Innovative Infrared Imaging.

Direct Imaging of Shale Gas Leaks Using Passive Thermal Infrared Hyperspectral Imaging

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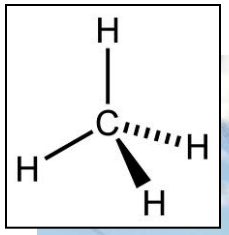
About Telops

- Established in 2000 in Quebec City.
- About 50 employees (Ph.D., M.Sc., Eng.).
- Privately owned and profitable since its creation.
- Worldwide network with distributors around the globe.
- Established as a world leader in thermal infrared imaging solutions.

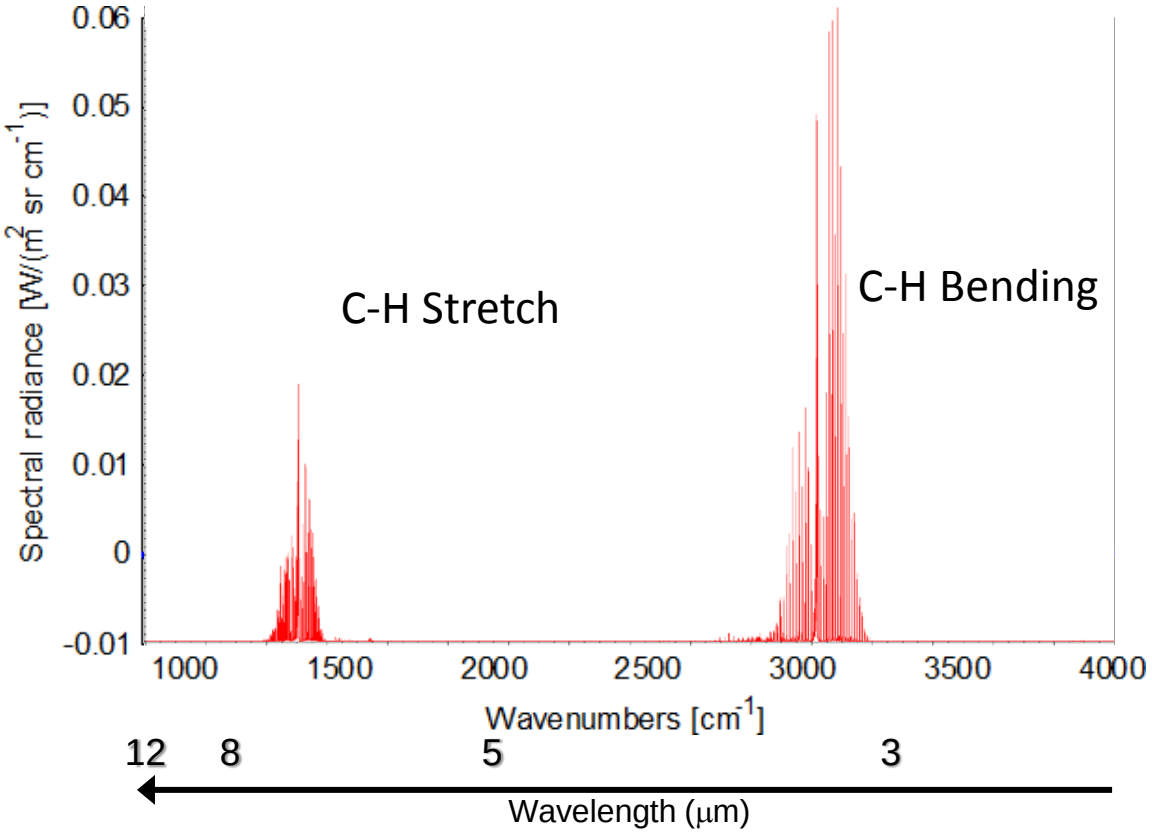
Methane

- Among the most infrared-active naturally occurring molecules
- Important greenhouse gas[1]
- Major component in
  - Landfill Gas (LFG)
  - Natural Gas, including shale gases
  - Bacterial decomposition products
- Flammable/Explosive
- Naturally present at low concentration (1.79 ppm) in the atmosphere



D.A. Lashof and D.R. Ahuja, "Relative Contributions of Greenhouse Gas Emissions to Global Warming," Nature, 344 (1990) pp.523-531

