Measuring chemical pollutant gases in the port of Antwerp using imaging spectroscopy

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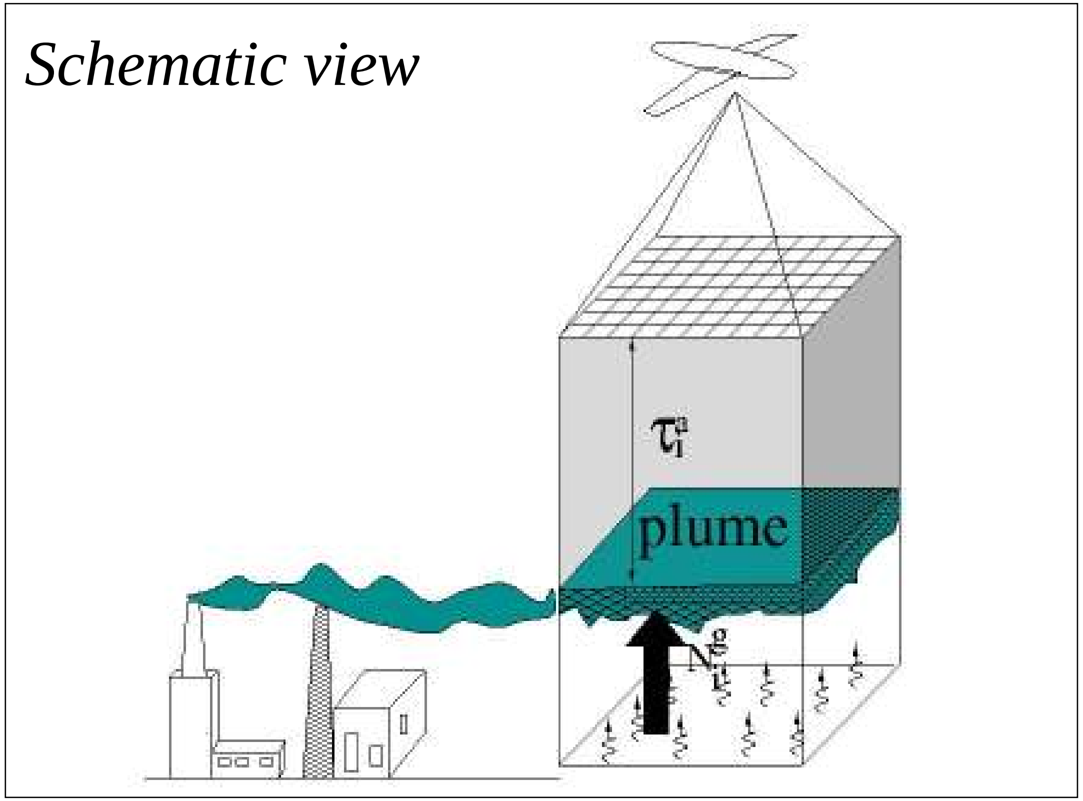
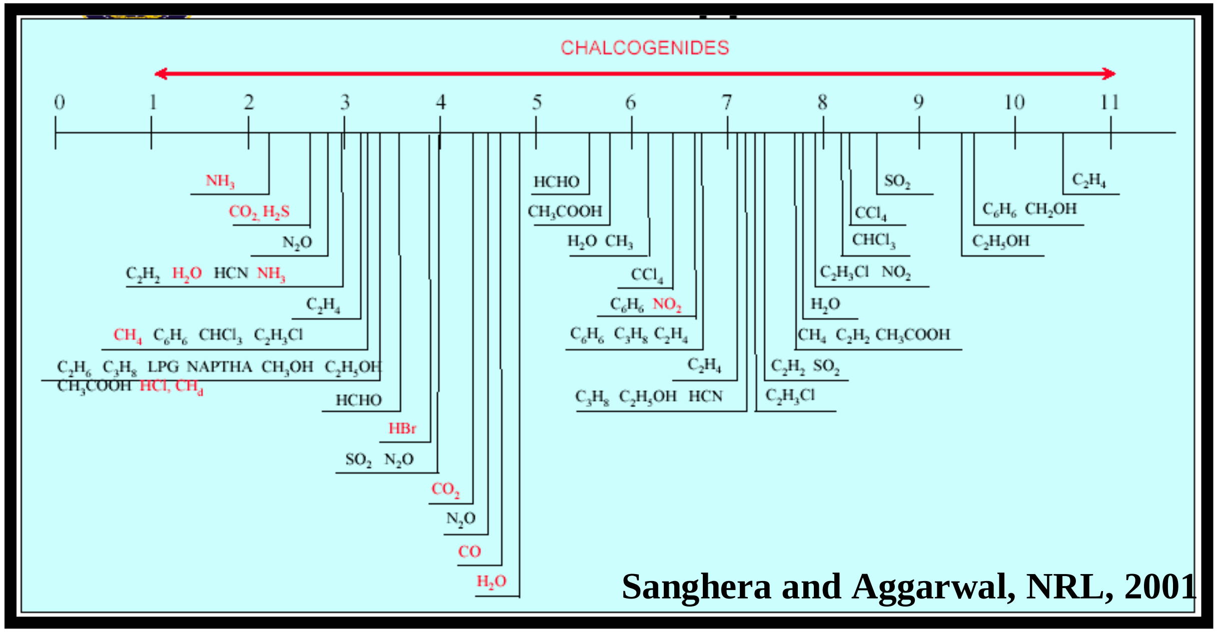
The OBJECTIVE of this project is to detect the presence and the concentration of polluted gas compounds in the atmosphere using the airborne MWIR and LWIR imaging spectroscopy data.

Scene scenario:



MOTIVATION:

- MWIR (~3 to ~5 μm) and LWIR (~7.5 to ~13.6 μm) remote sensing utilise the EM spectrum;
- Day and night capability;
- Solar influence low to negligible;
- Many chemical compounds have spectral ‘signature’ in these wavelengths.



Sanghera and Aggarwal, NRL, 2001

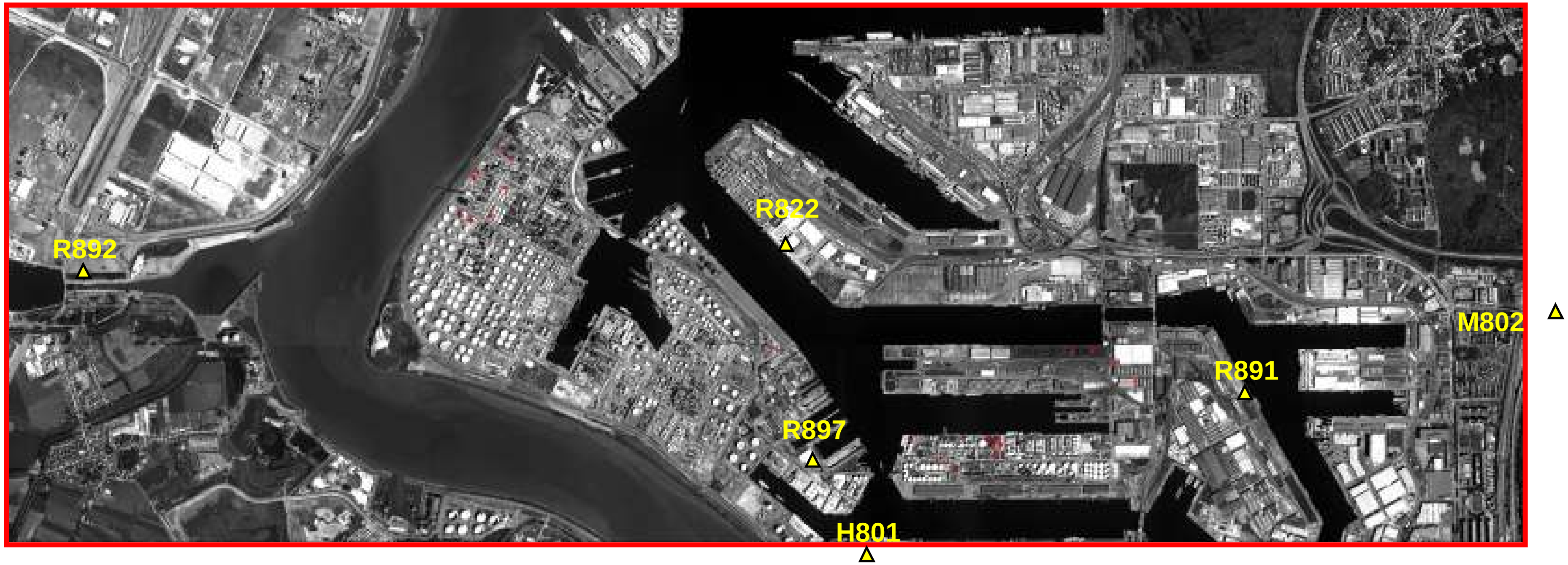
Petrochemical harbour - Antwerp

Total Petrochemicals **Nynas Pertroleum**

	Total	Nynas
Petro production (k ton/year)	16,760.0	1,200.0
Emission (ton/year)		
CO	1,682.6	8.9
SOx	12,696.0	207.0
NOx	4,976.6	83.4
Thin dust	959.8	

