CONCENTRATION LENGTH

NOISE EQUIVALENT CONCENTRATION LENGTH

GAS CONTRAST

GAS SENSITIVITY MATRIX

FALSE ALARMS

Useful Figures of Merit for Selection of OGI Cameras

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Content

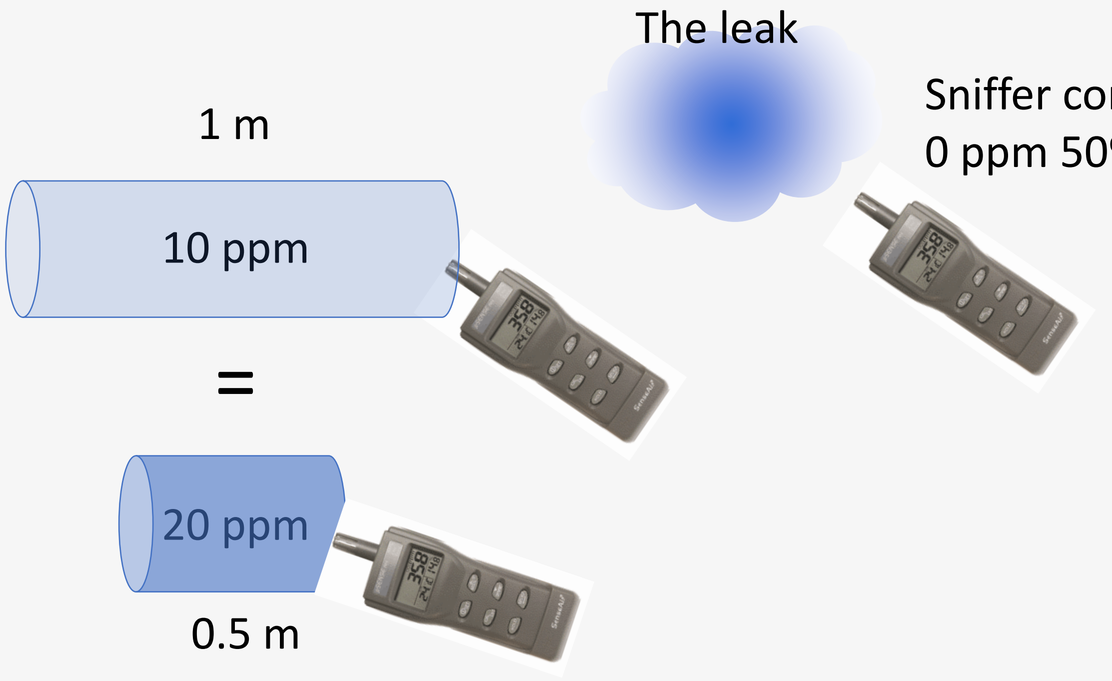
Useful Figures Of Merit (FOM):

- Concentration Length (CL)
- Noise Equivalent Differences (NETD and NECL)
- FLIR Systems use NECL as independent measure for OGI cameras
- Gas Contrast (GC)
- How we optimize the OGI cameras based on these Figures of Merit
- Show the gas sensitivity camera matrix
- The physics behind false positives in the field and how to interpret and minimize false alarms.

Concentration Length

- **CL is the path integrated Concentration Length of the gas**
- Normally used in line of sight instruments, e.g. open path infrared gas detector
- Measure gas concentration multiplied with gas plume length, e.g. [ppm x m]

Camera concentration length:
10 ppm x m



Sniffer concentration:
0 ppm 50% of the time

Noise Equivalent Concentration Length

Recap from A&WMA 2015

- Measurement of **Gas Sensitivity**
- Depends on:
  - $\Delta T = T_B - T_G$ [K]
  - Gas plume depth [m]
  - Gas concentration [ppm_v]
- Compare with Noise Equivalent Temperature Difference (NETD)

Carbonated water. One bubble ruptures.
GF343 CO_2 camera image.

