INVERSE DISPERSION MODELLING FOR A QUICK SCAN SERVICE TO ASSESS FUGITIVE EMISSIONS FROM LANDFILLS

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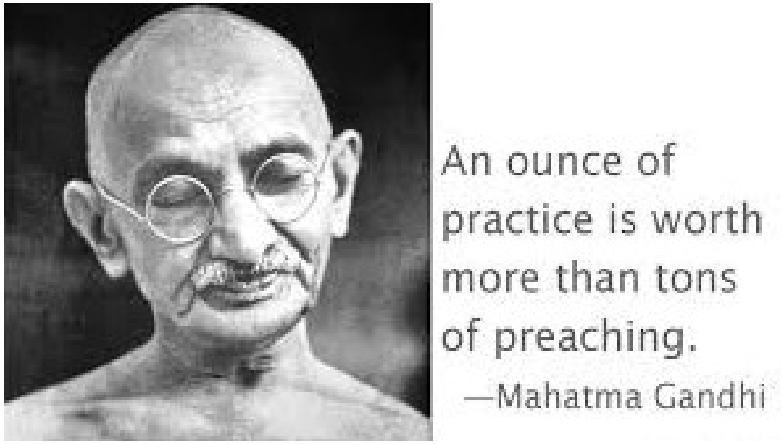

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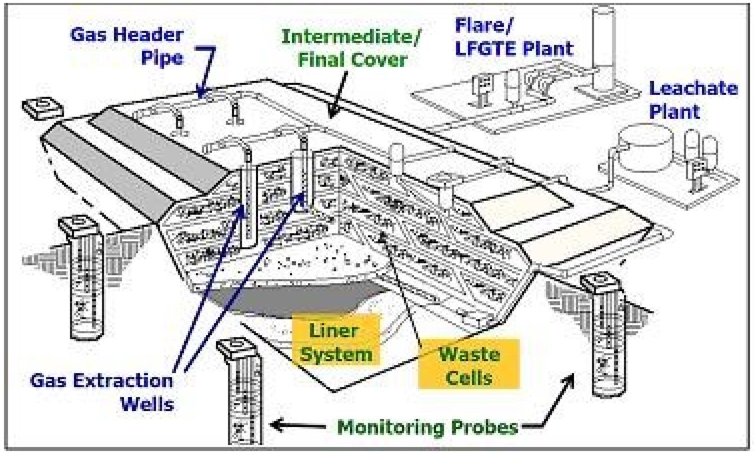
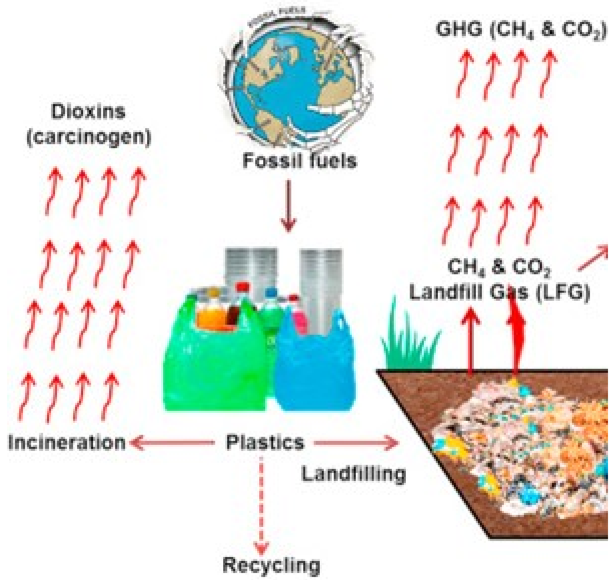
Outline

- **Context**
  - **CH_4 produced by landfills**
  - **GHG MRV and mitigation**
- **Inverse modeling approach**
  - **Experimental site**
  - **Measurement protocol**
  - **Multi-sources back-plume approach**
  - **AMIS adaptive Bayesian approach**
- **Dual tracer method**
  - **Methodology**
  - **Measurement protocol**
  - **Results**
- **Conclusion**





From Chidambarampadmavath et al Renewable and Sustainable Energy Reviews Volume 71, May 2017, Pages 555-562

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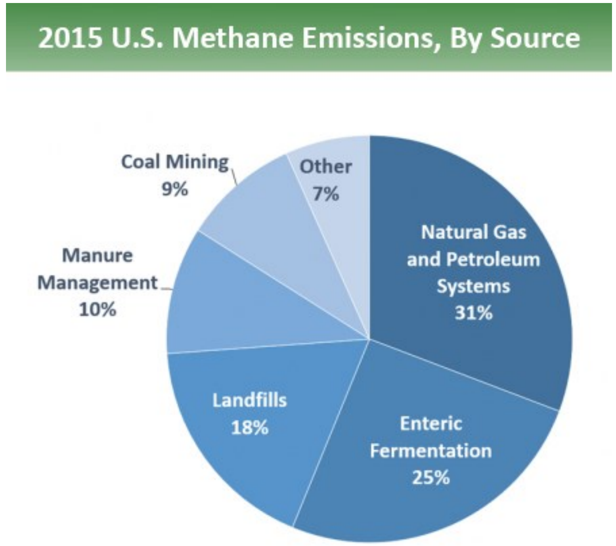
CONTEXT

- 1 kg of CH_4 has the same impact on global warming than releasing 28 kg of CO_2 on a 100 years scale (IPCC 2013).
- CH_4
  - 14% of the world GHG emissions
  - 8.6 % of the European Union GHG emissions in 2010.
    - *595 MtCO2eq in 1990*
    - *405 MtCO2eq. in 2010 (a reduction of more than 30%).*
    - *49% Agriculture & 32% Waste*

Sources : http://www.eea.europa.eu/dat a-and-maps/data/data-viewers/greenhouse-gases-viewer



Source US-EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015.