Data Collection

AHS-160 data campaign 16 June 2005, in two flight lines and twice a day (09h30-10h00); (15h30-16h00)



VMM stations

M – meteo measurements:
- Wind direction
- Wind speed
- Temperature
- Air pressure
- Relative Humidity
- Rain

R – Air quality measurements (∝ : 10 sec)
- Profiles (Nox, Sox, CO, dust…)
- Temperature

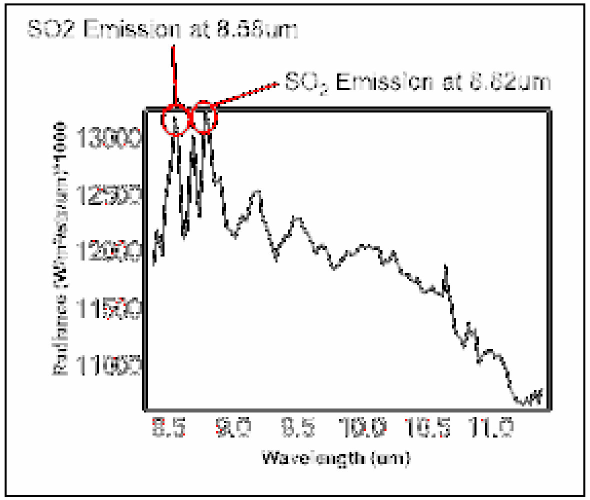
Ground truth stations

ASD spectrometer
0.45-2.5 µm

SOC 400-T reflectometer
2.0-25.0 µm

Infrared Radiation Pyrometer
T°

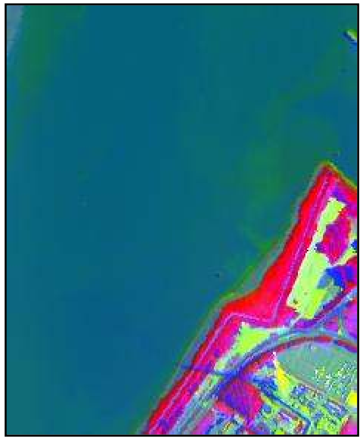
SO_2 Plume – Total Fina location



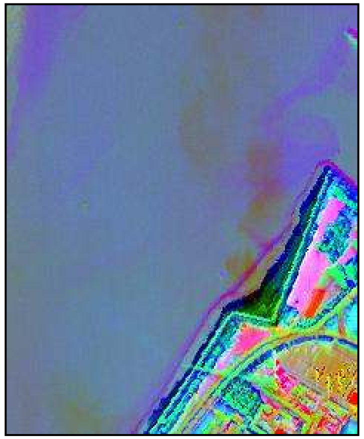
R:band66, G:band74, B:band78

PCA analysis VNIR

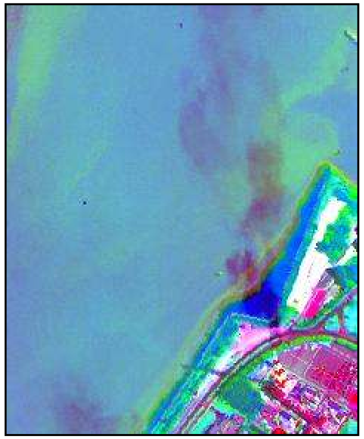
R:band9, G:band7, B:band2



R:PCA1, G:PCA2, B:PCA3



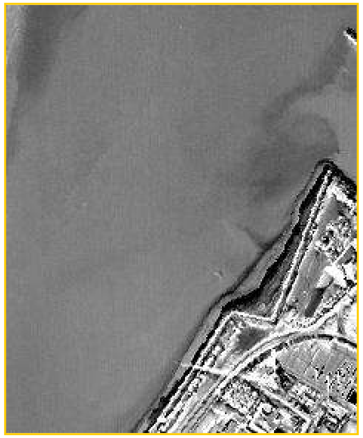
R:PCA2, G:PCA3, B:PCA4



R:PCA2, G:PCA4, B:PCA5

PCA1

PCA2



PCA3

PCA4

PCA5

Plume classification using SAM

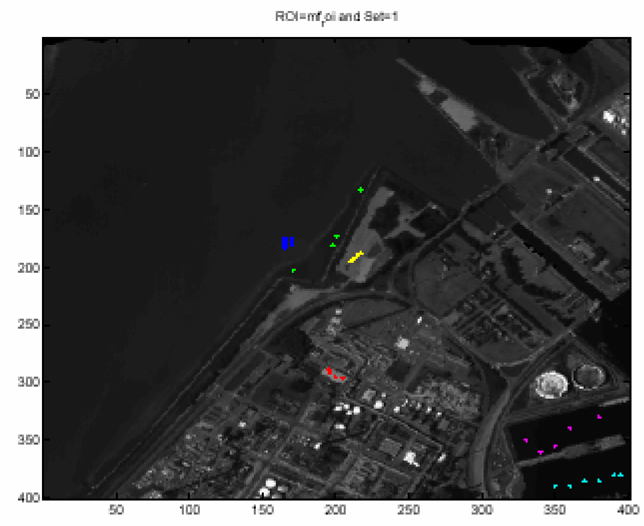
The angle between two vectors $\vec{s}$ and $\vec{t}$ in the 3D space can be obtained by considering the scalar product or dot product between them as follows:

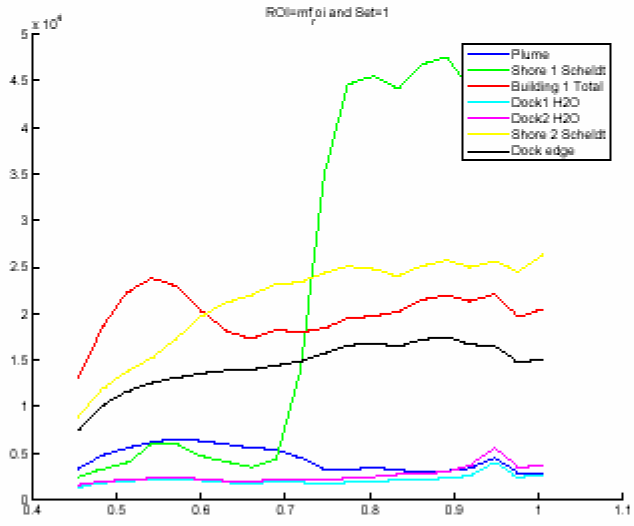
$$\begin{aligned} \vec{s}\,.\,\vec{t} &= |\vec{s}||\vec{t}|\,cos\theta \\ &= s_1t_1 + s_2t_2 + s_3t_3, \end{aligned} \tag{1.1}$$

with $|\vec{s}| = \sqrt{s_1^2 + s_2^2 + s_3^2}$ and $|\vec{t}| = \sqrt{t_1^2 + t_2^2 + t_3^2}$. The angle is thus given by;