Noise Equivalent Differences

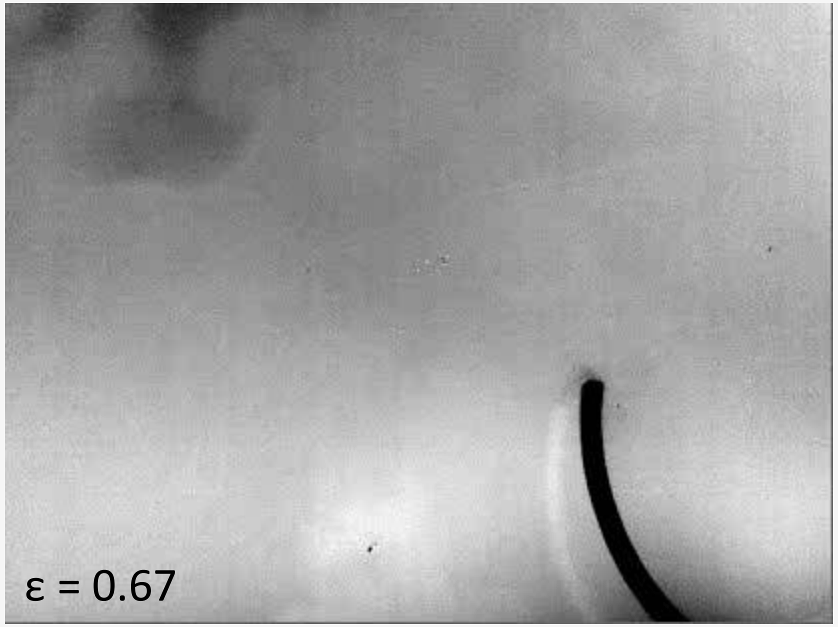
NETD	NECL
Noise Equivalent Temperature Difference	*Noise Equivalent Concentration Length*
$S(T + \Delta T^{NETD}) - S(T) = noise$ $\Delta T^{NETD} = \frac{noise}{\frac{dS(T)}{dT}}$	$S(CL + \Delta CL^{NECL}, \Delta T) - S(CL, \Delta T) = noise$ $\Delta CL^{NECL} = \frac{noise}{\frac{dS(CL,\Delta T)}{dCL}}$
Dependent on T	Dependent on $\Delta T = T_B - T_G$ and CL
Noise: temporal SD @ 30 °C	Noise: temporal SD @ 30 °C
Gain, $\frac{dS(T)}{dT}$, from calibration	$\frac{dS(CL,\Delta T)}{dCL}$ *from curve fit to experimental data*

Why is the figure of merit, NECL useful?

Recap from A&WMA 2015

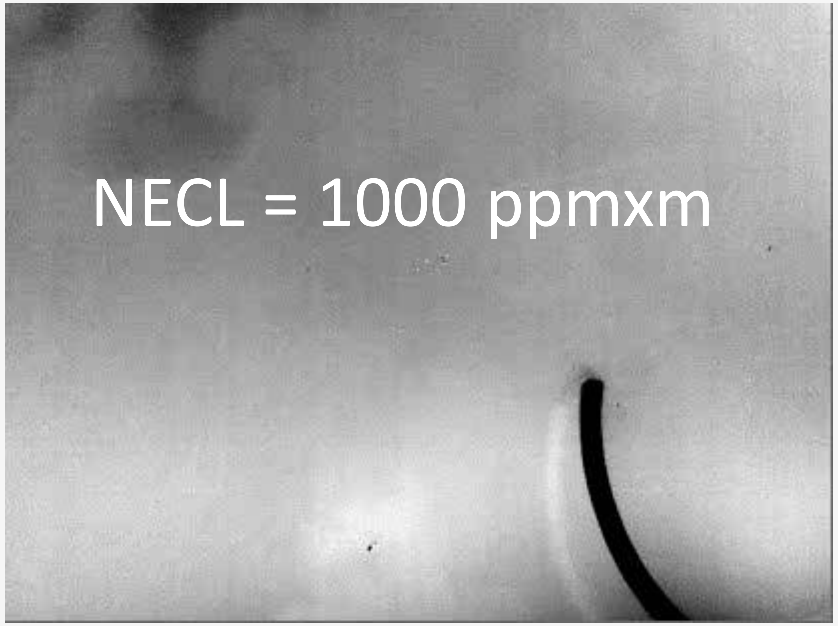
Low sensitivity camera : 7-14µm
NETD = 108 mK

