show contribution (**C**) images
- Two factors have high contributions on the aluminum pan and show distinct ozone features in the 1070-1010 1/cm range
  - reflection of sky shine
  - "two" might be due to differences in phase correction.

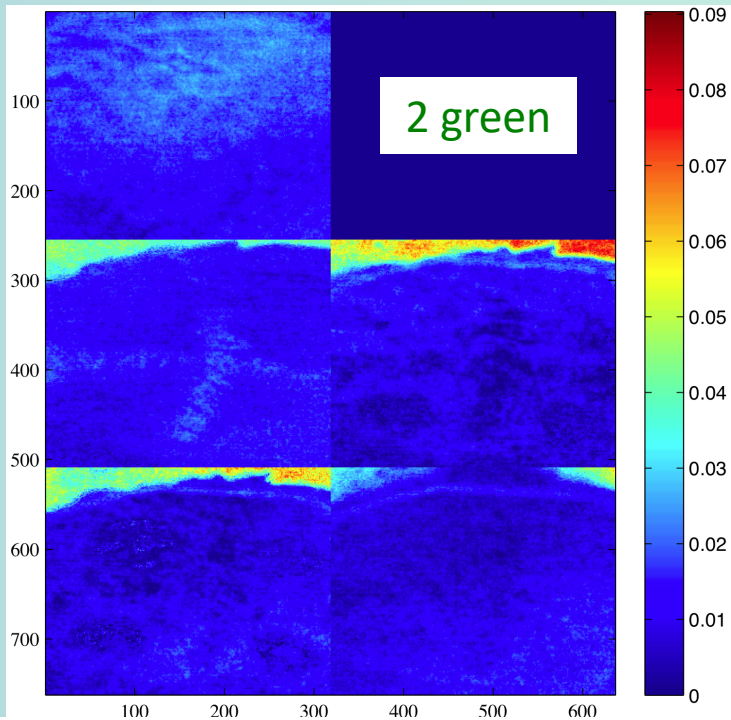


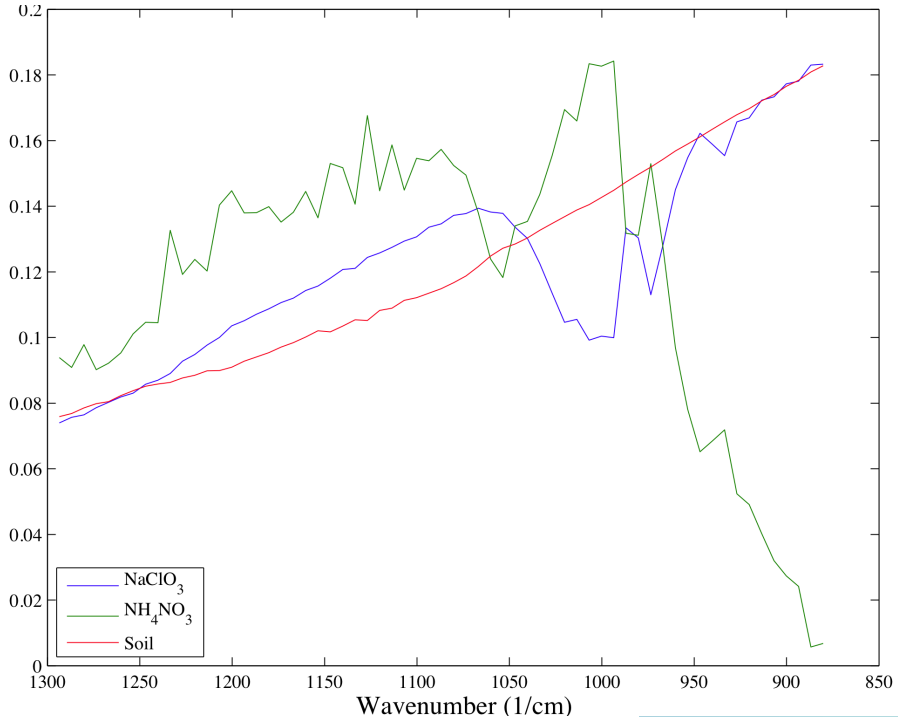




- Two factors have high contributions on the aluminum pan (reflection of sky shine).
- Factor 1 (blue) also shows contributions on the Quincy soil
  - appears to be glint off soil
  - NH_4NO_3 circles have low reflection
- Factor 2
  - may be off scratches on aluminum pan (?).