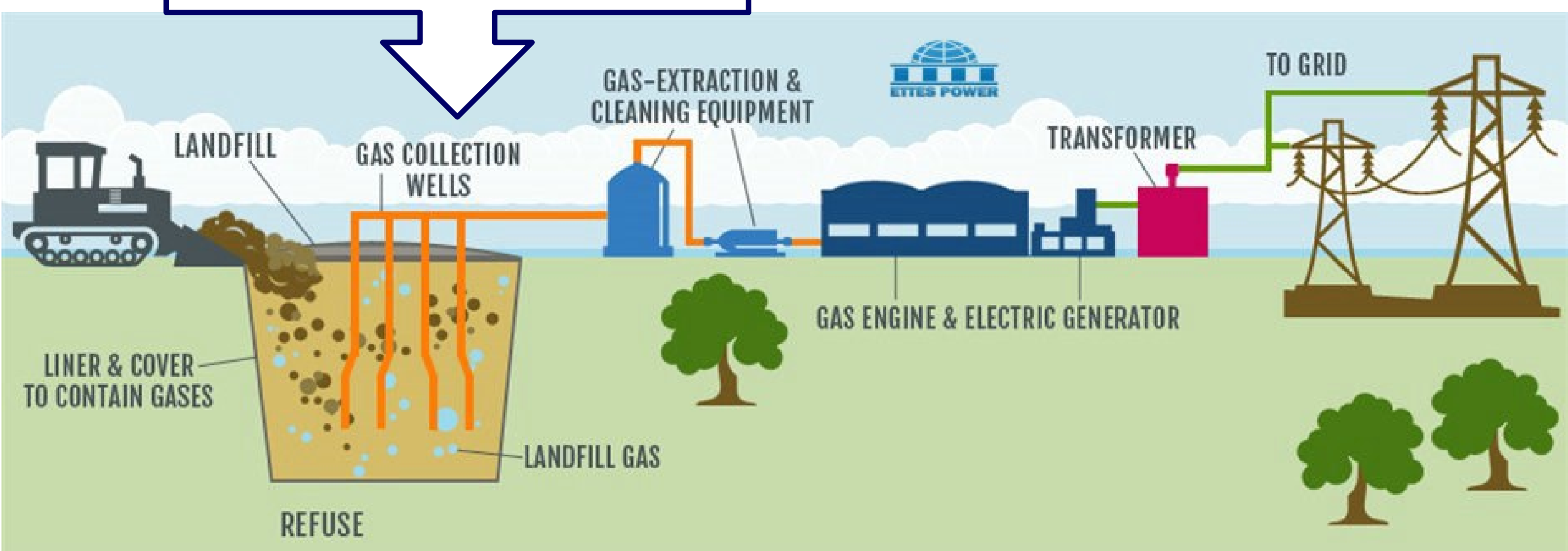
- Landfills : >15% of the total emission of CH_4

CONTEXT

Need of a routine “quick scan” service

- **GHG MRV**
- **Checking collect and countermeasure efficiency**
- **Optimizing the biogas collect and its valorisation**

- **METHANE: ~50%**
- **CO_2 : 35%**
- **Other gases : 15%**



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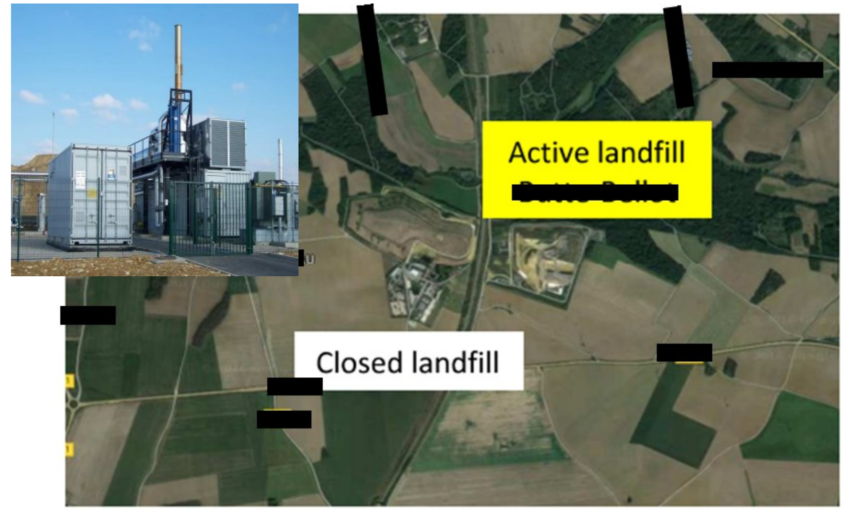
Experimental site