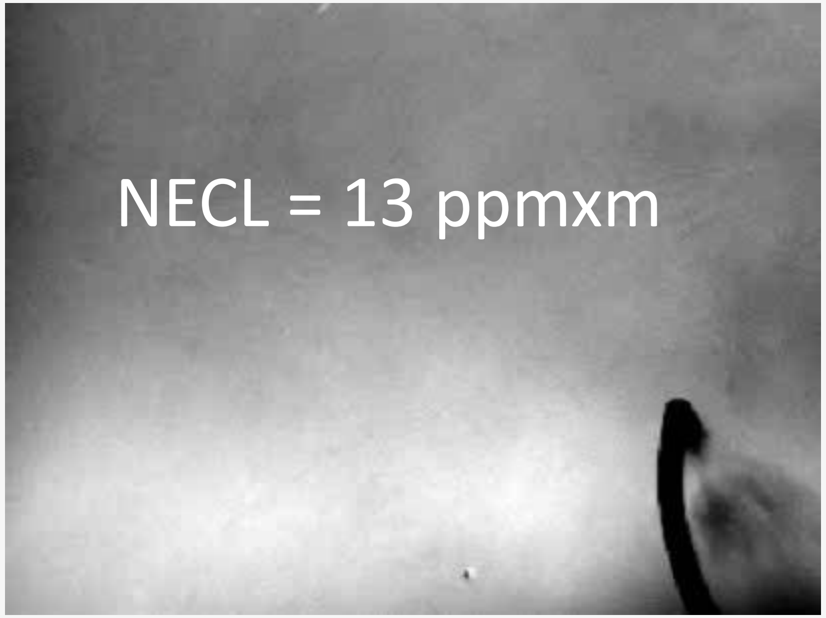
GF 320: 3.2-3.4µm
NETD = 15 mK



Outdoor wall Tb=39°C, Tg=17°C, ΔT = 22°, Methane flow = 10 liter/min,
Wind 5-10 m/s, Rel. humidity = 23%, Distance = 1 m
Low sensitivity camera: F# 1.1, 12.5 Hz, -40°C to 150°C
GF320: F# 1.6, 15 Hz, 10°C to 60°C

Methane visualization





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Gas Contrast

The gas contrast against the background is a fundamental function of the apparent temperature and the gas concentration path length. T, Delta T and CL

Gas contrast camera qualities :