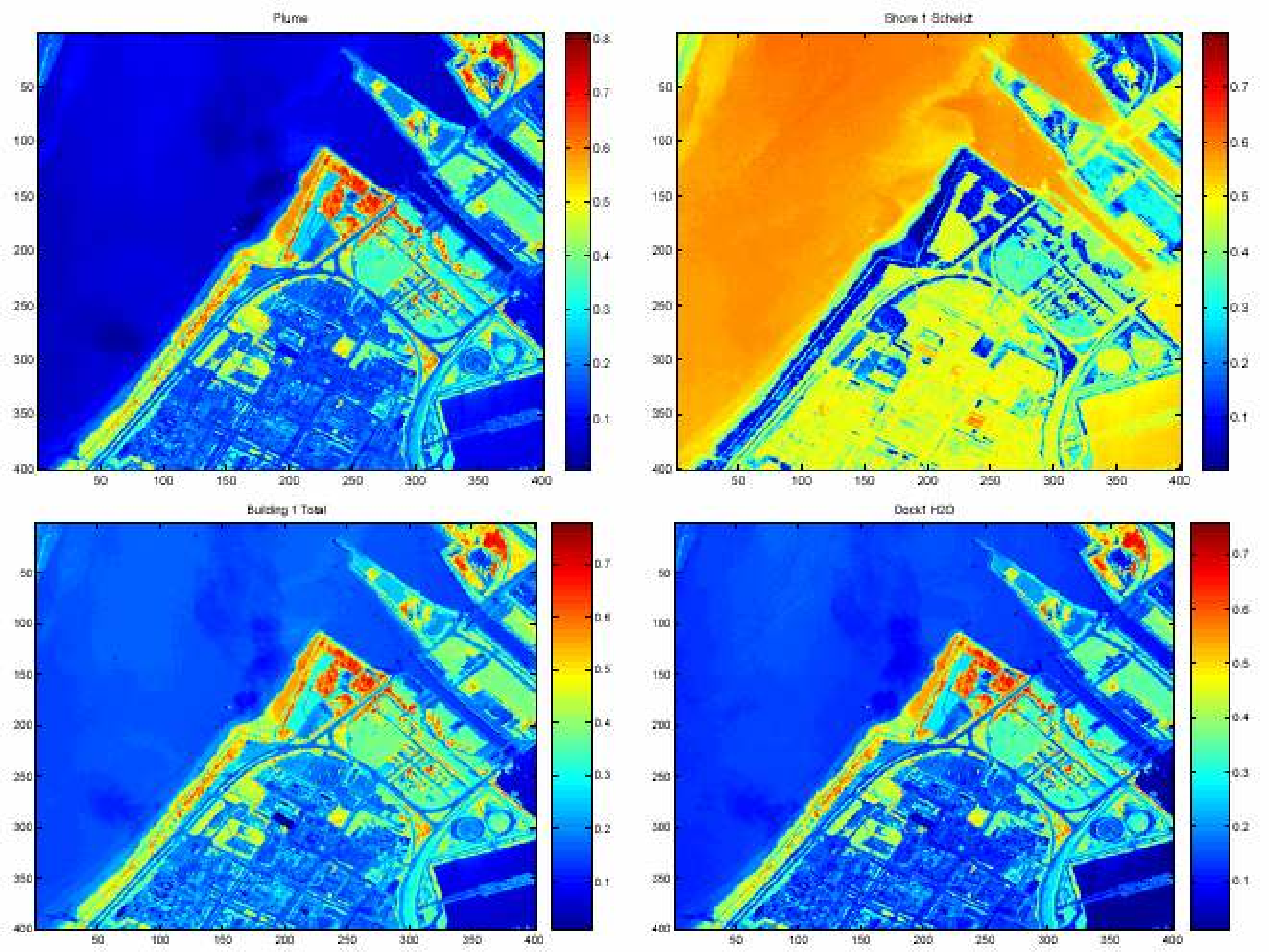
$$\theta = Acos\left(\frac{s_1t_1 + s_2t_2 + s_3t_3}{\sqrt{s_1^2 + s_2^2 + s_3^2}\sqrt{t_1^2 + t_2^2 + t_3^2}}\right). \tag{1.2}$$

Morning image: regions of interest “dock”, locations and corresponding spectra.