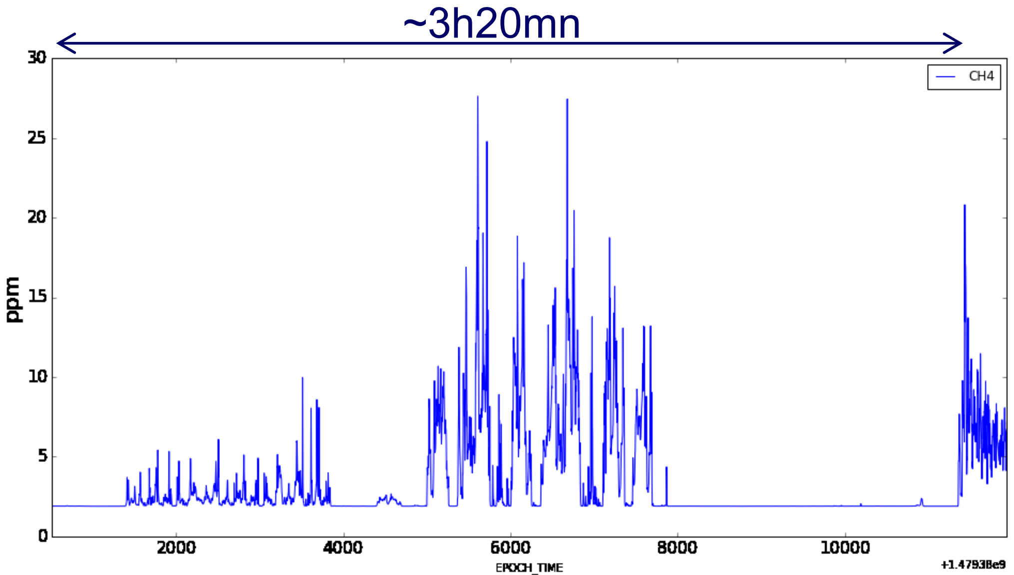
- **Domestic /urban waste landfill**
- **Rural site - Flat natural terrain**
  - **Old one closed (1974- 2004)**
  - **Active one from 2005**
    - ***~ 250 000 t / year***
    - ***30 ha x H=20m ; 2.8 M m^3 /3.1 M t***
  - **Biogas 4.5 M Nm3 collected**
  - **9.5 Gwh_e ~900 toe (tep) saved**



Présentation de l'Installation

Experimental set-up & data

- CH_4 measurement (dt = 1s)
  - Picarro analyser (G2203)
  - Cavity Ring Down Spectroscopy
  - PC +GPS
  - Power supply
- Meteorological ground station



Multi-sources back-plume approach

- **Base on linearity between sources and receptors and steady state assumption : n area sources, m receptors**

$$\begin{bmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \ddots & \vdots \\ A_{m1} & \cdots & A_{mn} \end{bmatrix} \begin{bmatrix} Q_1 \\ \vdots \\ Q_n \end{bmatrix} + \begin{bmatrix} B_1 \\ \vdots \\ B_m \end{bmatrix} = \begin{bmatrix} C_1 \\ \vdots \\ C_m \end{bmatrix}$$

  - A_{ij} **is the atmospheric transfer coefficient from source *i* to measurement *j***
  - Q_j **is the emission rate of the source *j* from 1 to n**
  - C_i **is the measured concentration at receptor *i* from 1 to m**
  - B_i **is the background at receptor *i* from 1 to m => <B>**

- **Finding Q_j required $[A_{ij}]$ (pseudo)inversion**
  - **Quick means n and m not to big**
  - $[A_{ij}]$ **well conditioned**

Multi-sources back-plume approach

- The “Condition Number” of matrix *A*, $\kappa(A)$, is an indicator of how the error on concentration may be amplified when source rates are obtained

$$\kappa(A) = \frac{M_{max}}{M_{min}} = \|A\|_M . \left\|A^{-1}\right\|_M$$

- Considering Euclidian distance

$$\|x\|_E = \sqrt{\sum_1^N {x_i}^2}$$

- How much the matrix A(n,m) can stretch vectors ?
  - $M_{max} = max\left(\frac{\|Ax\|}{\|x\|}\right) = \|A\|_M$ *Considering “max distance”*
- how much the matrix A can shrink vectors ?
  - $M_{min} = min\left(\frac{\|Ax\|}{\|x\|}\right) = \frac{1}{\left\|A^{-1}\right\|_M}$

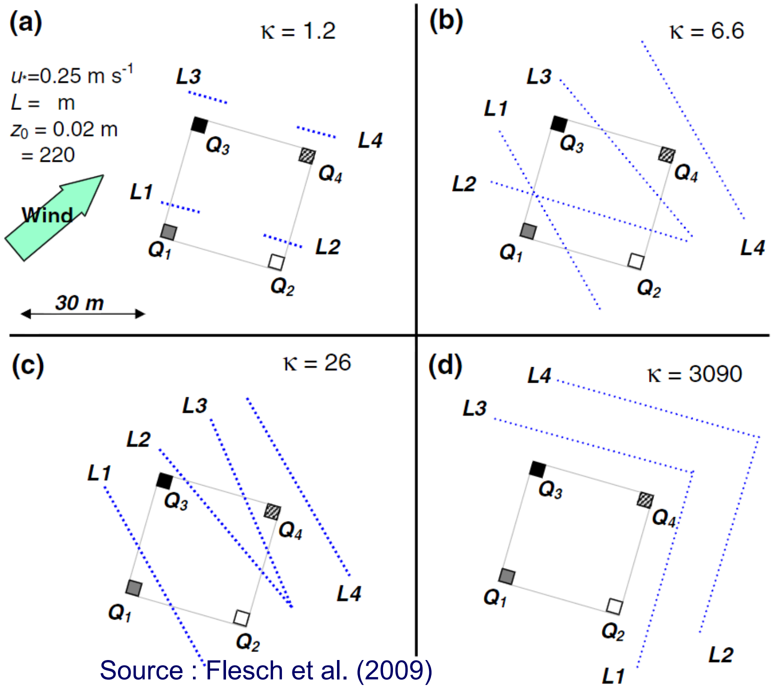
Multi-sources back-plume approach

- We need to solve a system ***AQ = C***
  - **C is corrected from background**
  - $\|C\| \leq M_{max} \|Q\|$
- $A(Q + \delta Q) = C + \delta C \text{ or } A\delta Q = \delta C$
  - $\|\delta C\| \geq M_{min} \|\delta Q\|$
- $\|C\|. M_{min} .\|\delta Q\| \leq M_{max} \|Q\| \|\delta C\|$

$$\frac{\|\delta Q\|}{\|Q\|} \leq \kappa(A) \left(\frac{\|\delta C\|}{\|C\|}\right)$$