- spectral range
- camera settings (temperature range)
- display

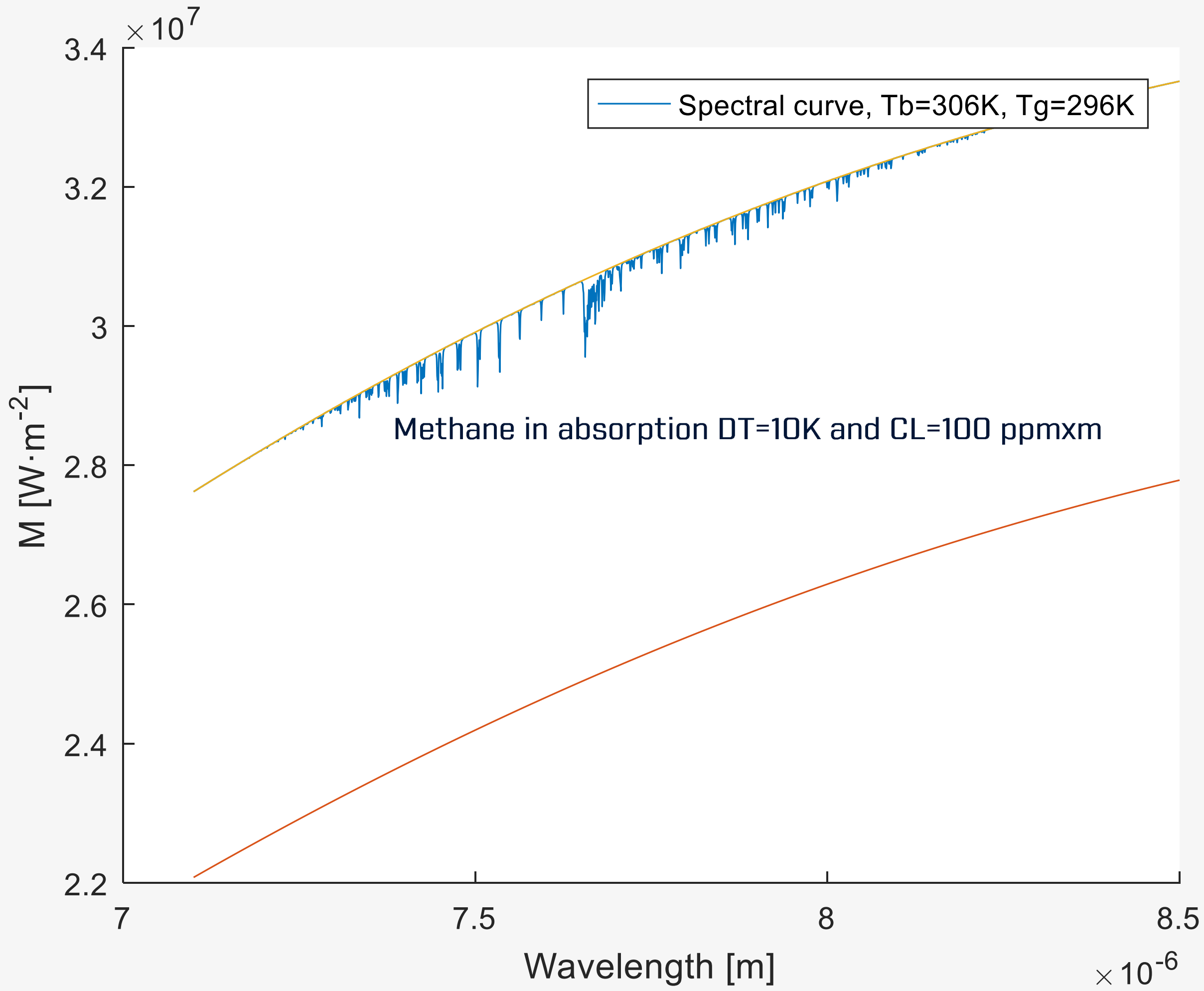
Environmental/user conditions:

- perception
- distance
- humidity
- wind
- visibility (snowstorm, rain, dust)