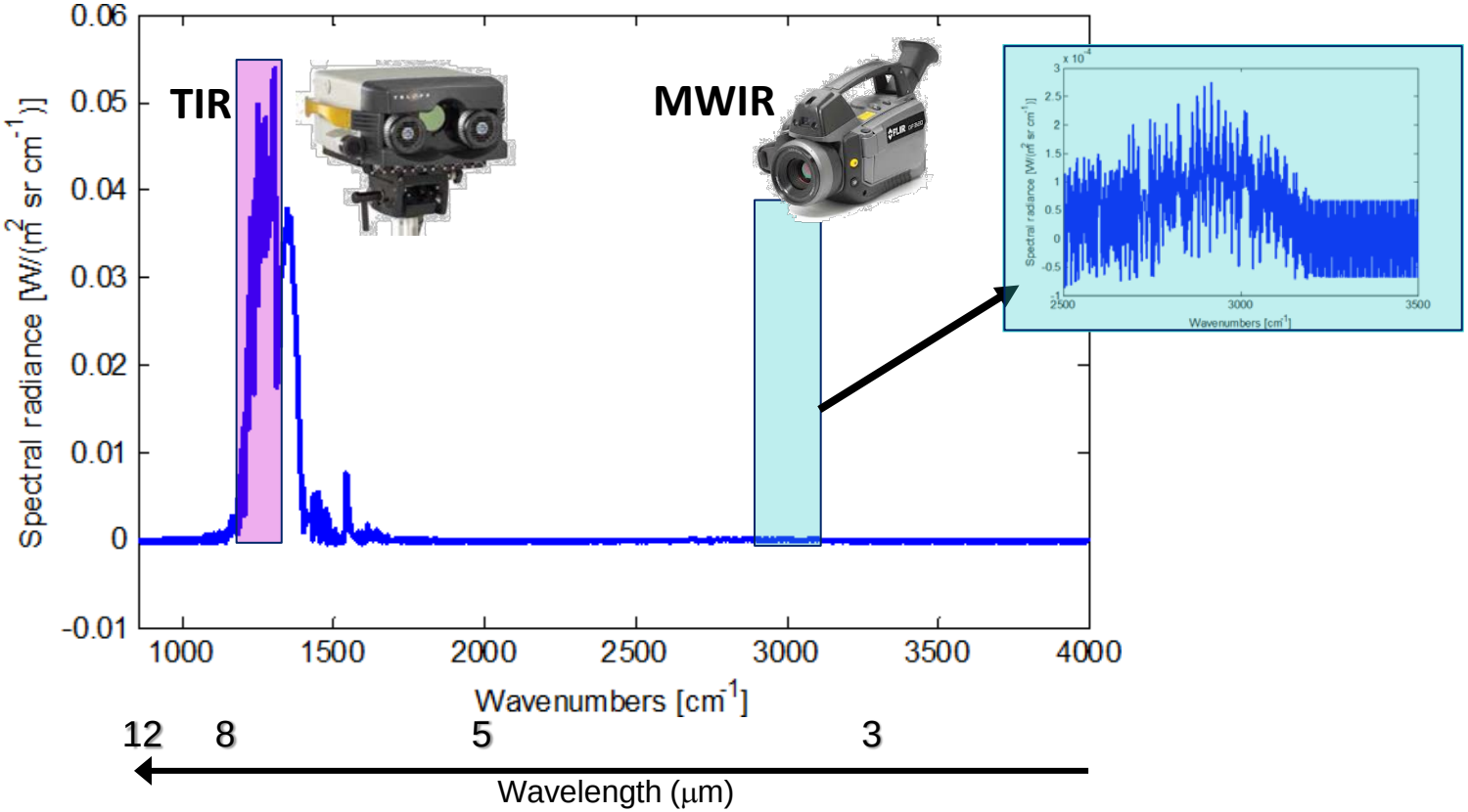
Methane Infrared Absorption Features



- The 2 main vibrational modes of methane

Methane Infrared Remote Sensing

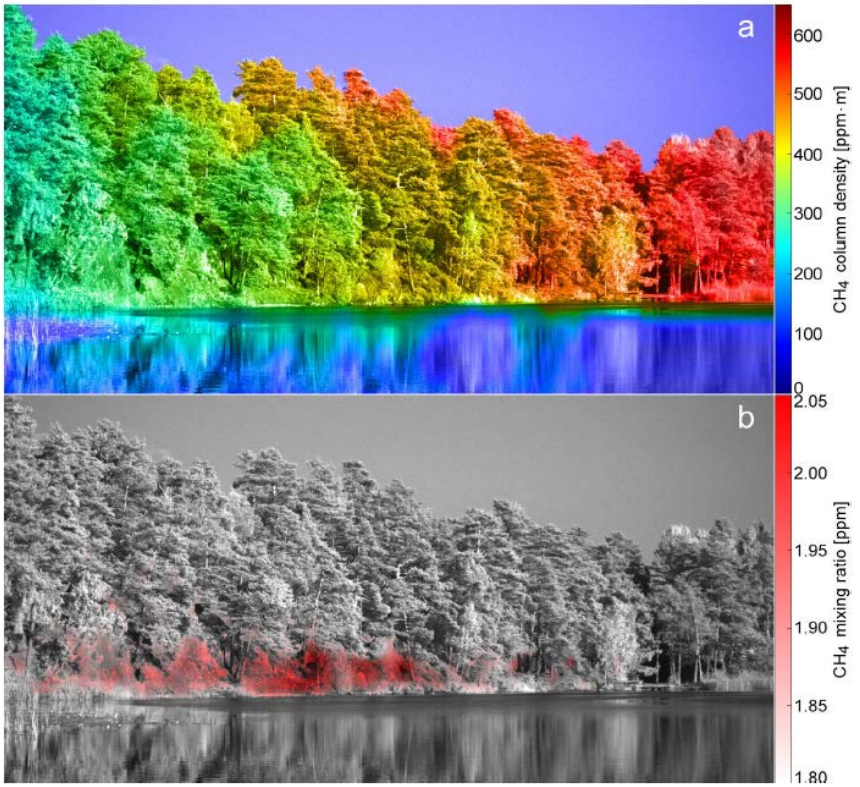
Methane self-emission@298 K (25 °C)



- Under ambient conditions, methane self-emission is much higher in the thermal infrared (TIR) spectral range (7.65 μm) than in the midwave infrared (MWIR) spectral range (3.3 μm).

Methane Imaging

- Passive infrared hyperspectral imaging of methane :
  - Spectroscopic confirmation from high-resolution spectra
  - Methane quantification
  - 2D spatial resolution for surveying large areas
  - Temporal resolution



Supplementary Figure 6. Mapping and quantification of the CH_4 gradient above the nutrient poor lake Lillsjön, having the lowest CH_4 emissions among the boreal lakes studied in (28) (14 cubes, acquisition time 11.2 min). The calculated column density map (**a**) shows the total amount of CH_4 along all lines of sight in the image. Background distances range from 120 to 350 meters (resulting in increasing amounts of CH_4 per lines of sight from left to right due to increasing background distance) with a field of view of 25 x 9.4°. After division with distances, a map of mixing ratios shows areas with excess CH_4 (**b**). The squares marked with numbers in panel **a** mark the locations of the two selected spectra shown in Supplementary

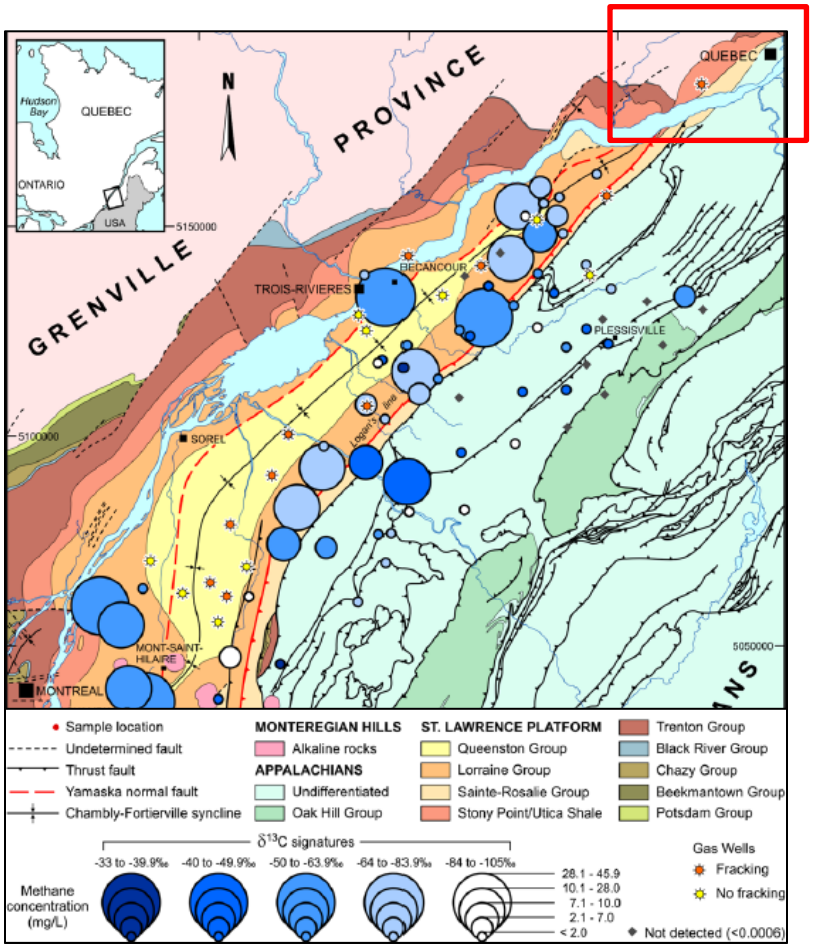
M. Gålfalk, G. Olofsson, et al., "Making methane visible," *Nature Climate Change*, **2877**, pp. 1-5, 2015.