- **If is greater than ~20**

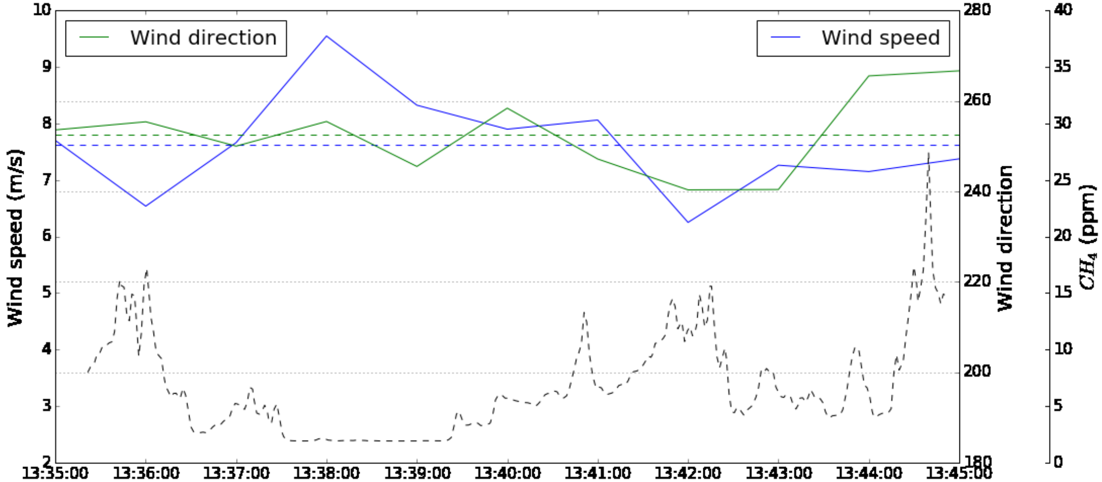
→ We cannot separate the different sources

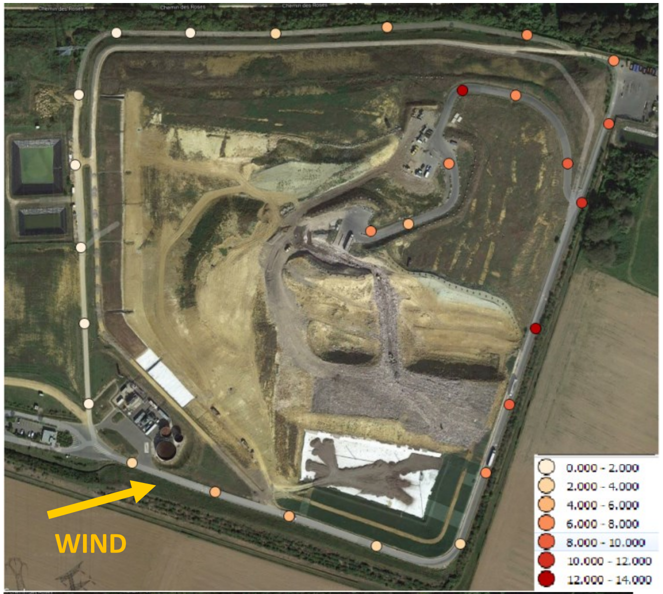


Source : Flesch et al. (2009)

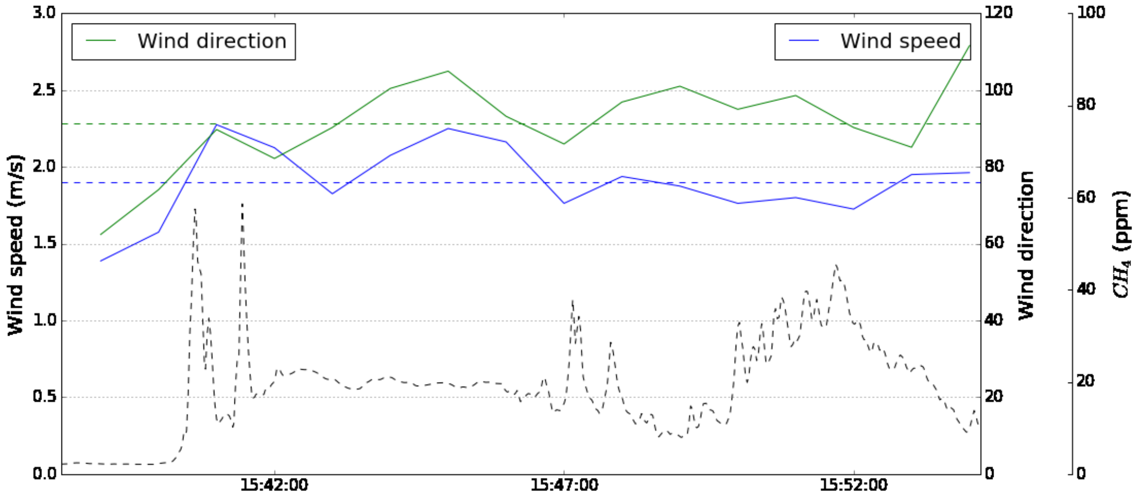
Optimisation of pseudo-sensors (matrix C)