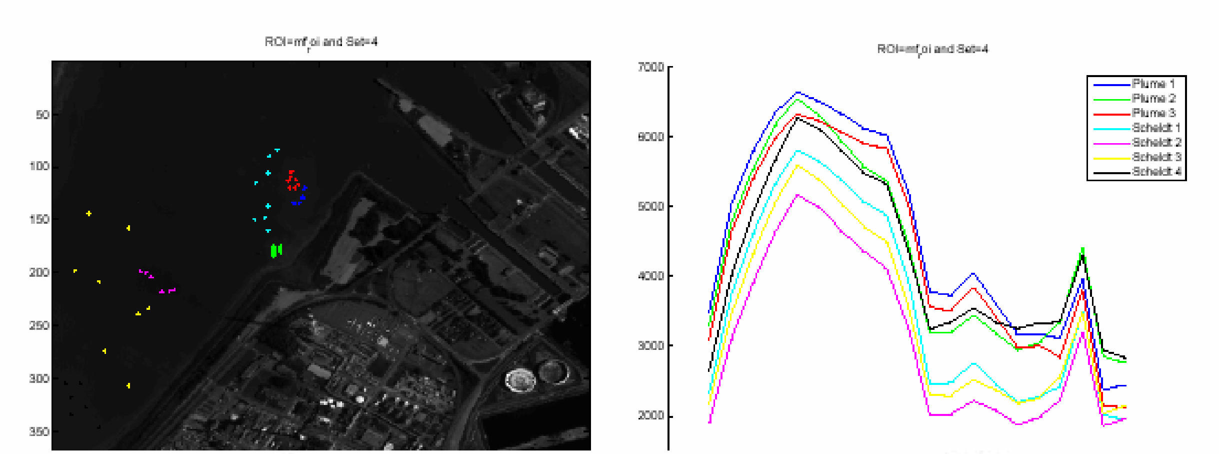




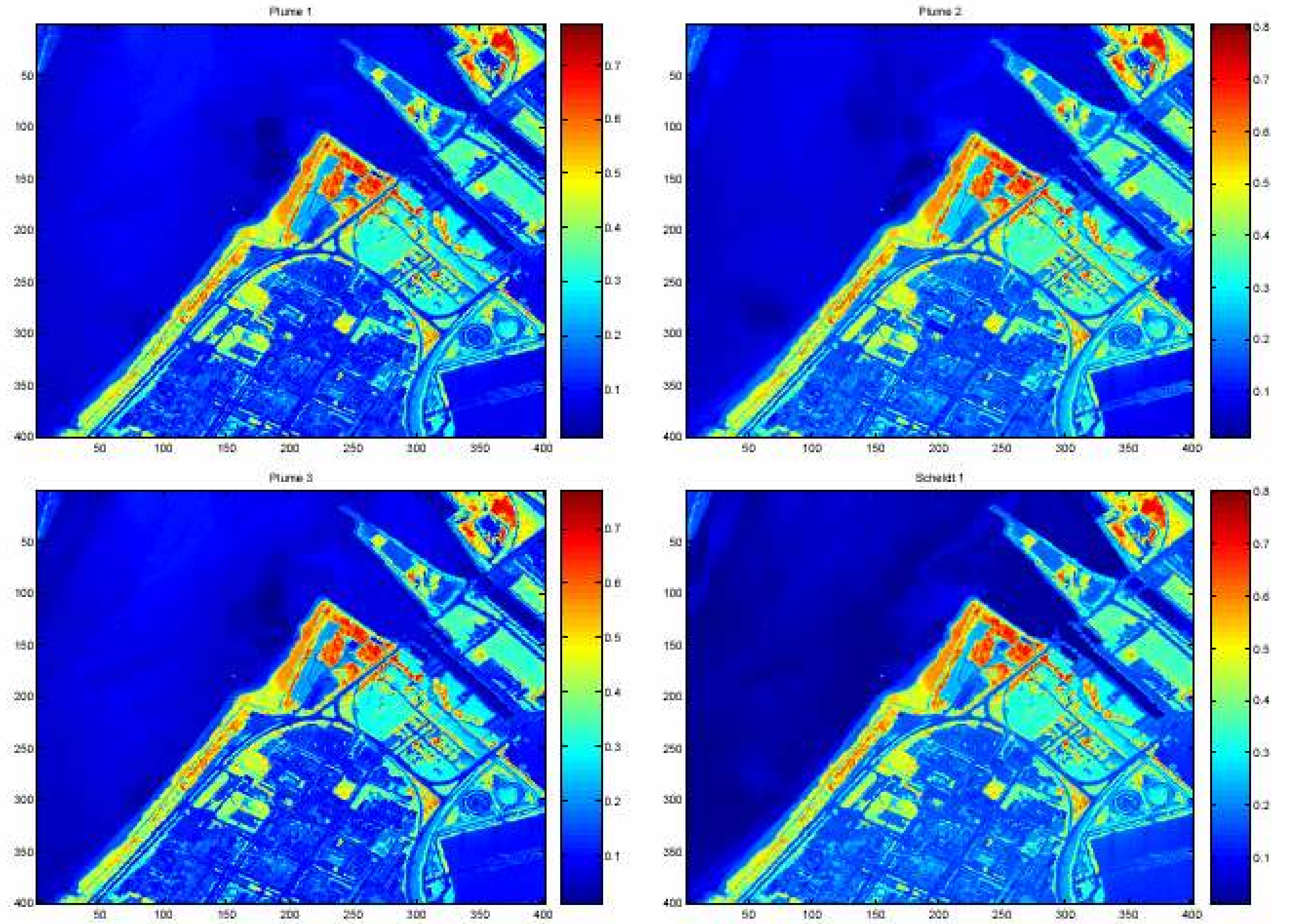
SAM results morning data set



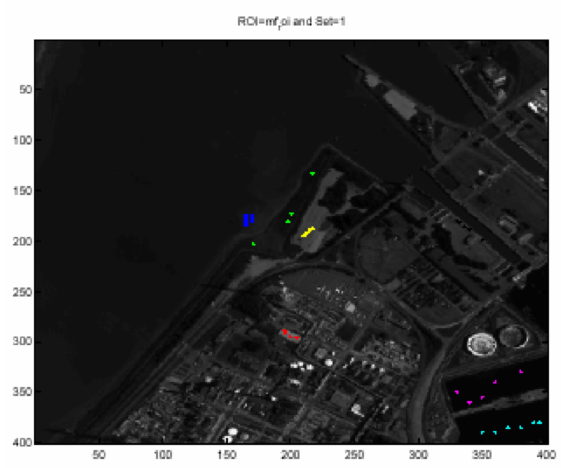
Regions of interest "Scheldt", locations and corresponding spectra

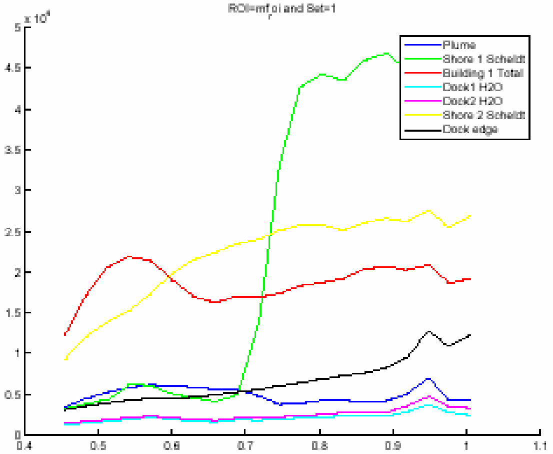


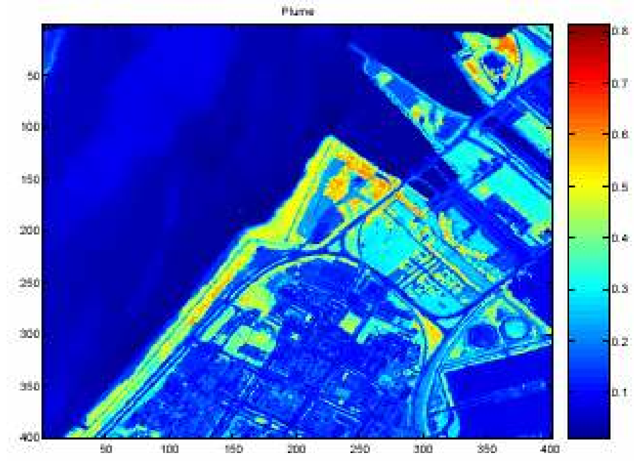
Plume classification using SAM (morning)

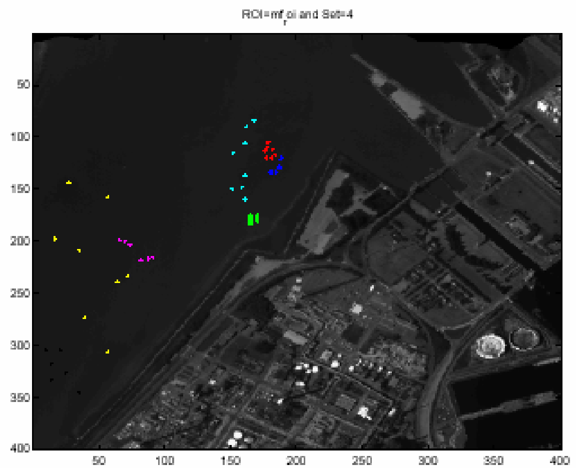


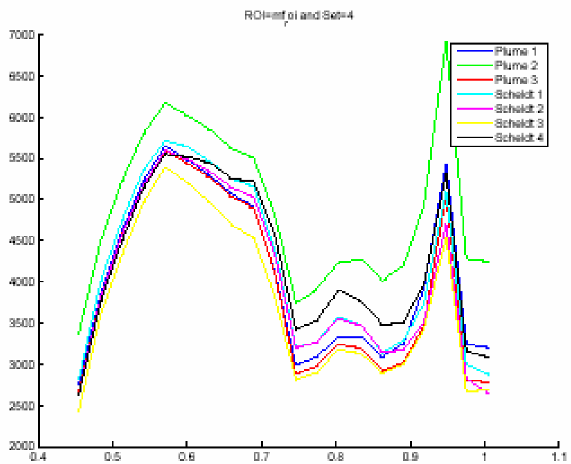
SAM results afternoon data set

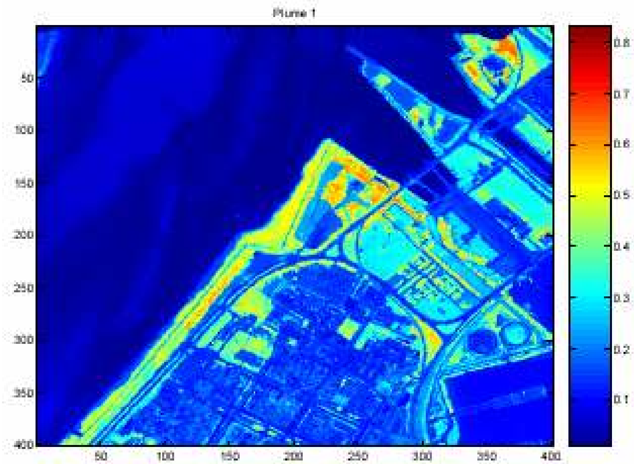












Orthogonal Subspace Projector (OSP)

A mixed pixel containing *p* spectrally distinct materials, denoted by the $l \times 1$ vector $\vec{r}(x,y)$ can be described by the linear model:

$$\vec{r}(x,y) = M.\alpha(x,y) + \vec{n}(x,y) \tag{2.1}$$

Separating the desired signature from the undesired signature, one can reformulate previous expression as,

$$\vec{r}(x,y) = U.\gamma(x,y) + \vec{d}.\alpha_p(x,y) + \vec{n}(x,y) \tag{2.2}$$

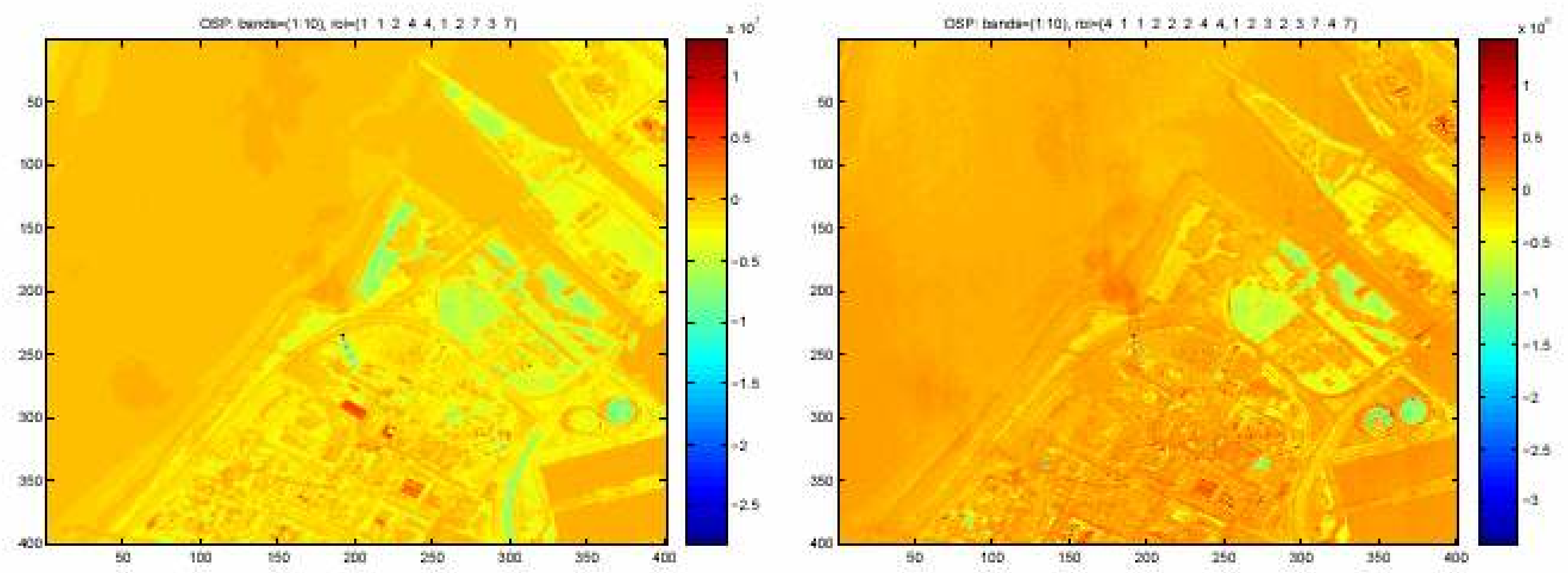
An operator *P* can be constructed which projects $\vec{r}(x,y)$ onto a subspace that is orthogonal to the columns of *U*:

$$P = (I - UU^{\dagger}) \tag{2.3}$$

The pixel classification operator q^T that maximizes the signal to noise ratio is given by:

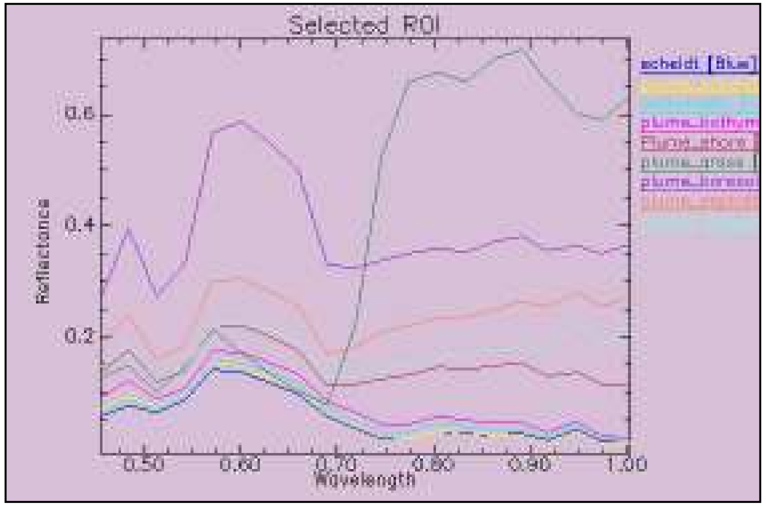
$$q^T = d^T \; P \tag{2.4}$$

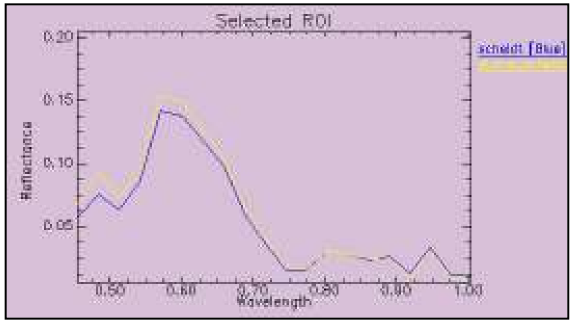
OSP results morning data set

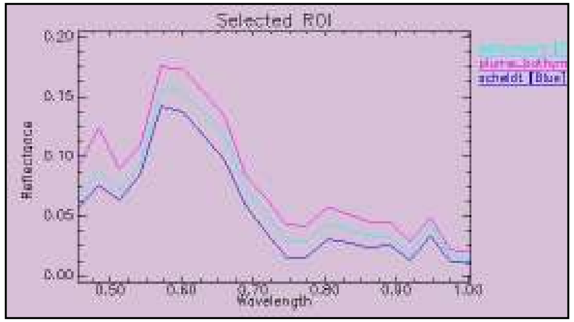


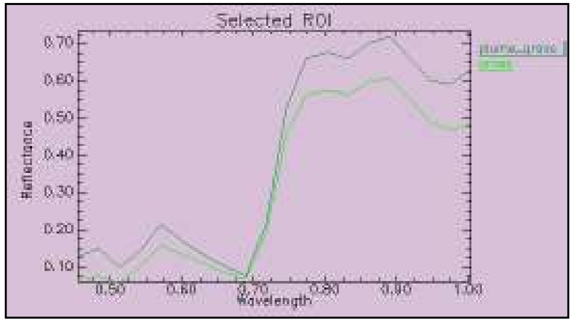
Orthogonal Subspace Projector with (left) plume (1,1) as reference and (Shore 1 Scheldt, Xilo 5, Scheldt 1, Scheldt 4) as undesired spectral signatures and (right) plume (4,1) as reference and (Shore 1 Scheldt, Building 1 Total, Xilo 1centre, Xilo 2 edge, Xilo 5, Scheldt 1 and Scheldt 4) as undesired spectral signatures.

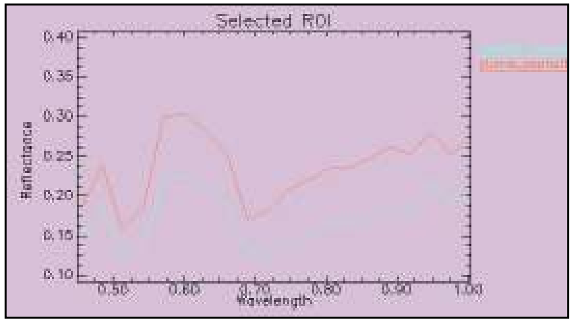
Selected spectra







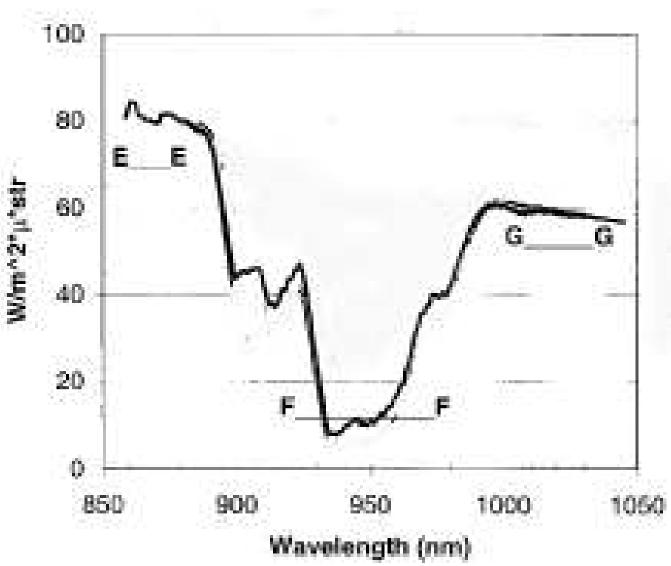




SUMMARY

* The plume is in the data and it appears in the 5 first VNIR bands;
* It has no significant abundance in the VNIR wavelengths;
* It has high reflectance values related to its background spectra;
* It is detectable over homogeny background.