M. Gålfalk, G. Olofsson and D. Bastviken, "Approaches for hyperspectral remote flux quantification and visualization of GHGs in the environment," *Remote Sensing of Environment*, **191**, pp. 81-94, 2017.

Shale Formations

- Very common porous mineral formations found in eastern Canada regions
- Energy reservoir : methane bubbles trapped in the shale formation

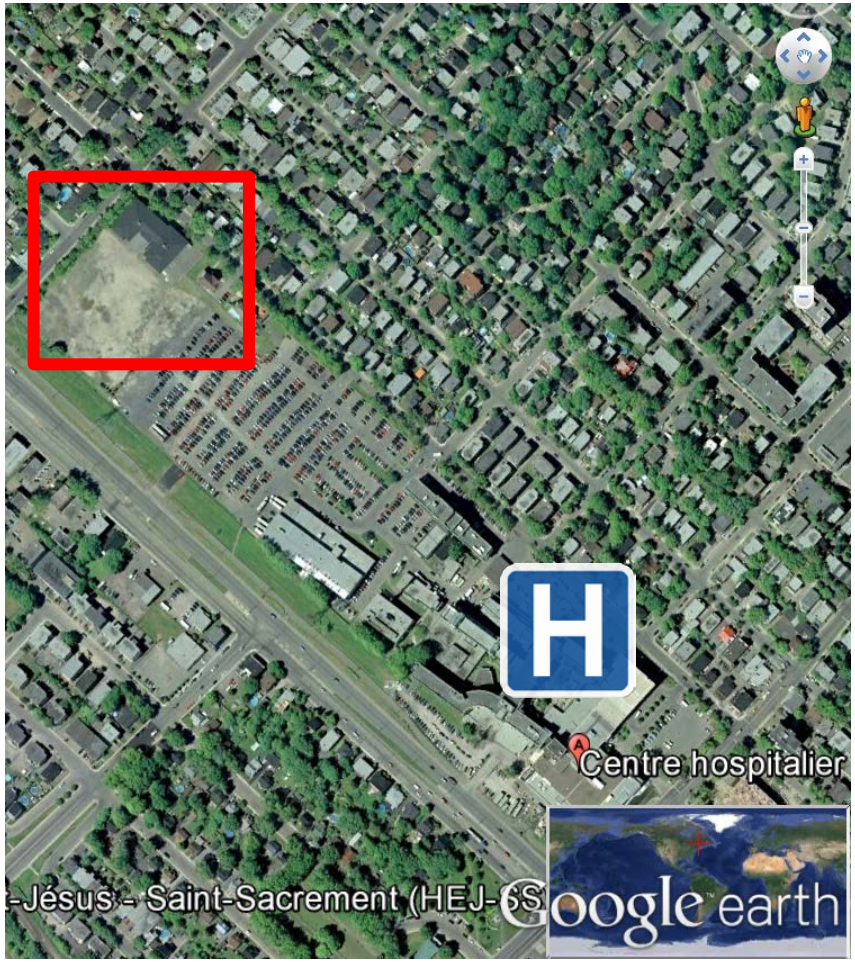

By Travis via Flickr.com



Moritz, A., et al.,"Methane baseline concentrations and sources in shallow aquifers from the shale gas-prone region of the St. Lawrence lowlands (Quebec, Canada) " *Environ Sci Technol* 2015;**49**(7):4765-71.