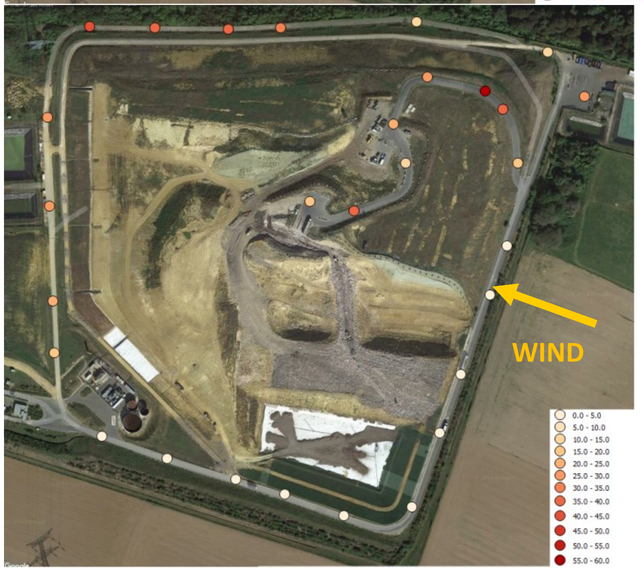
17 November 2016





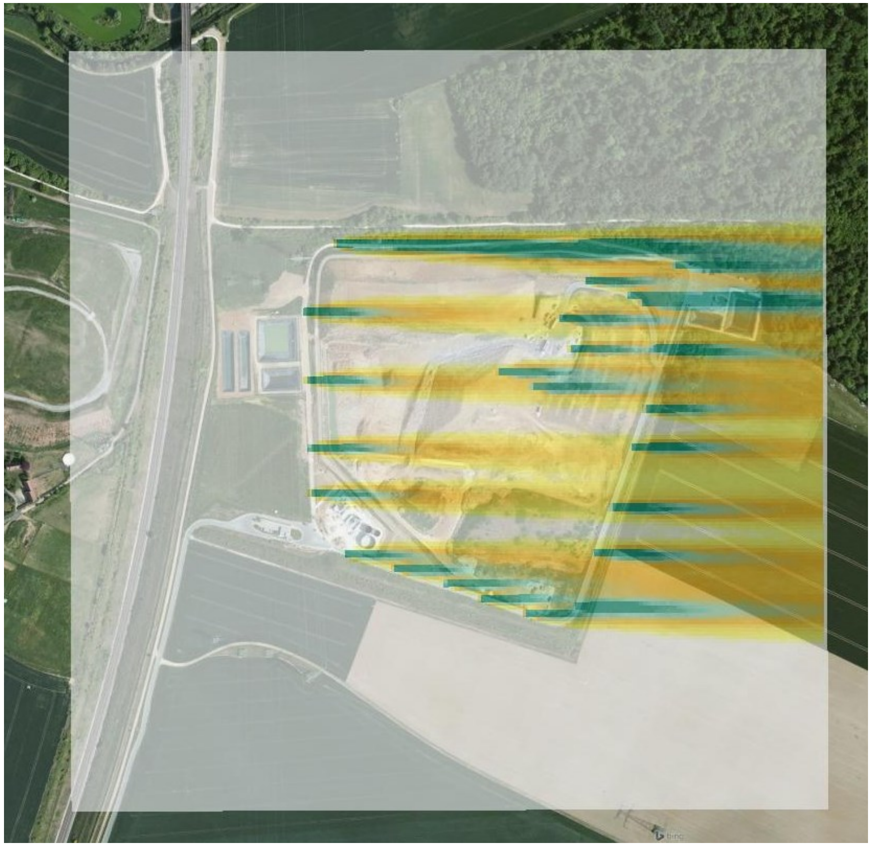
5 December 2016

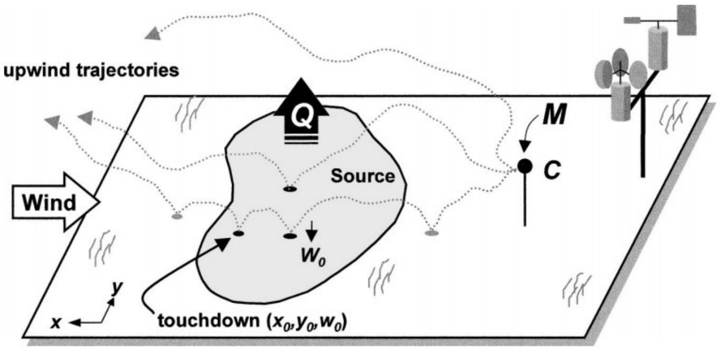




Atmospheric transfert coef. (matrix A)

- ***Matrix A is computed using back-plume stochastic lagrangian model (MSS in ARIA View Package)***