Continuum Interpolated Band ratio (CIBR)



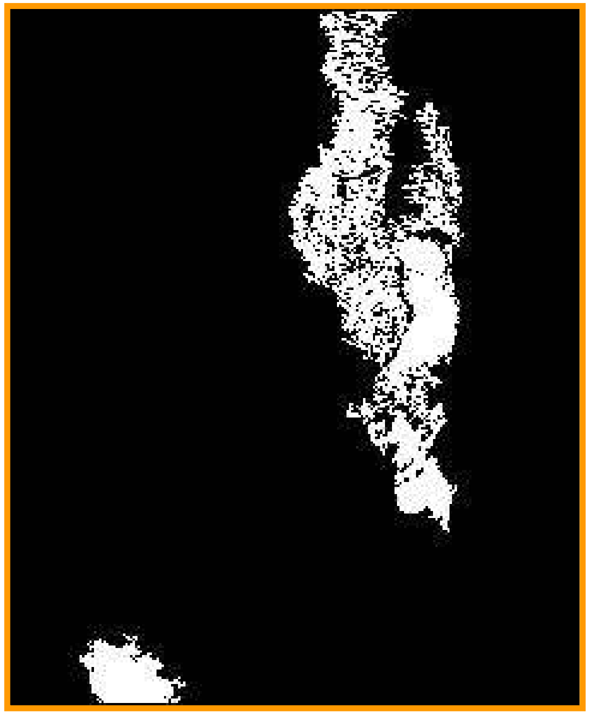
$$R_{CIBR} = \frac{2L_m}{w_{r1}L_{r1} + w_{r2}L_{r2}}$$

$$R_{CIBR(E/G,F)} = \frac{2 \cdot F_m}{E_r + G_r}$$

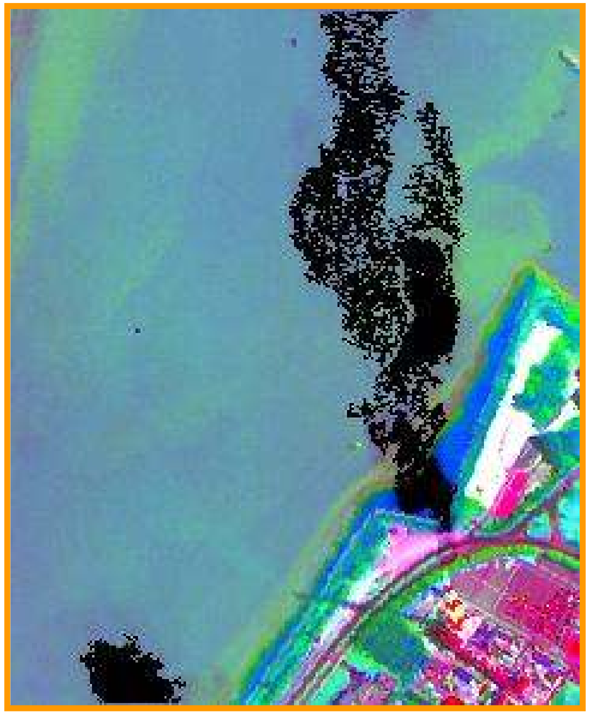
Plume detection using CIBR

$$R_{CIBR(0.488/0.455,0.513)} = \frac{2 \cdot b_2}{b_1 + b_3}$$

$CIBR_{(b1/b3,b2)}$



Segmentation



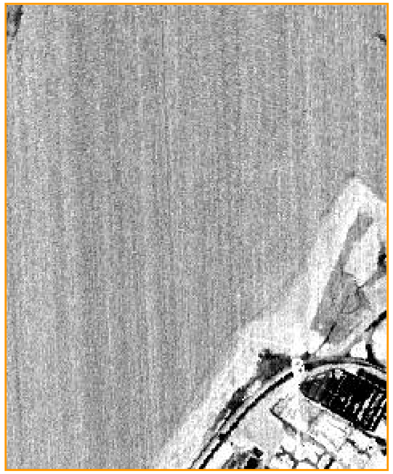
Plume classification over PCA(2,4,5)

Plume detection in the LWIR

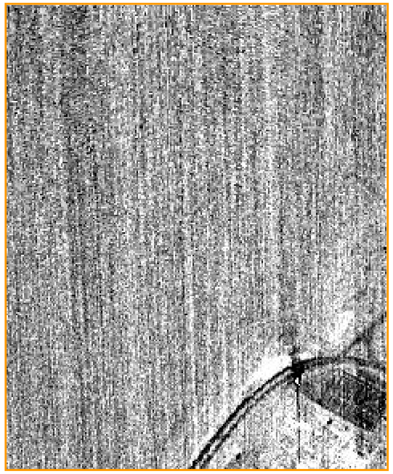
R:band66, G:band74, B:band78

AHS-Band64 (2.7214-3.686)
+(Mean Filter 3X3)

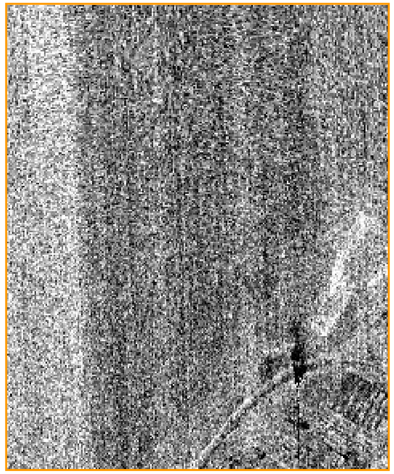
PCA1



PCA2



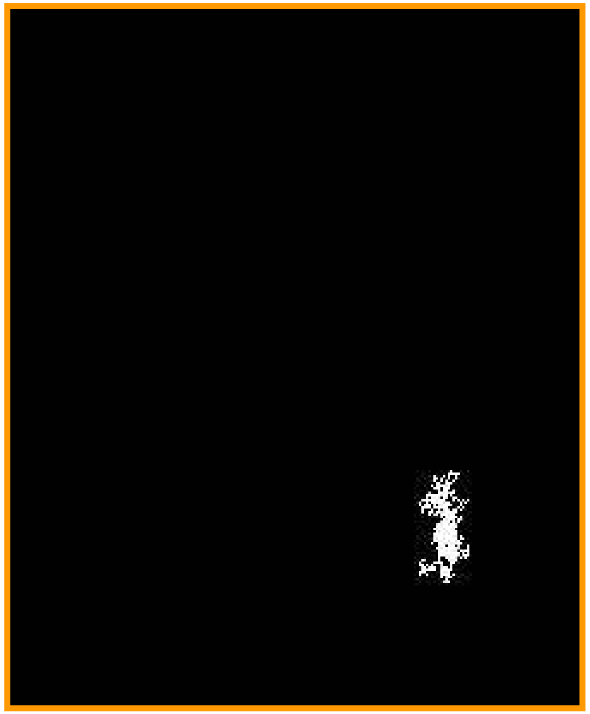
PCA5



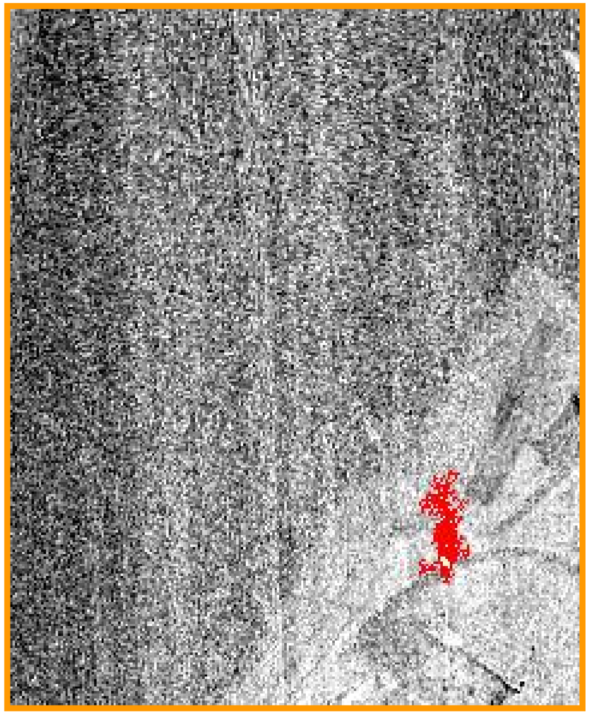
PCA9

$$R_{CIBR(8.19/8.66,9.17)} = \frac{2 \cdot b_{72}}{b_{71} + b_{73}}$$

CIBR(b71/b73,b72)