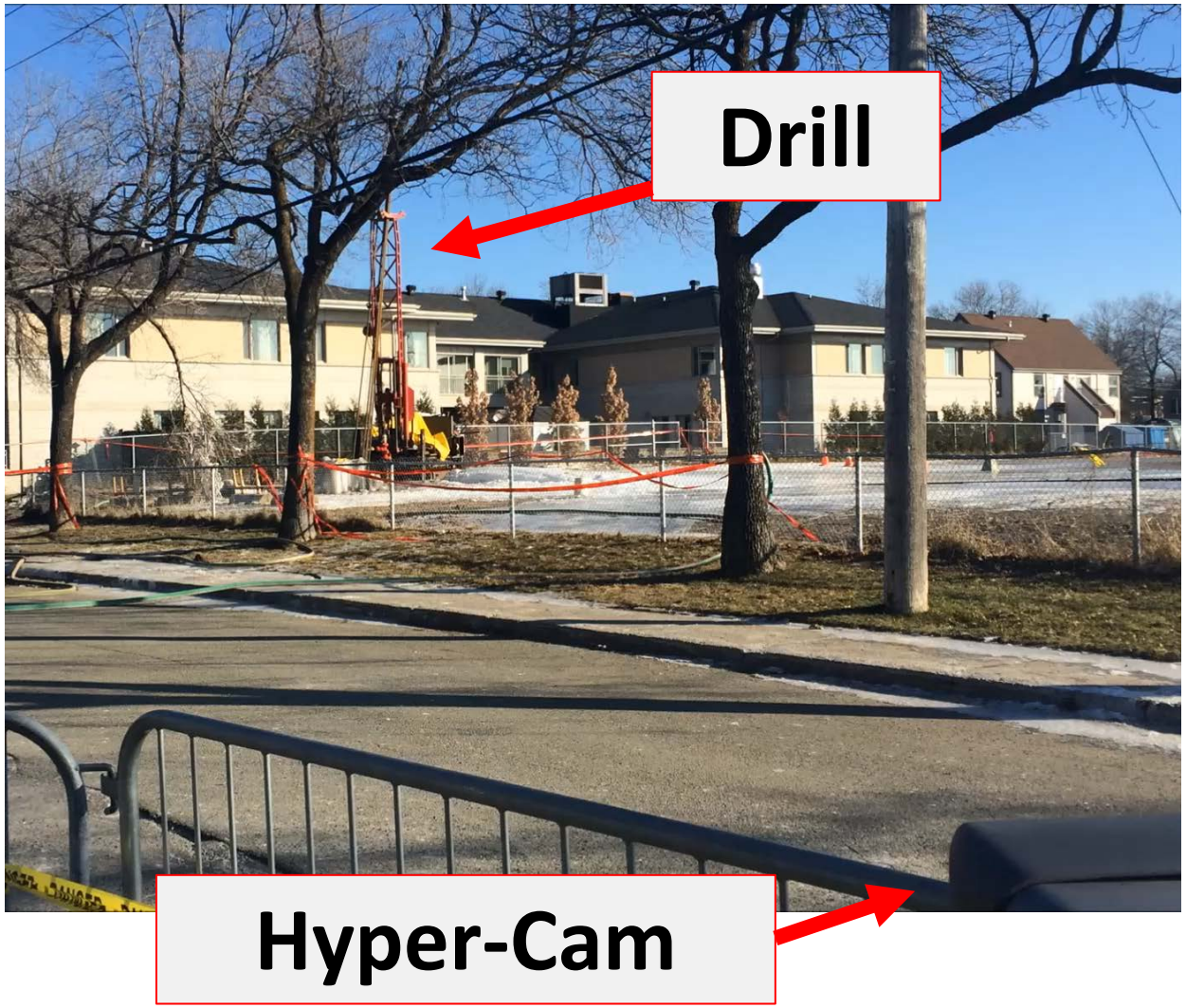
A Tricky Geological Survey

- The drill digs into a natural shale gas reservoir
- Survey carried out in a residential area in the parking of a hospital
- Winter conditions (-20 °C)

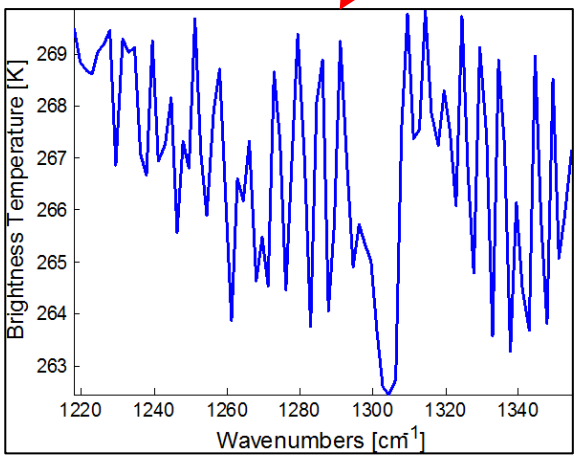


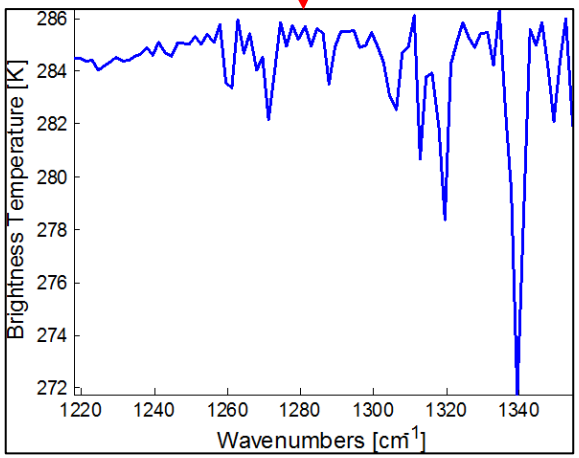
Experimental Parameters

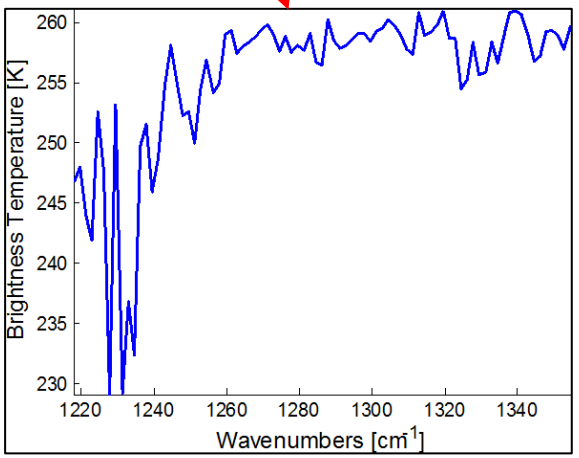
- Distance: 50 m
- Instrument
  Hyper-Cam Methane
- Spectral range :
  7-8 µm(LWIR)
- Spectral resolution:
  2 cm^{-1} (85 bands)
- Image size
  128 x 256 (50 cm^2/pixel)



Typical Measurements







Radiative Transfer Model

Radiance at sensor

$$L_{tot} = \left[L_{bkg}\tau_{plume} + L_{plume}\left(1 - \tau_{plume}\right)\right]\tau_{atm} + L_{atm}(1 - \tau_{atm})$$