- Three factors are directly related to soil and the two targets.
- Factor 1 (blue) shows distinct features from $NaClO_3$ and the cross pattern.
- Factor 2 (green) shows the four circles from NH_4NO_3.
- Factor 3 (red) is related to the soil.

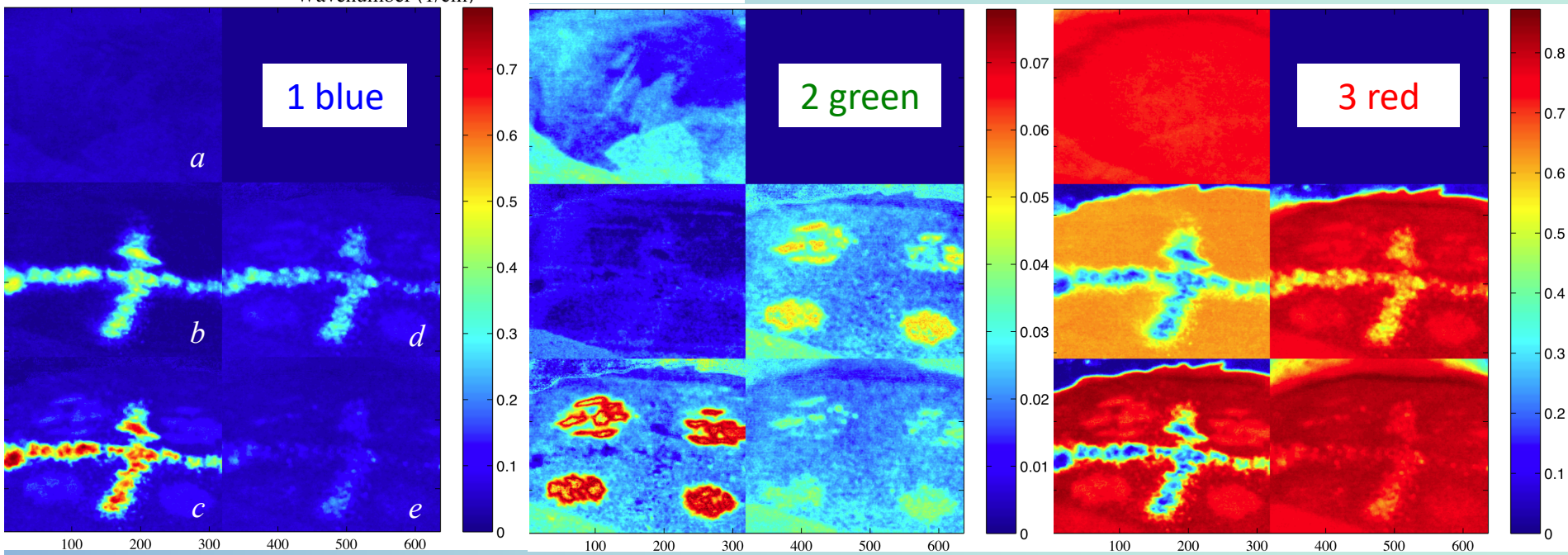
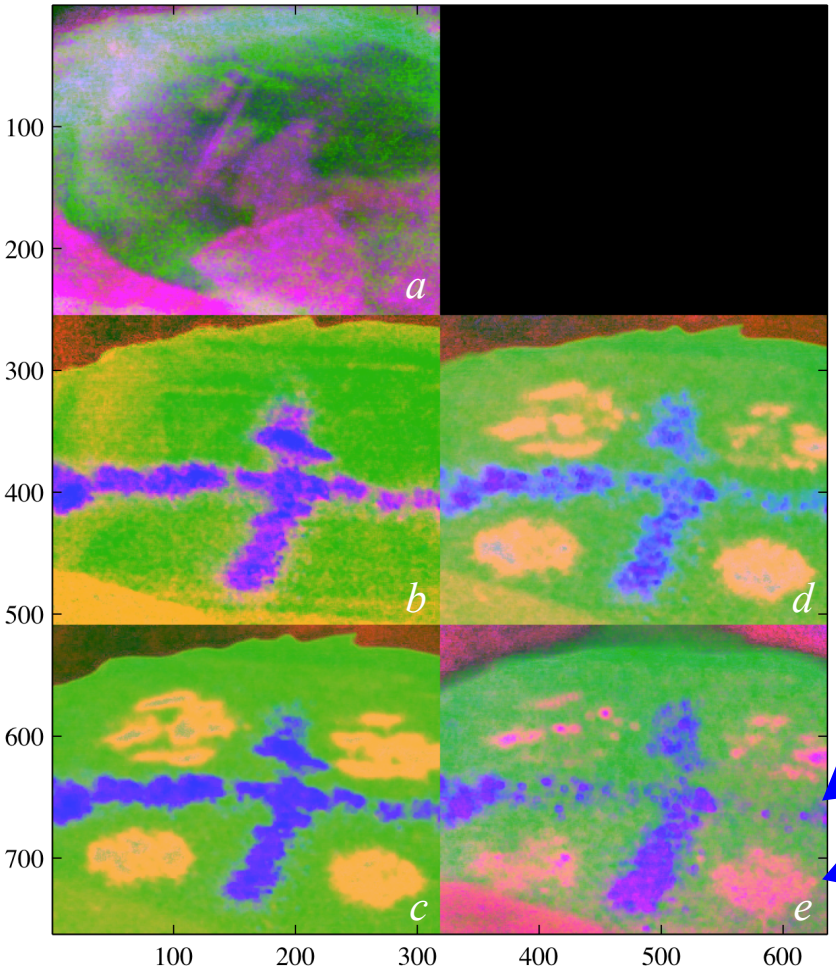