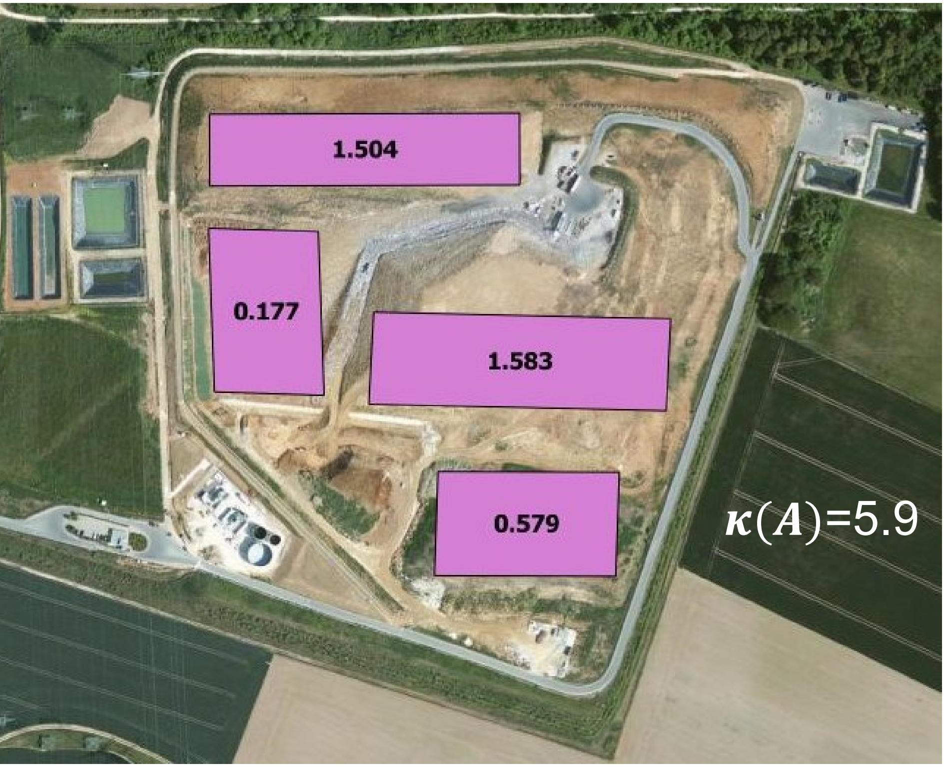




Horizontal grid resolution	5 meters
Domain dimension	1 kilometer x 1 kilometers
Number of vertical levels	21
Lowest / Highest vertical level	3 / 600 meters
Number of receptors	27 (for the 17th November) 29 (for the 5th December)
Number of sources	4 (for the 17th November) 5 (for the 5th December)
Computation of source-receptor matrix	Each 5 minutes
Estimation of emission rates	Each 15 minutes

Results

- *17 November 2017*
- *Before mitigation actions*
- The global emission for the site: 3.85 t/day



- *5 December 2017*
- *After mitigation actions*
- The global emission for the site : 2.92 t/day

The AMIS algorithm

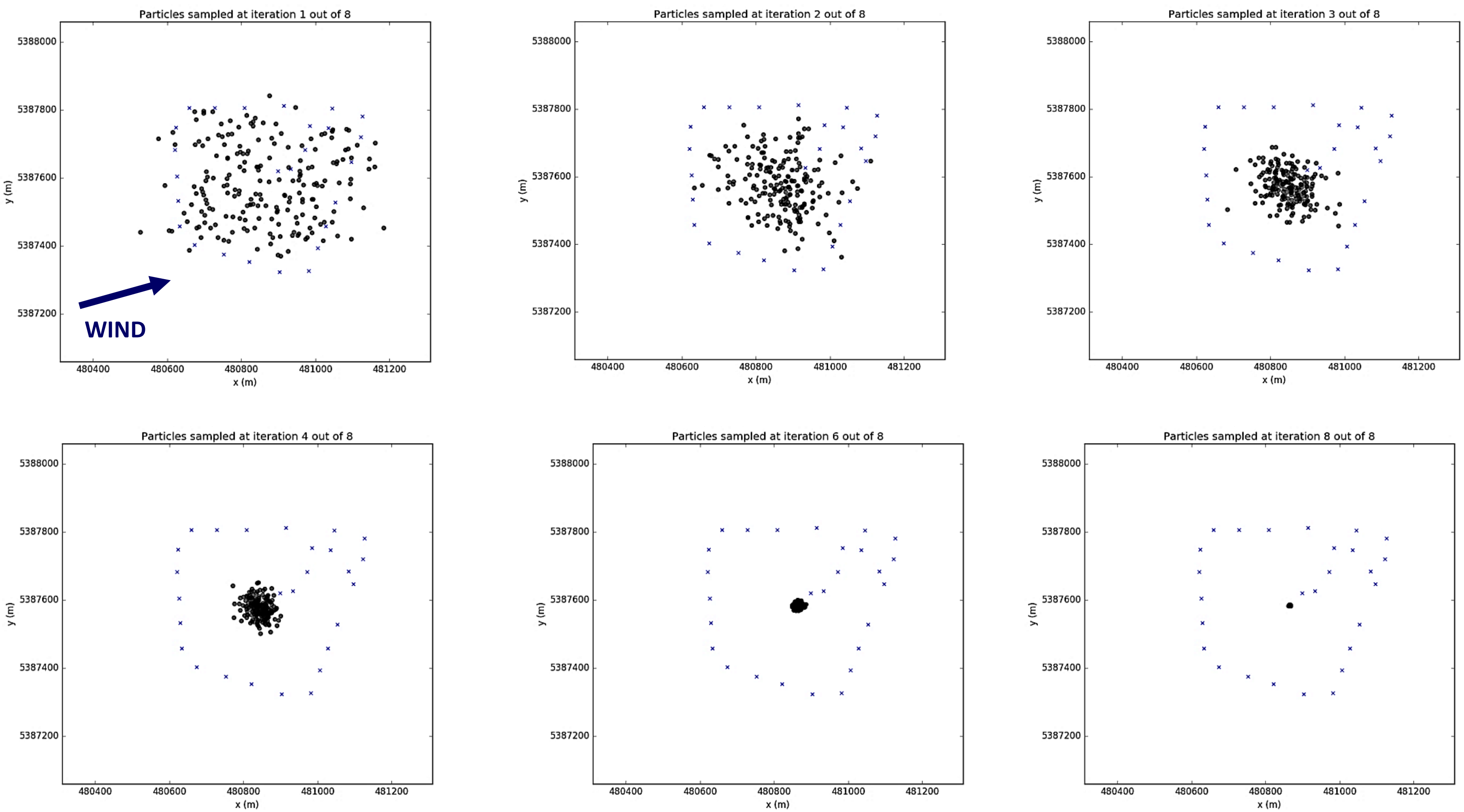
- **Find the minimum of a cost function**
- **The *Adaptive Multiple Importance Sampling* (AMIS) algorithm is based on an sampling scheme, where a target distribution (namely the posterior distribution) is approximated by weighted samples from a proposition distribution**
- **The "*Adaptive*" algorithm improves the standard importance sampling procedure by:**
  - **Allowing the update of the proposal distribution, which can be chosen as a flexible combination of well-known kernels (e.g. a multivariate Gaussian mixture)**
  - **Optimally recycling the importance weights at each iteration to fully exploit the full available information and accelerate the convergence**