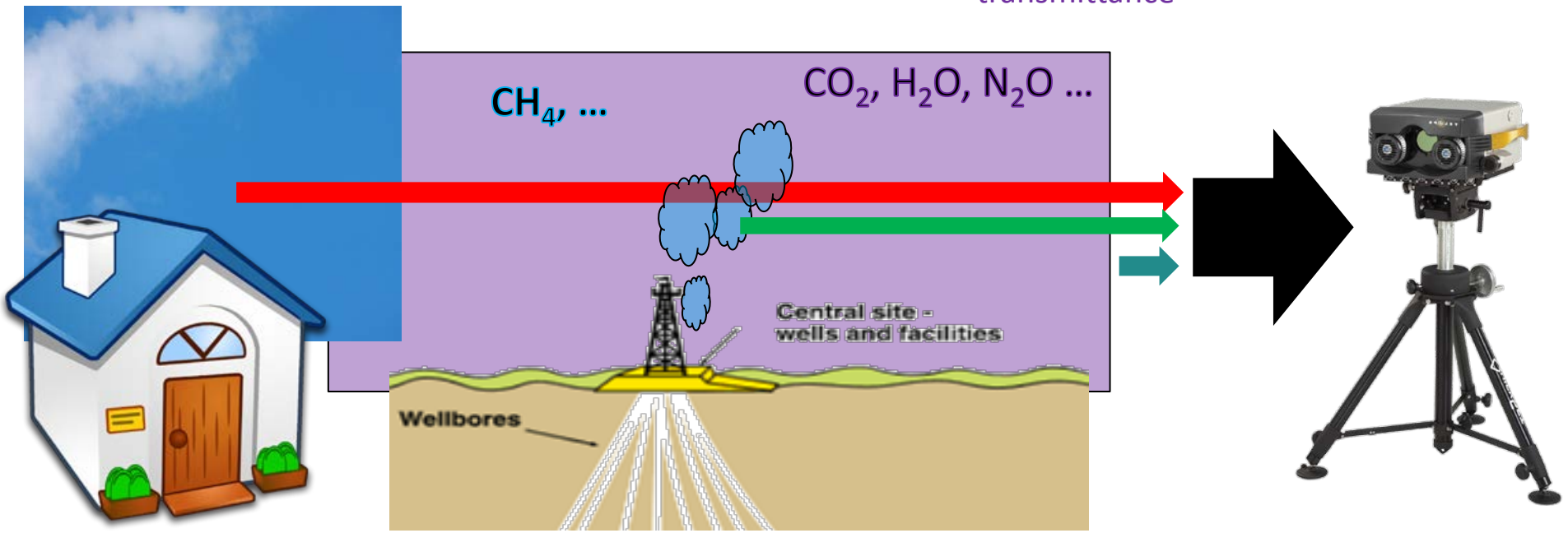
Sky radiance or other objects

Gas plume transmittance

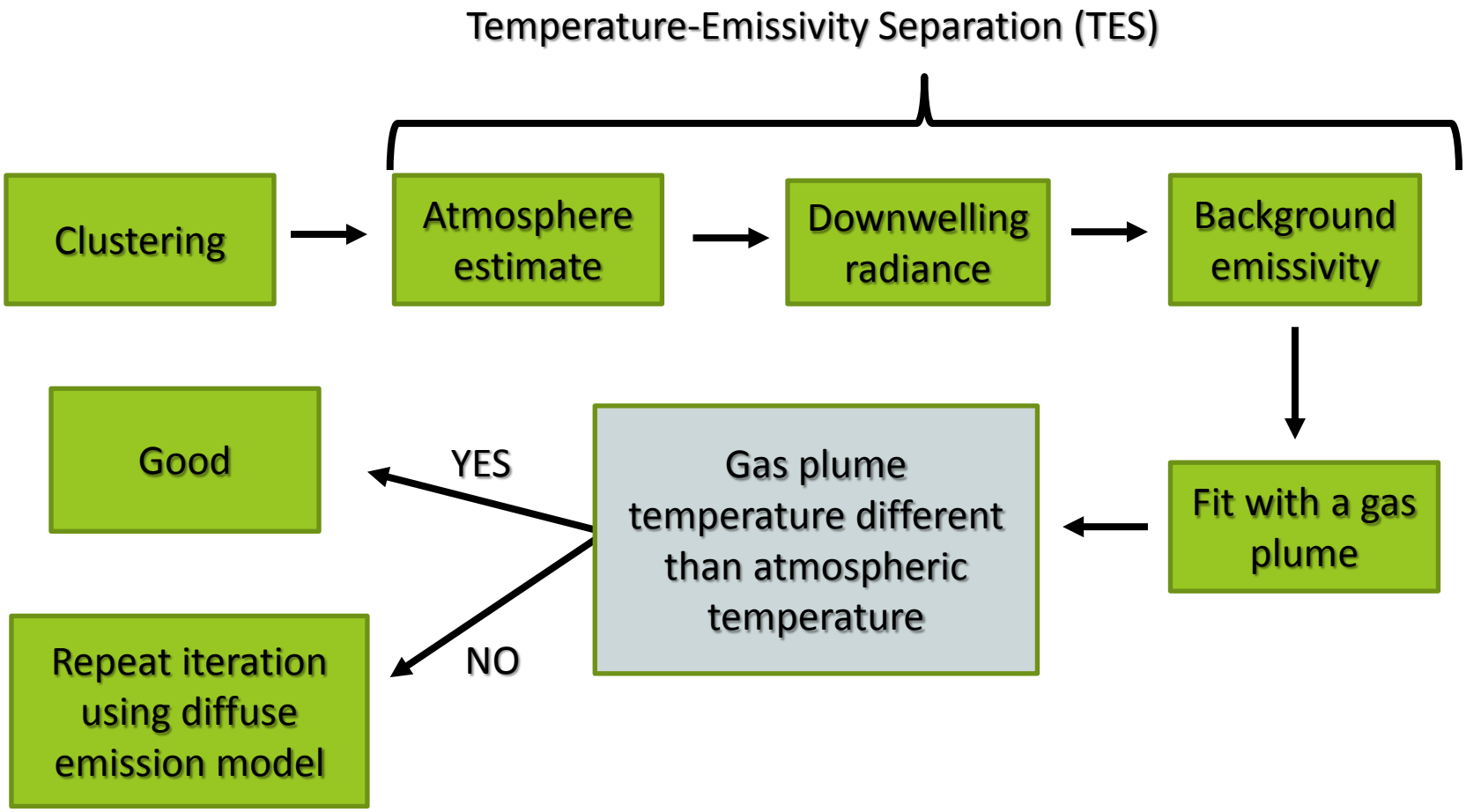
Self-emission from the gas plume

Atmospheric transmittance

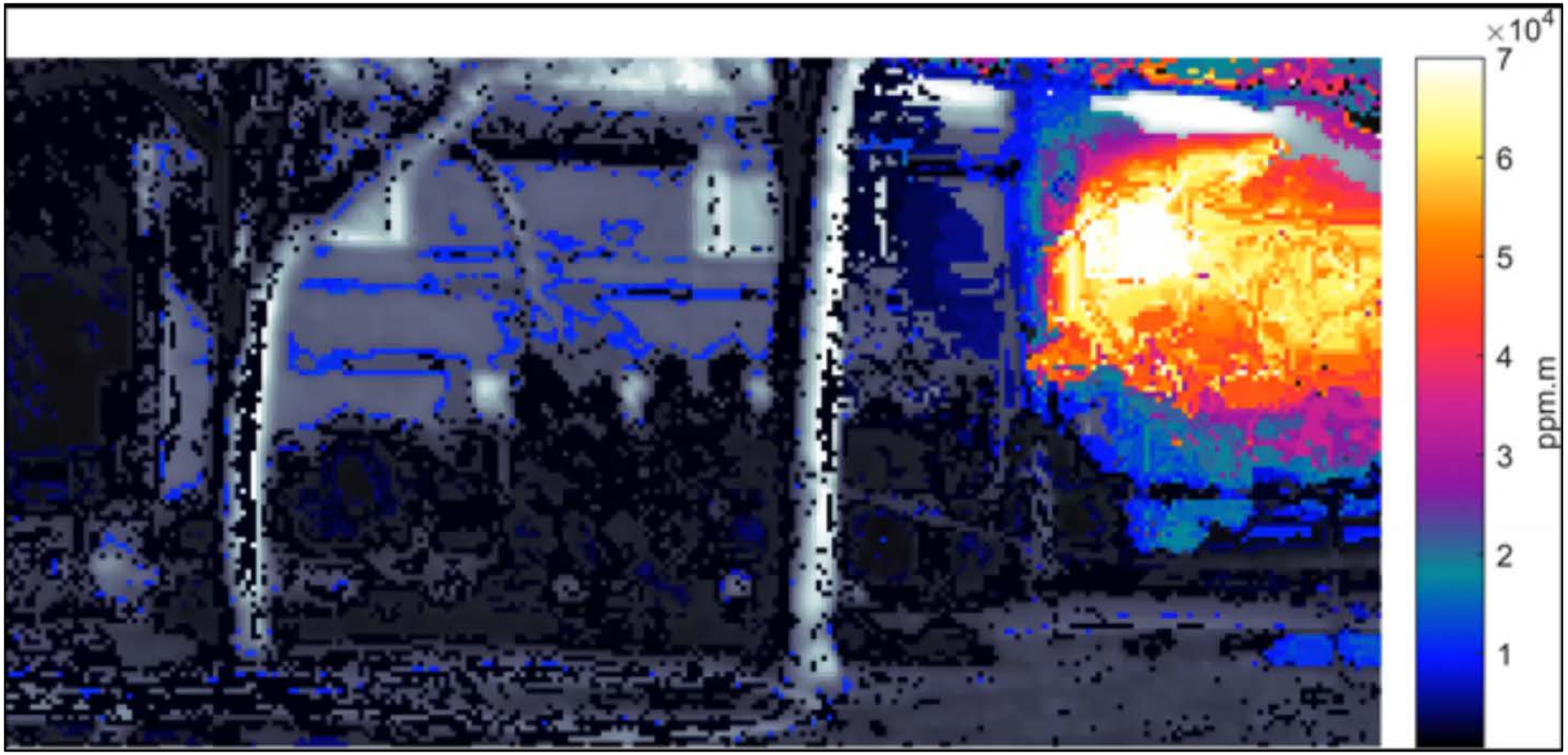
Self-emission from the atmosphere



Algorithm Scheme