Image	Acquisition Date	Acquisition Time	Temp. Amb. (K)	Target (mg/cm^2)
a	7/18/08	5:11 PM	313	blank
b	7/18/08	2:45 PM	308	$NaClO_3$ 37
c	7/19/08	4:06 PM	310	$NaClO_3$ 37, NH_4NO_3 55
d	7/18/08	4:35 PM	312	$NaClO_3$ 37, NH_4NO_3 55, 1 mm of soil deposited over targets
e	7/18/08	4:52 PM	313	$NaClO_3$ 37, NH_4NO_3 55, 3 mm of soil deposited over targets

Distance = 3.25 m
Image = 256 x 320 pixels
Freq. Range = 1297-880 cm^{-1}



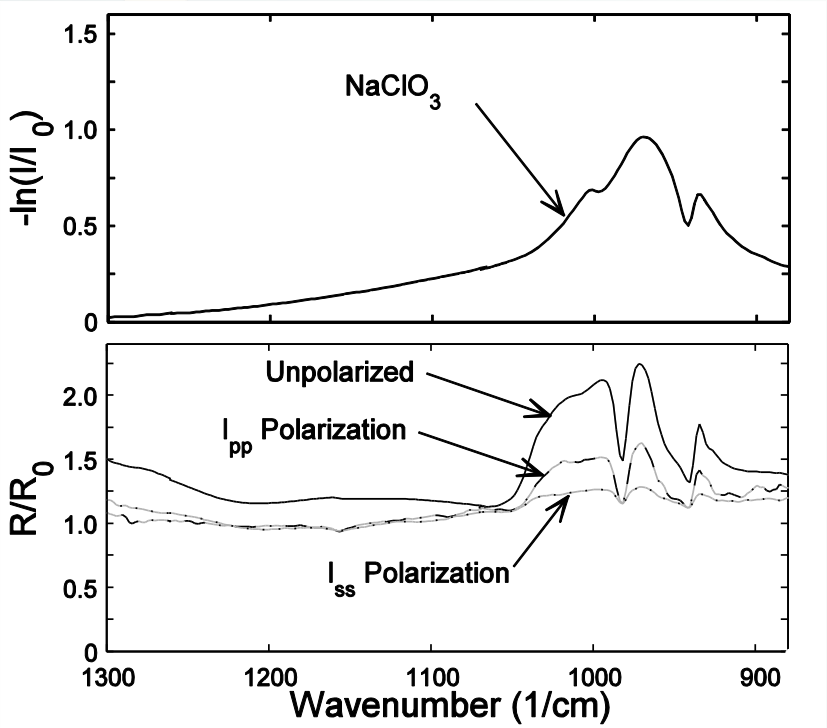
- RGB image of the three factors directly related to soil and the two targets.
- Targets are visible even with a 1-3 mm coating of Quincy soil.

$NaClO_3$ cross

NH_4NO_3 circles

EIGENVECTOR RESEARCH INCORPORATED

Laboratory Spectra with Polarization



R/R_0 measured using a specular reflection accessory for $NaClO_3$ buried 0.5 mm below Quincy soil surface (R_0) corresponded to bare Quincy soil.

Target was not apparent for >0.5 mm depths with laboratory spectra. *p*-polarized light appeared to penetrate deeper than *s*-polarized light.

Incident lighting in the lab was directed. Field soil was exposed to an ~entire hemisphere of sky radiance and may also be more influenced by temperature differences w/in the sample (e.g., aluminum pan sitting on warm asphalt).

EIGENVECTOR RESEARCH INCORPORATED

Conclusions

- Sodium chlorate and ammonium nitrate were detected using hyperspectral imaging at a distance of 3.25 m.
  - visible in images at selected wavenumbers, anomaly detection methods and using multivariate curve resolution
- Detection was made for compounds on, and below the soil surface for depths ~1-3 mm
  - the detected signal for sodium chlorate compared well with specular reflectance of the corresponding laboratory spectrum
- *p*-polarized light penetrated more than *s*-polarized light
  - although the mechanism is unclear, results suggest reflection of sky-shine is possible

Acknowledgements

- The authors would like to thank Vincent Farley and Jean-Pierre Allard of Telops, Inc. for help with LW-FIRST rental, service and training logistics.
- The experimental research described here was performed at the Pacific Northwest National Laboratory (PNNL), which is operated for the United States Department of Energy by the Battelle Memorial Institute under contract number AC05-76RL0 1830.
- This research was supported by PNNL's Laboratory Directed Research and Development, Initiative for Explosives Detection portfolio.
- The authors would like to thank the Initiative's director Dr. David A. Atkinson for his interest and support of this work and Dr. John Hartman for his comments on the manuscript.

EIGENVECTOR RESEARCH INCORPORATED

Related References

- Gallagher, N.B, Kelly, J.F., Blake, T.A., “Passive Infrared Hyperspectral Imaging for Standoff Detection of Tetryl Explosive Residue on a Steel Surface,” proceedings whispers’10, Iceland June 14-16 (2010).
- Blake, T.A., Kelly, J.F., Gallagher, N.B., Gassman, P.L., Johnson, T.J., “Passive Detection of Solid Explosives in Mid-IR Hyperspectral Images” *Anal. Bioanal. Chem.* **395**(2), 337-348 (2009). DOI 10.1007/s00216-009-2907-5

EIGENVECTOR RESEARCH INCORPORATED