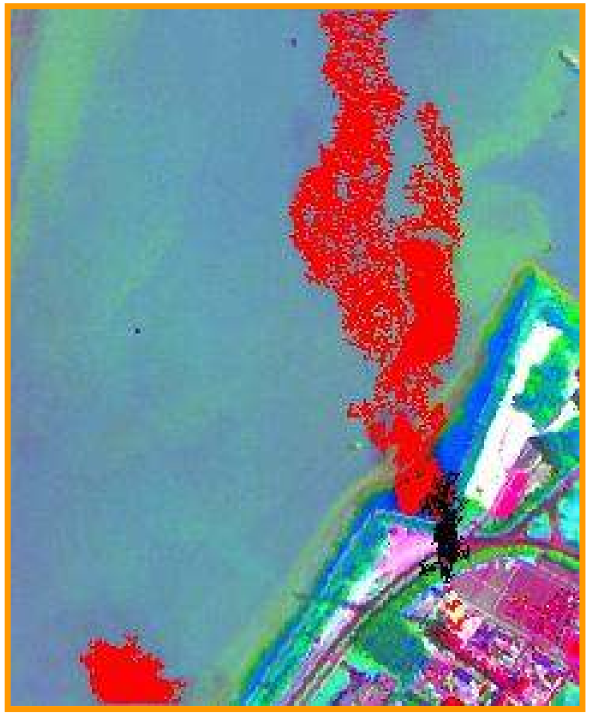


Segmentation

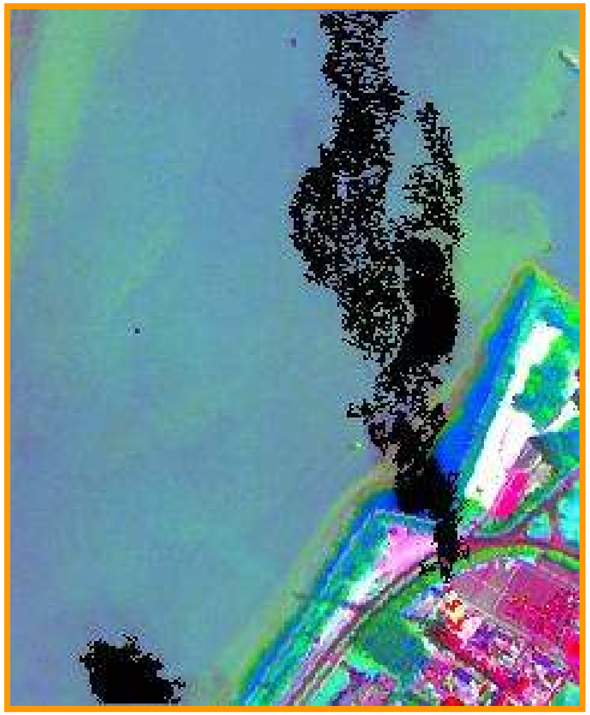


Plume classification over CIBRtherm

Plume Classification



Plume detection using CIBR
(red-VNIR, black – LWIR)

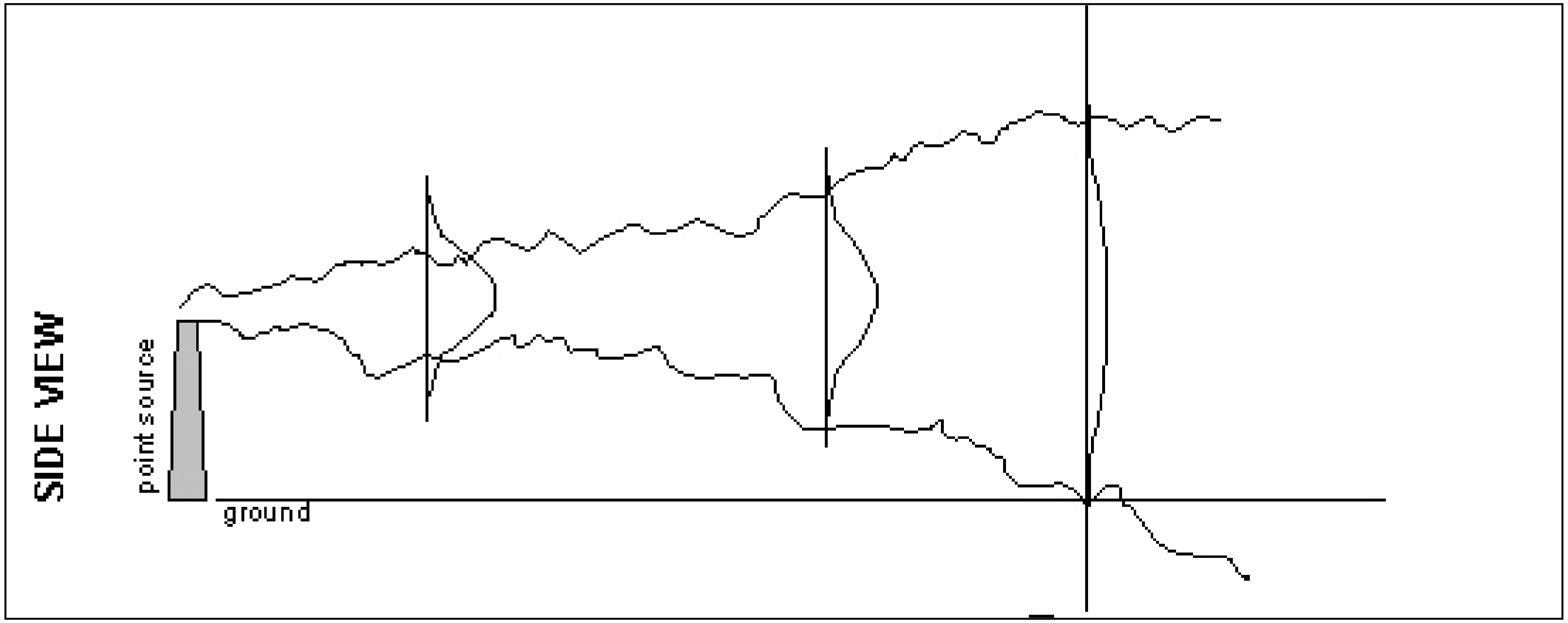


Plume classification based
decision fusion

Gaussian Plume Model

Goal: Predict concentrations of a pollutant released at a specific source point.

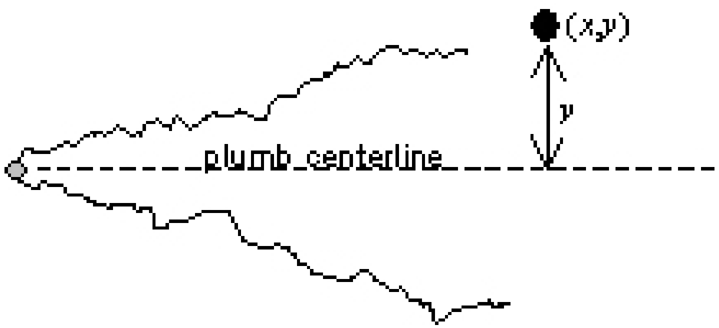
General concept: This model describes the transport and mixing of the pollutants. It assumes dispersion in the horizontal and vertical direction will take the form of a normal Gaussian curve with the maximum concentration at the centre of the plume (unless wind vectors are changing direction sporadically).



The **'Pasquill-Gifford'** Gaussian plume model, which predicts the concentration (*C*) of the pollutant at location (*x*, *y*, *z*):

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \times \left[\exp -\left(\frac{y^2}{2\sigma_y^2}\right)\right]\left\{\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right\} \quad (1)$$

C = Concentration of the chemical in air. $[M/L^3]$
Q = Rate of chemical emission. [M/T]
u = Wind speed in x direction. [L/T]
σ_y = Standard deviation in y direction. [L]
σ_z = Standard deviation in z direction. [L]
y = Distance along a horizontal axis perpendicular to the wind. [L]
z = Distance along a vertical axis. [L]
H = Effective stack height. [L]



$$\Delta H = 1.6 F_b^{1/3} x^{2/3} / u \quad (2)$$

$$F_b = g \frac{d^2 V}{4}\left(\frac{T_s - T_a}{T_s}\right) \quad (3)$$

ΔH = Plume rise as defined by Briggs equation. [L]
x = Downwind distance. [L]
u = Wind speed in x direction. [L/T]
F_b = Buoyancy flux. $[L^4/T^3]$
g = Acceleration due to gravity. $[L/T^2]$
d = Stack diameter. [L]
V = Exit velocity. [L/T]
T_s = Absolute gas temperature. [D]
T_a = Absolute air temperature. [D]

Gaussian Plume Model

Please enter the following parameters, then click on the "Run" button:

NOTE! System load can affect performance time! Please be patient!