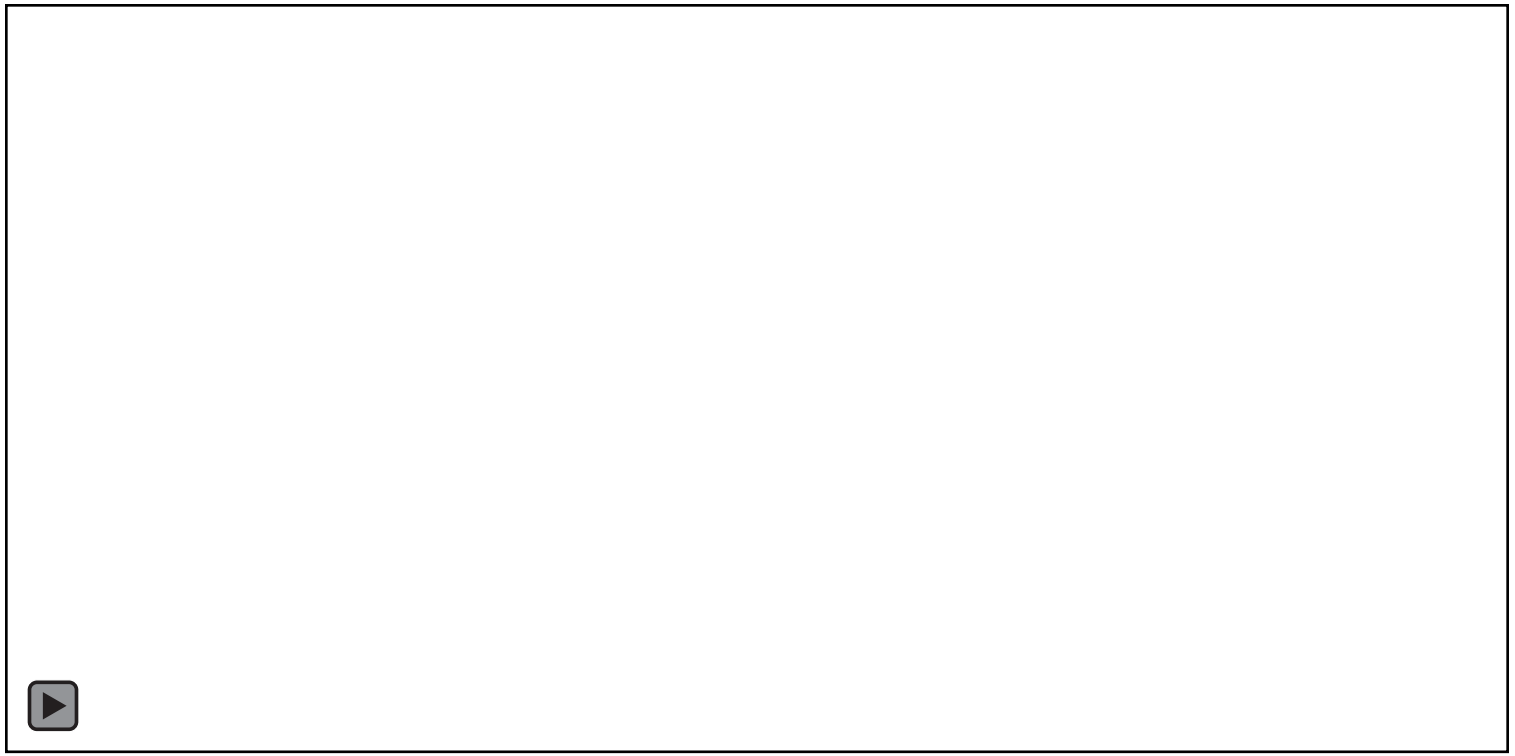


Methane Chemical Imaging



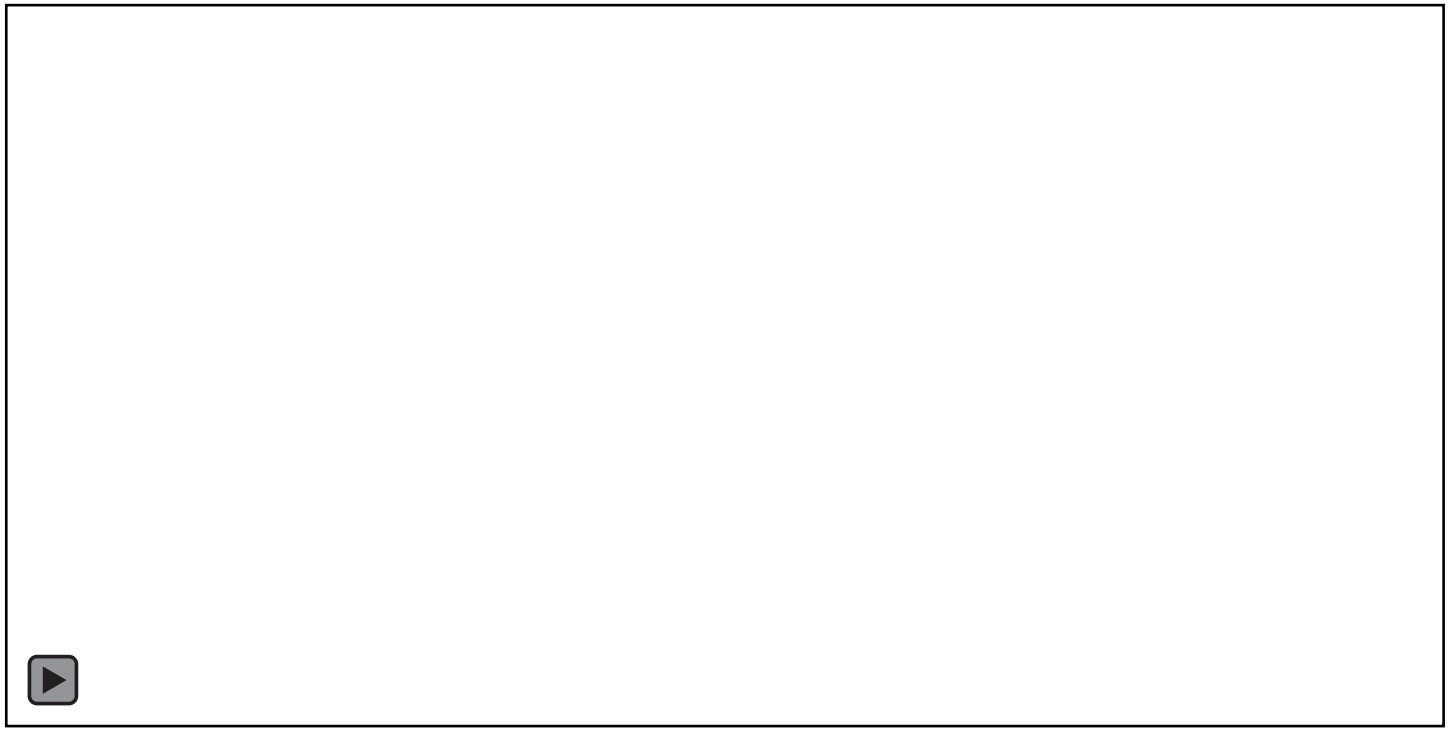
- Assuming a cylindrical geometry of the gas plume next to the drill, the methane concentration is on the order of 6-7%

Velocity Estimation using Optical Flow