ΔT exactly 0 -> no gas visualized

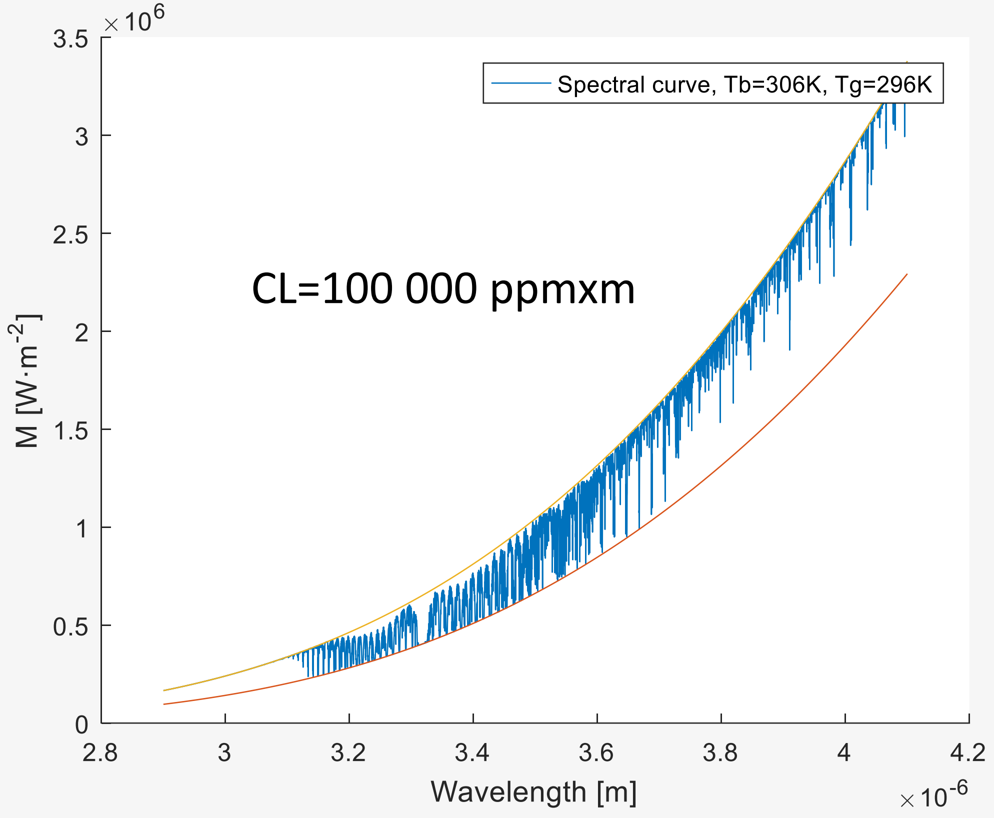
Gas Contrast Definition

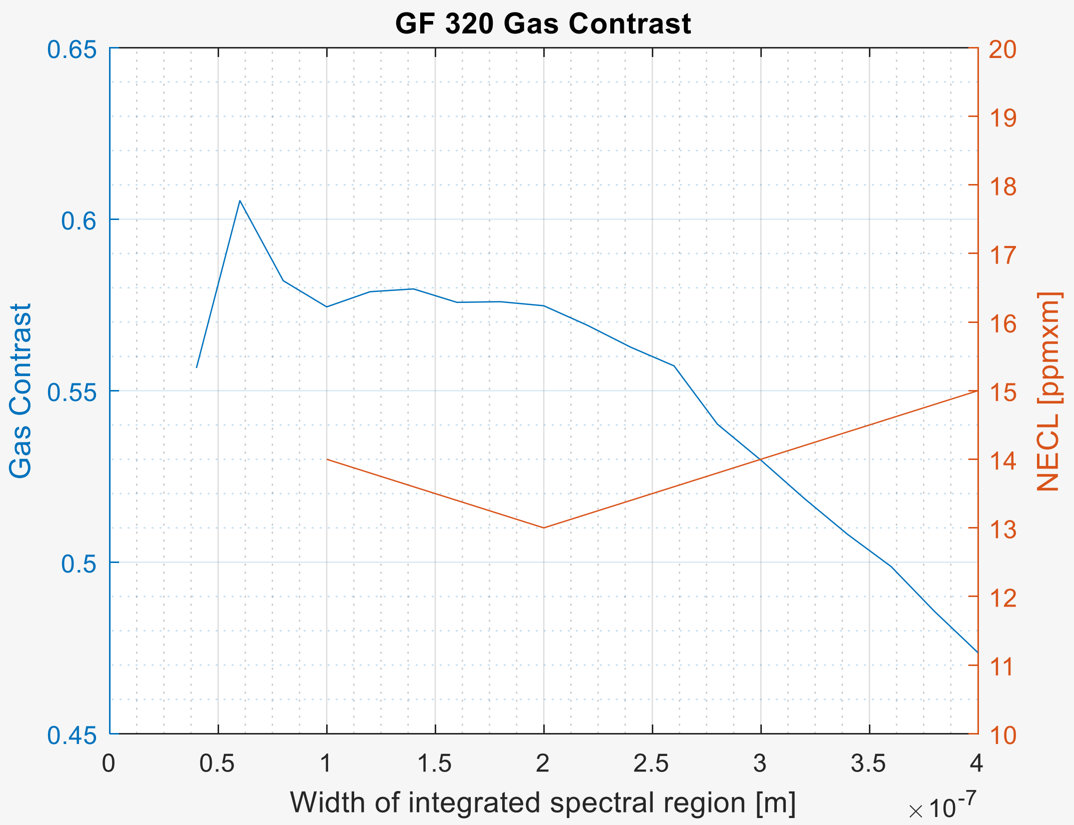
$$GC = 1 - \frac{\int_{\lambda_1}^{\lambda_2}\left(M_b(\lambda) - M_g(\lambda)\right) \times T(CL,\lambda) \times \tau_{resp}(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2}\left(M_b(\lambda) - M_g(\lambda)\right) \times \tau_{resp}(\lambda)\, d\lambda}$$