Run Plume Model ---- Erase this run

Initial Values:

Height of the stack (in meters)	204.0	Diameter of the stack (in meters)	1.05	Emission rate (grams per second)	119.72
Exit velocity of the gas (in meters per second)	10.0	Temperature of the exiting gas (in degrees Celsius)	232.0	Ambient temperature of the air (in degrees Celsius)	22.0

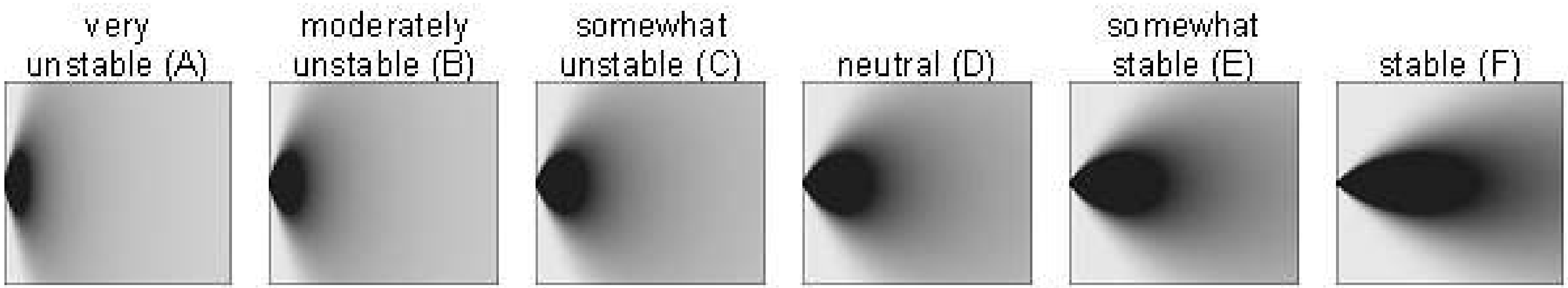
Atmospheric condition:
- Very unstable
- Moderately unstable
- Slightly unstable
- Neutral (selected)
- Somewhat stable
- Stable

Wind velocities (in meters per second, must have 11 points)

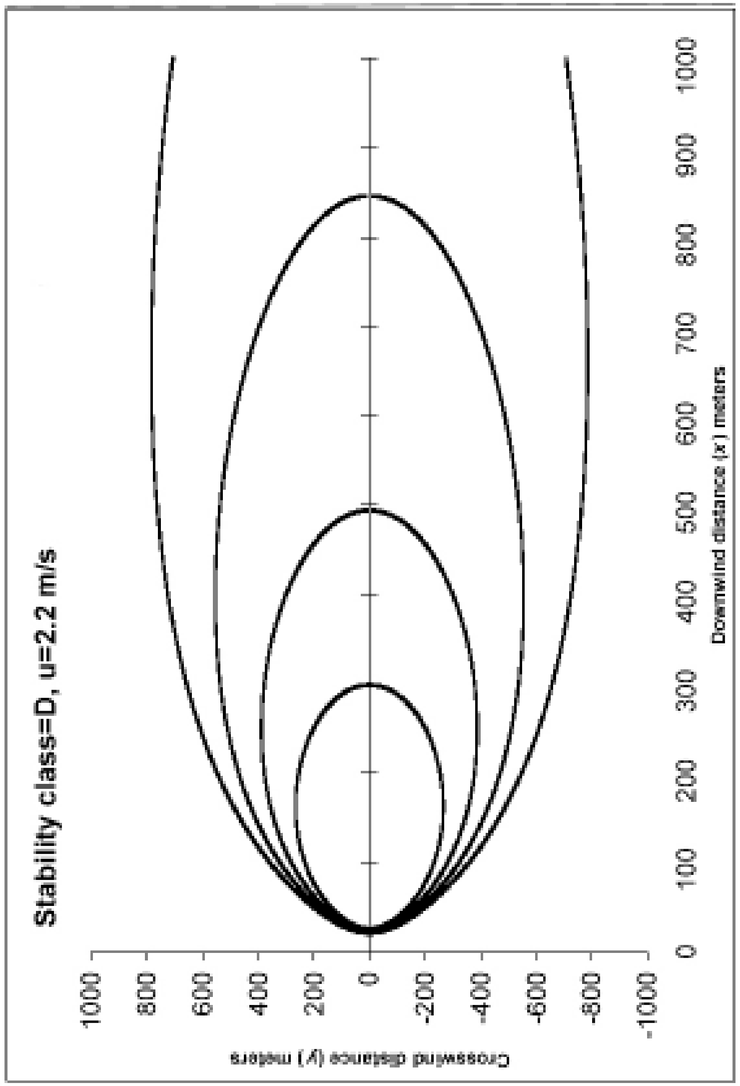
1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6

Distances downwind to be calculated (in meters, must have 11 points)

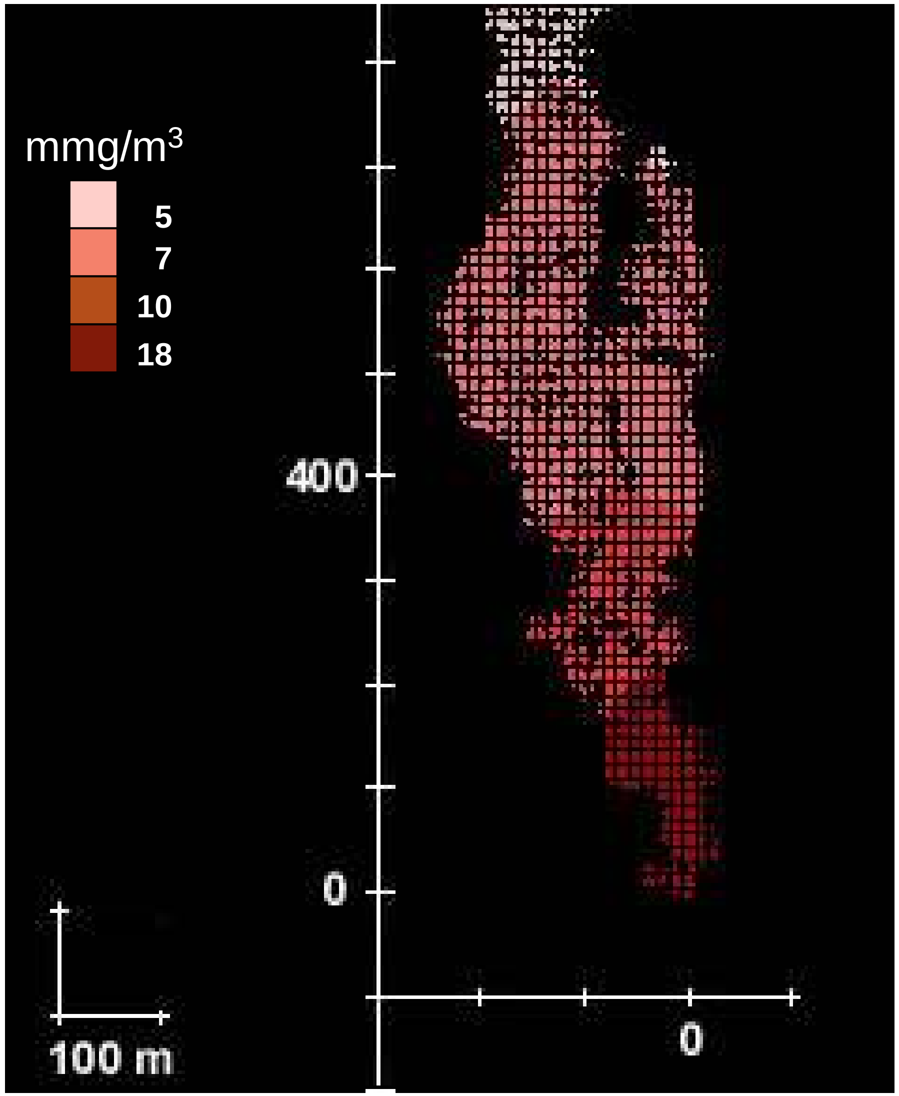
100	200	300	400	500	600	700	800	900	1000	1100



Plume concentration at effective stack height 292 m



Cross/downwind distance for ROI H=292 m



Plume concentration H=292 m

Conclusions

MWIR-LWIR:

- **The AHS-160 bandwidths are not sufficient for detection of gas compound based on their spectra abundance;**
- **Using the CIBR ratio, it is possible to detect pollutant plume in the LWIR wavelengths;**
- **The LWIR information is complimentary to the VNIR data (detection over heterorganic background).**

VNIR:

- **It is possible to detect pollutant plume using CIBR in the VNIR wavelengths over homogeny background (no mix pixel).**

Future perspective

Plume detection/concentration:

- **To use other ratio technique based on mix information from the VNIR+LWIR data;**
- **To study the effect of the atmospheric calibration on the plume detection;**
- **To apply adapted atmospheric model and atmospheric calibration;**
- **To apply other plume concentration models.**

Future studies using the AHS-data

- **Man-made feature detection using MWIR-LWIR data;**
- **The chemical port of Antwerp as “heat island”.**