- Telops Hyper-Cam is a 2-in-1 camera collecting broadband-like frames at high-velocity

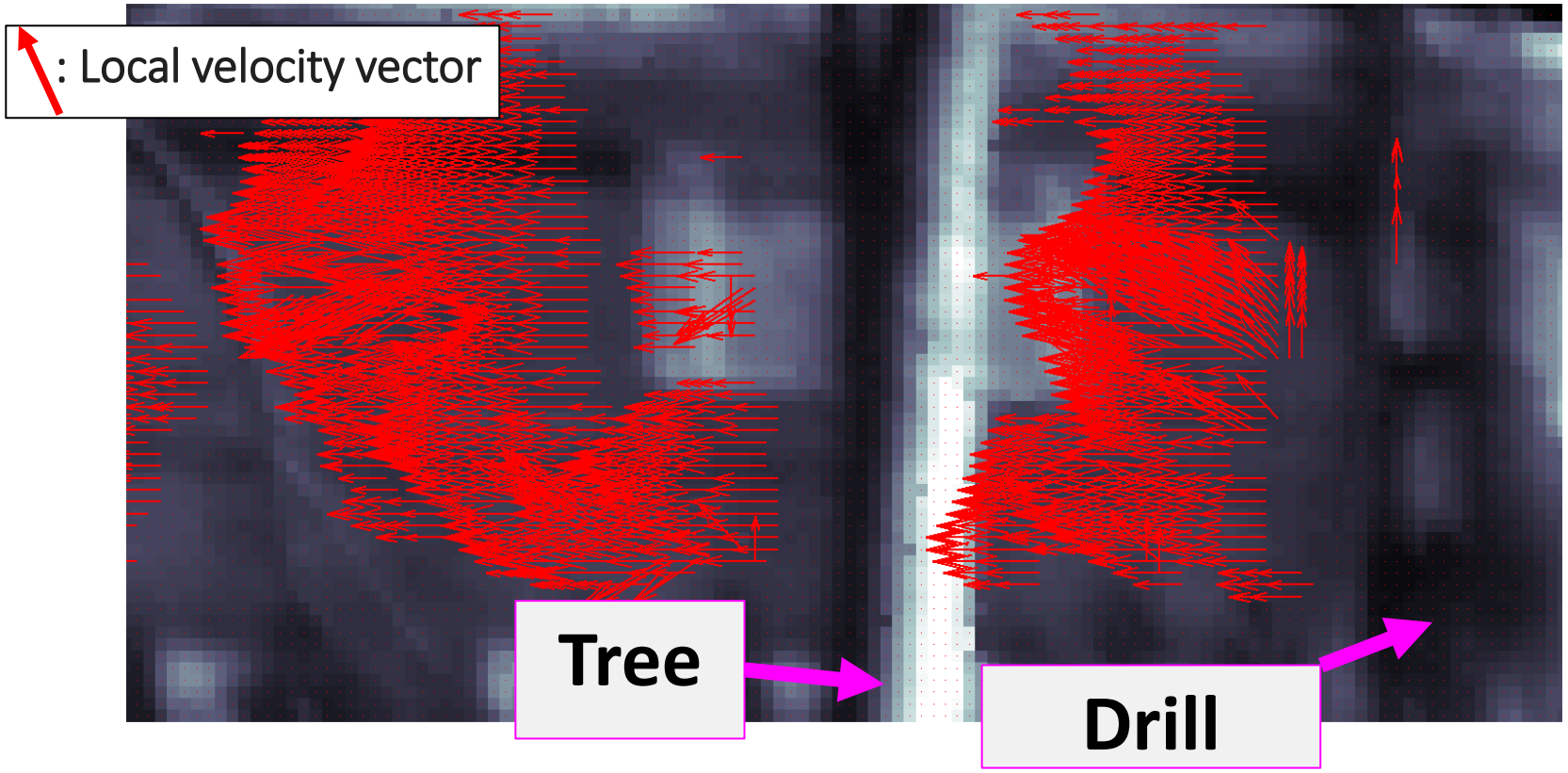
Velocity Estimation using Optical Flow



- Gas cloud velocity is estimated using spatio-temporal correlation algorithms

Horn, B.K.P., Schunck, B.G., Determining Optical Flow, 17, 185-203 (1981).