$\lambda =$	*Wavelength*
$M(T,\lambda) =$	*Exitance at T_b or T_g*
$T(CL,\lambda) =$	*Gas Transmittance*
$\tau_{resp} =$	*Spectral system response*

Gas Contrast Optimized





GC = 0.575 at bandwidth = 0.2 µm

Four useful Figures of Merit (FOM)

NETD	NECL
Noise Equivalent Temperature Difference	*Noise Equivalent Concentration Length*
$S(T + T^{NETD}) - S(T) = noise$ $T^{NETD} = \frac{noise}{\frac{dS(T)}{dT}}$	$S(CL + CL^{NECL}) - S(CL) = noise$ $CL^{NECL} = \frac{noise}{\frac{dS(CL)}{dCL}}$

Alternative def.:
Gas Contrast

$$GC = \frac{T(CECL) - T(CL = 0)}{T_{max}^{span} - T_{min}^{span}}$$

Minimum Lab. Leak Rate

Personal subjective measure of minimum lab. leak rate seen with a camera, can be used to fine tune the image processing.

The gas sensitivity camera matrix

Can I See "x" Compound with a FLIR GF Camera?

NOTE: This data is for reference only and should be confirmed by in-field testing or other means
NOTE: Cameras gas detection sensitivity levels vary dependent on camera model

YES					
MAYBE (requires field testing)					
NO (or Assumed No)					
high	< 50 ppm x m	medium	< 150 ppm x m	low	< 250 ppm x m

			Cooled Cameras					Uncooled Cameras	
Gas	**Chemical Name**	**Chemical Formula**	**GF320/GFx320**	**GF343**	**GF346**	**GF304**	**GF306**	**GF77-LR**	**GF77-HR**
Ammonia	Ammonia	NH_3					high		high
Butane	Butane	C_4H_{10}	high					low	
Carbon Dioxide	Carbon Dioxide	CO_2		high					
Carbon Monoxide	Carbon Monoxide	CO			high				
Ethyl Alcohol	Ethanol	C_2H_6O	high			high		medium	medium
Ethylene	Ethylene	C_2H_4	high				high		high
Hydrocarbons	Multiple	C_xH_x	high			low		medium	
Methane	Methane	CH_4	high					medium	
Propane	Propane	C_3H_8	high						
R22	Chlorodifluoromethane	$CHClF_2$	medium			medium		medium	
R134A	1,1,1,2-Tetrafluoroethane	$C_2H_2F_4$				high	medium	high	low
R410A	R-32 / 125 (50% / 50%)	50% CH_2F_2 · 50% C_2HF_5				high		high	low
Sulfur Dioxide	Sulfur Dioxide	SO_2				medium		high	
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6					high		high

Sandsten, Jonas:
NECL=13 ppmxm
CL=130 ppmxm

Multiple Hydrocarbons: Methane 68.49%, Ethane 11.21%, Propane 10.41%, Isobutane 1%, Butane 3.68%, Isopentane 0.72%, Pentane 0.84%, (Hexanes Pus 0.46%)

The physics behind false positives in the field

Some of the false alarms encountered:

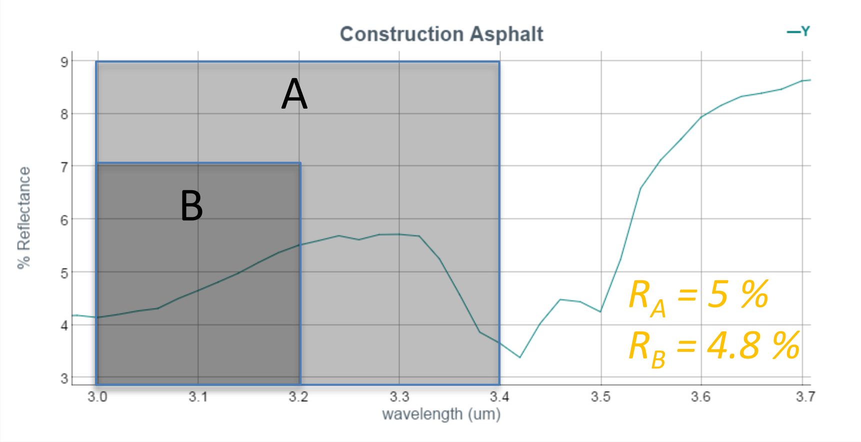
- Condensing and non-condensing water, steam
- Clouds low height, fast moving
- Supersonic jets
- Air convection and humidity variations against smooth surfaces

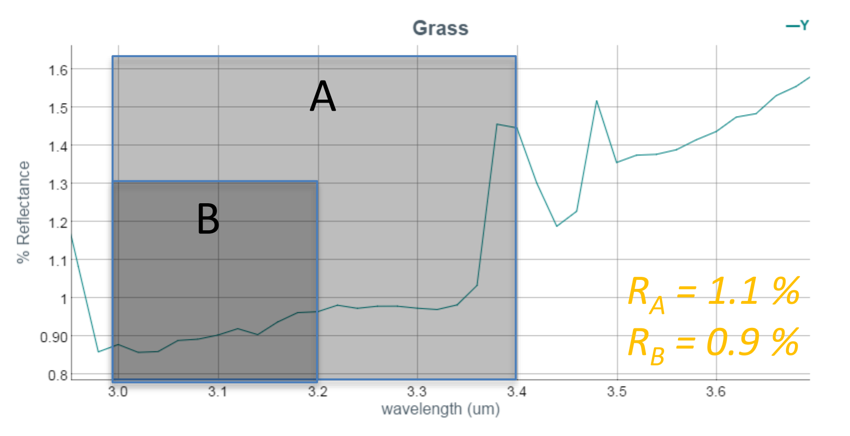
- Other hydrocarbons and spectrally interfering gases
- Exhaust gases

- Sun reflectance, much stronger in MWIR than LWIR
- Shadows of clouds
- Moving objects: birds, trucks, people, flags, swaying grass

Physics

- Interferences which are wavelength dependent
    - Slowly varying scattering with wavelength
        - Atmospheric disturbances/turbulence
- Faster reflectance and emissivity changes with wavelength
- MWIR vs LWIR & Planck's law → Large exitance variations





Source: Aster database

Remedies

- Traditional image processing with background subtraction, mostly used with fixed mount OGI cameras:
  - In time, High Sensitivity Mode
  - Spatially, collect background images
- Choice of spectral bands optimized based on NECL and GC. Atmosphere and interfering gases can be included.
- Multispectral or hyperspectral detection
- Gas detection by constantly training AI
- Operators knowing which gas is leaking from the processing plant components e.g. valves, pack boxes

Conclusions

- We see that measured and simulated FOM's in combination are user friendly when selecting an OGI camera.
- We have NEDT, NECL and Gas Contrast in MATLAB and use them as powerful development tools.
- Depending on gas flow in motion pictures the concept gas contrast is important. Human perception is excellent in detecting optical flow in videos.
- We have looked at the gas sensitivity OGI camera matrix:

https://www.flir.com/instruments/optical-gas-imaging/what-gases-can-i-see-cooled-vs.-uncooled/

- False alarms in the field can be understood and reduced

Thanks!

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