- **Current version of the software: a unique point source → here 4 or 5 area sources !**

Rajaona H., Septier F., Delignon Y., Armand P., Olry C., Albergel A., Moussafir J. 2015: "An adaptive Bayesian inference algorithm to estimate the parameters of a hazardous atmospheric release" Atmospheric Environment Volume 122, December 2015, Pages 748-762

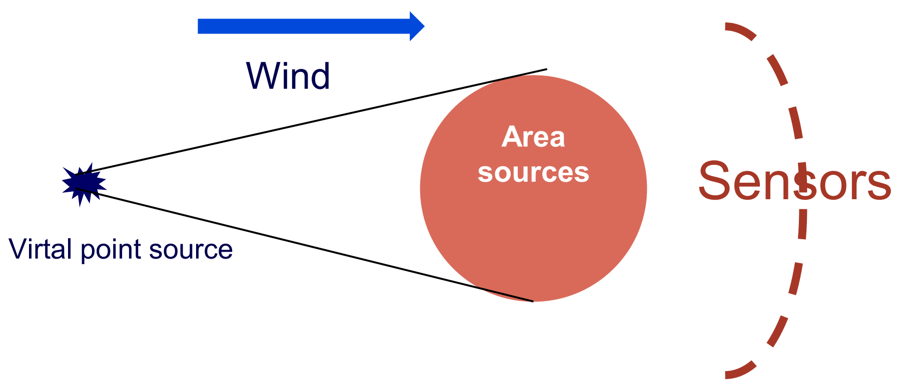
The AMIS algorithm

Test of the software “as is” on the 17 Nov 2017



Result 17 Nov 2017

- **Surprise : good order of magnitude !**
  - **Back-plume method : 3.85 tons/day**
  - **AMIS method : 3.46 tons/day**
- **What we should expect with a single source**
  - **A virtual point source upwind**
  - **If in the area source → a large underestimation**



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Dual tracer experiment

Experimental set

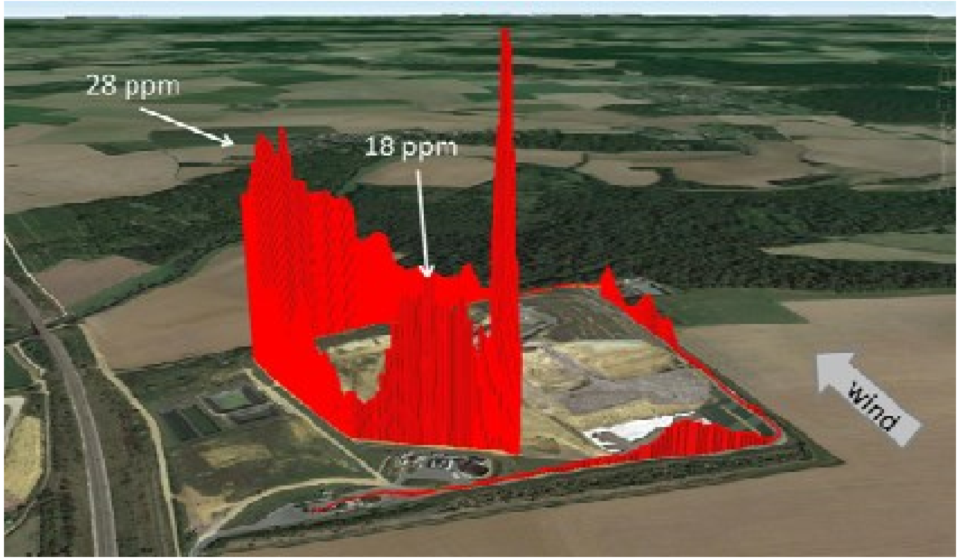
- Dual gas is acetylene C_2H_2
- A C_2H_2 bottle and suitable flowmeter
- Same mobile C_2H_2 /CH_4 PICARRO (G2203) installed in car
- Additional measurements with G2201Piacarro CDRS (carbon isotopes apportionment)