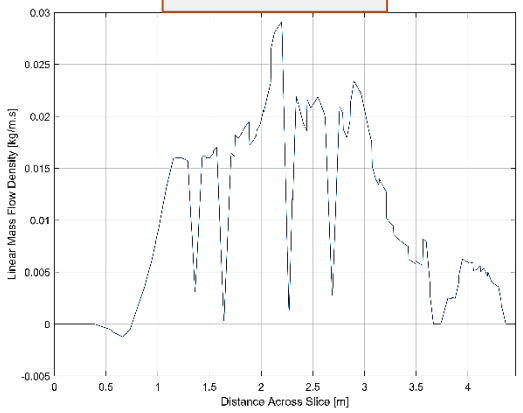
Mean Velocity Map



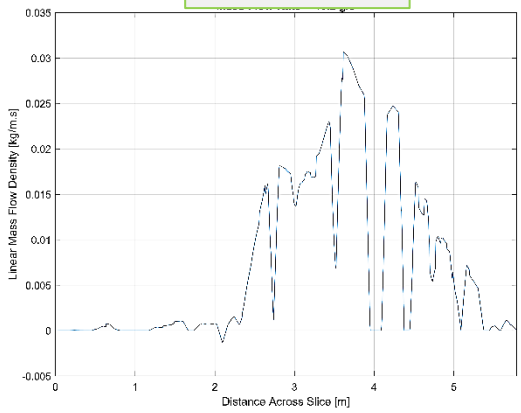
- By combining column density values (ppm×m) and speed (m/s), information about the depth of the gas cloud, i.e. the path (m), is no longer needed

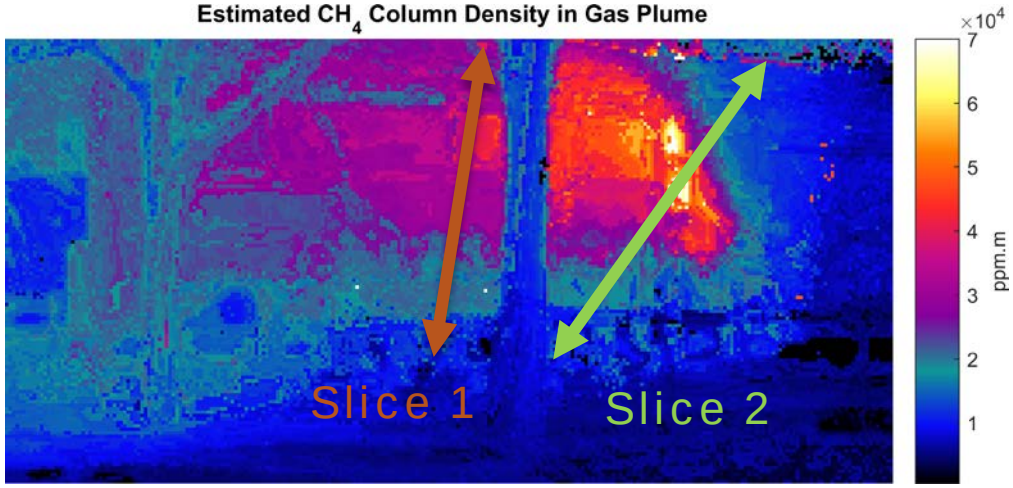
Mass Flow Rate

43 g/s



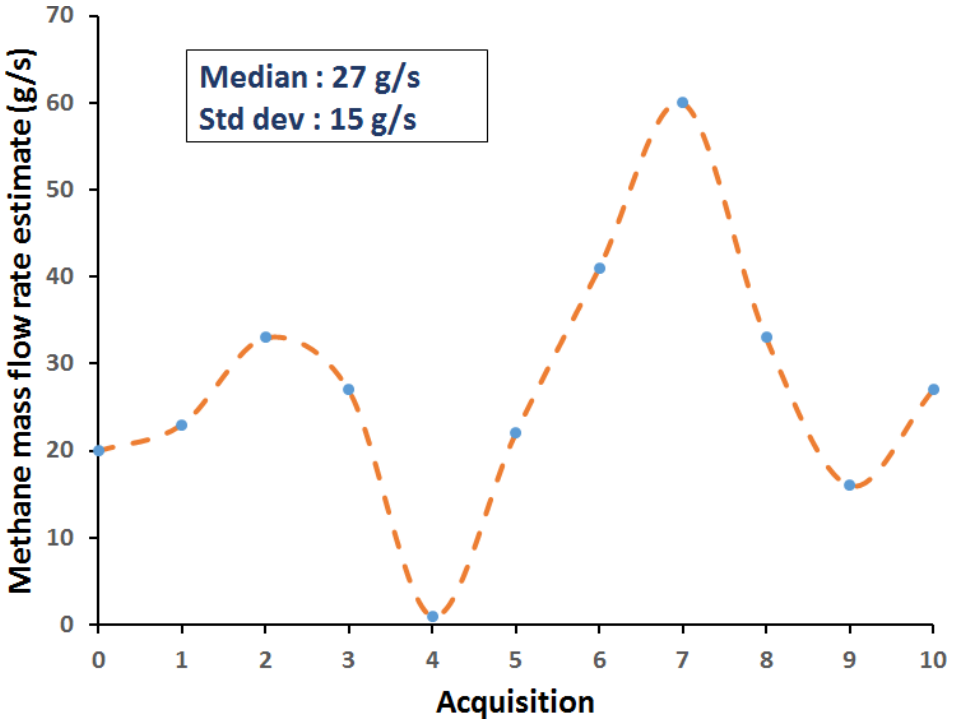
40 g/s





- By combining column density values (ppm×m) and speed (m/s), information about the depth of the gas cloud, i.e. the path (m), is no longer needed
- By summing all linear velocities across a selected slice, a mass flow rate is obtained

Methane Mass Flow Rate Estimates



- The methane gas cloud is significantly driven by cross-wind that keep changing orientation as a function of time
- Net mass flow rate of about 27 ±15 g/s
- Corresponds to ~2000 L/min of methane

Conclusion

- High spectral resolution provides selectivity for methane detection
- High sensitivity due to the stronger self-emission signal in the thermal infrared spectral range
- Quantitative chemical imaging can be carried out as a function of time
- The combination of high-speed broadband-like frame imaging and spectral information allows mass flow rate estimations
- Information obtained from a safe location

Methane concentration above the lower explosion limit (LEL) was measured from a 2-meter distance from the drill

Questions ?

http://m.radio-canada.ca/regions/quebec/2014/11/29/002-fuite-gaz-poche-samedi-canalisations-tentative.shtml.

- A rescue flare was installed for safety purposes …