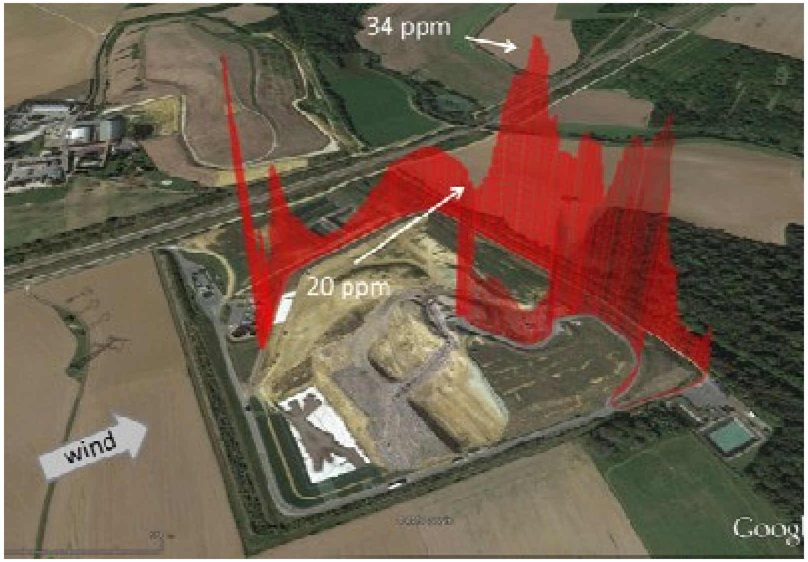
Principle

- Release a known gas (here C2H2) in the same place of the unknown emission (here CH4)
- $Q_{CH4} = Q_{C2H2} \frac{A_{CH4} M_{CH4}}{A_{C2H2} M_{C2H2}}$
  - *Q_{CH4} targeted emission*
  - *Q_{C2H2} is the know release of acetylene (flowmeter + the bottle is weighted before and after the release (kg/h))*
  - *$\frac{A_{CH4}}{A_{C2H2}}$ ratio of area peaks for the two gases (Picarro measurements)*
  - *$\frac{M_{CH4}}{M_{C2H2}}$ ratio of molar mass*

Dual tracer experiment

13 Sept 2016 Preliminary survey (before any mitigation actions)





- **Identifying pics and order of magnitude**
- **Optimization of the C_2H_2 release**
- **Optimization of ambient concentration measurement protocol**

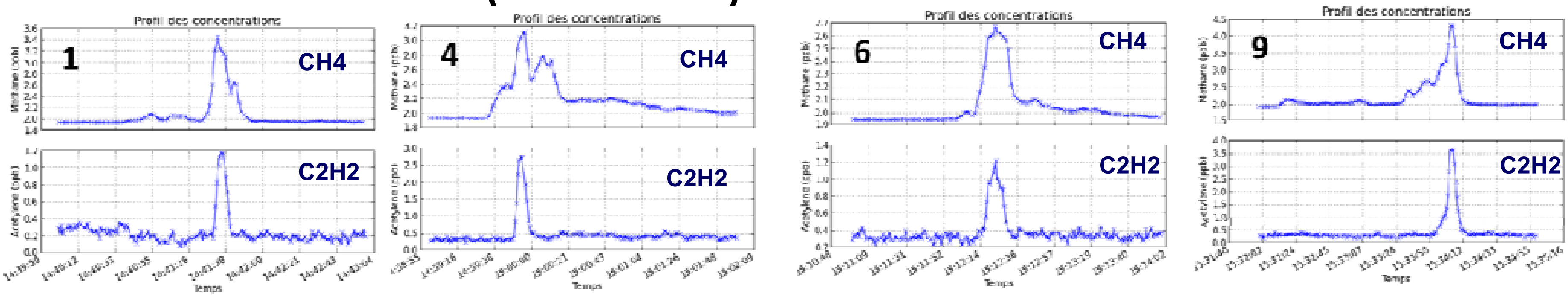
Variable (unit)	Typical value (during measurement)	Range of value (min/max)
Temperature (°C)	28	23/31
Air Pressure (hPa)	1011	1009/1013
Wind speed (m/s)	5	2.7/12.1
Wind direction (degrees) (coming from the direction)	SE	ESE/SSE
Rain (mm/3h)	0	0/1.4

Dual tracer experiment

19 Sept 2016 Dual gas tracer release

Variable (unit)	Typical value (during measurement)	Range of value (min/max)
Temperature (°C)	20	15/20
Air Pressure (hPa)	1018	1018/1020
Wind speed (m/s)	5	3.1/6.7
Wind direction (degrees) (coming from the direction)	NNW	NNW/WNW
Rain (mm/3h)	0.2	0/0.3

Time series downwind (14 transects)



Results

N° Pic	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Emissions de CH4 (kg/j)	5533	6005	7823	6925	4375	5177	3314	5278	6688	5697	4528	3485	6920	7497
Moyenne (kg/j)	5813 ± 1318													

Ouline

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Conclusion

Application to a mitigation policy

	Units	Reverse Modelling (1)	Dual Tracer (2)	((1)- (2)) /(2)
Before Mitigation (dual tracer, no reverse modelling)	t CH_4 emitted/d	5.8	5.8 ± 1.3	
After phase I (North west of site : biogas network improvement)	t CH_4 emitted/d	3.85	3.6 ± 1,3	- 6,5%
After phase II (cover and biogas network improvement)	t CH_4 emitted/d	2.92	2 ± 0,5	-31%

On progress

- **In 2017: installation of an additional cogeneration engine corresponding to the amount of CH4 recovered and it is working!**
- **Test on an other site in Netherland (with TNO)**

Acknowledgments

- **To HARMO18 Organizers !**
- **For your attention !**

- **For Partners of the WASTE MITI 2 consortium**

- **For Climate KIC Contribution**