Source term estimation using an adjoint model: a comparison of two different algorithms

Gianni **Tinarelli** [1], Giuseppe Carlino [2] and Francesco Uboldi [1]

[1] ARIANET S.r.l., Milan, Italy
[2] SIMULARIA S.r.l., Turin, Italy

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Introduction – **S**ource **T**erm **E**stimation Algorithms

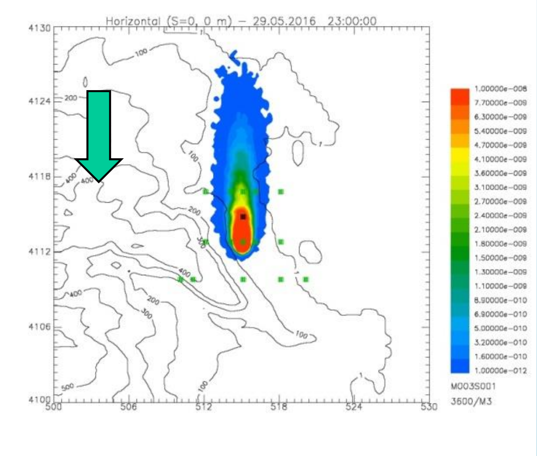
The reconstruction of unknown Source Terms of pollutants is one of the most challenging problems. The need of such a reconstruction is not so uncommon in many situations (emergency response, odor events)

A **STE** algorithm (in the worst case)
given observations of pollutant concentration and meteorological information, should estimate:

- Source location
- Emission time series
- Emitted quantities

Two **STE** algorithms are tested, based on:

- The application of the adjoint Lagrangian Particle Dispersion model RetroSpray



Backward trajectories starting from measuring stations identify possible emission zones and intensities
Stations measuring **zero** identify exclusion zones

- different postprocessing systems
  - ✓ Simple (Maximum Overlap)
  - ✓ Complex (Variational Method)

simularia ARIANET

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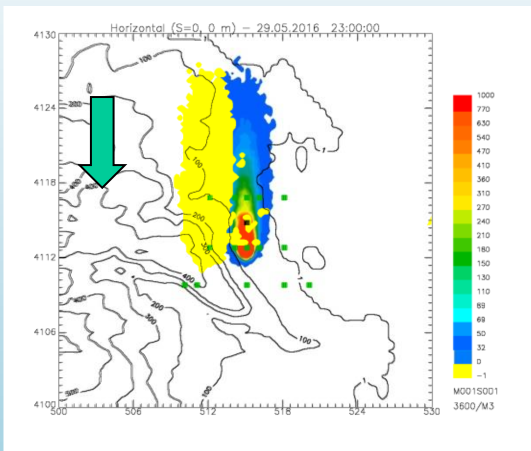

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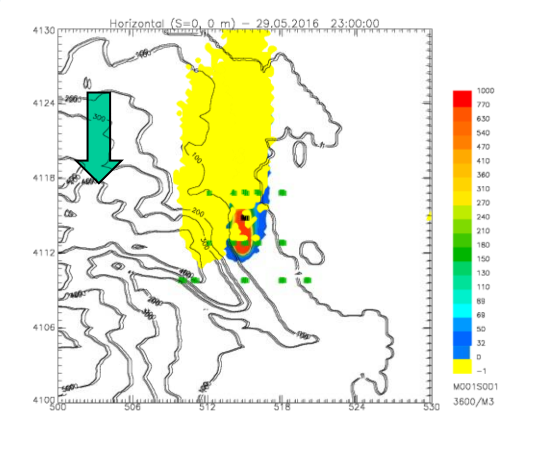

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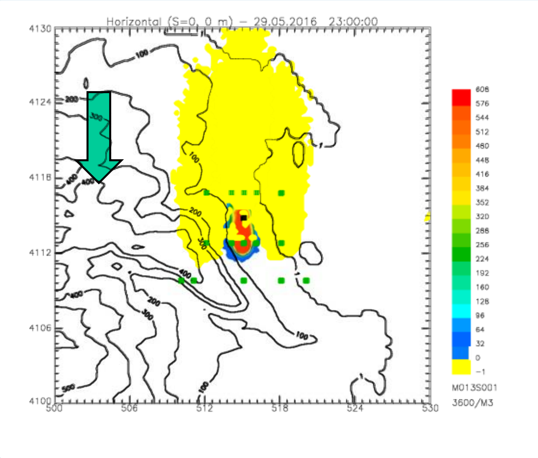

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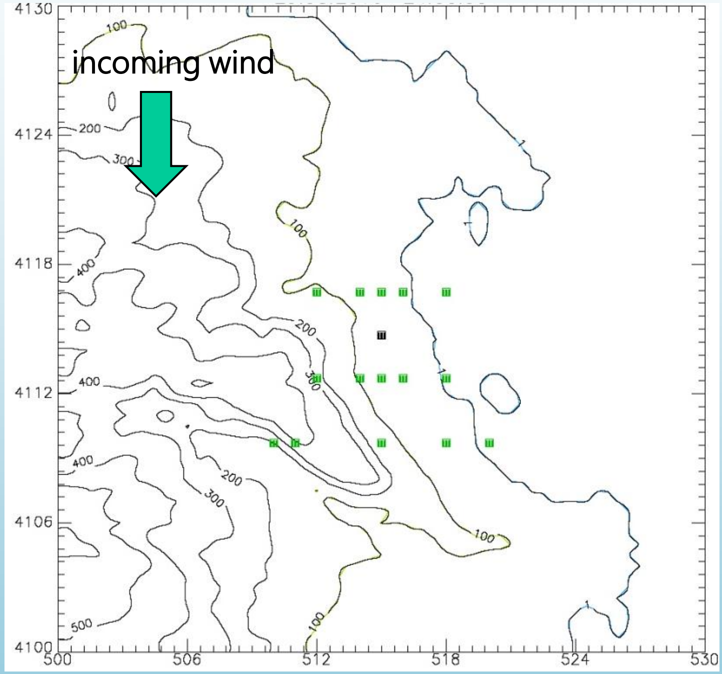
Maximum Overlap vs Variational Method
why two different systems?

- MO is conceptually simple, easy to implement and already operational
- VM is more complex to implement, but better in principle

These two methods are compared in different conditions:

- data from the 'FFT07' field campaign
- synthetic cases in a real environment
- real cases

MO simply 'counts' at each point, during a certain time interval, the number of times that independent retroplumes coming from receptor points overlap



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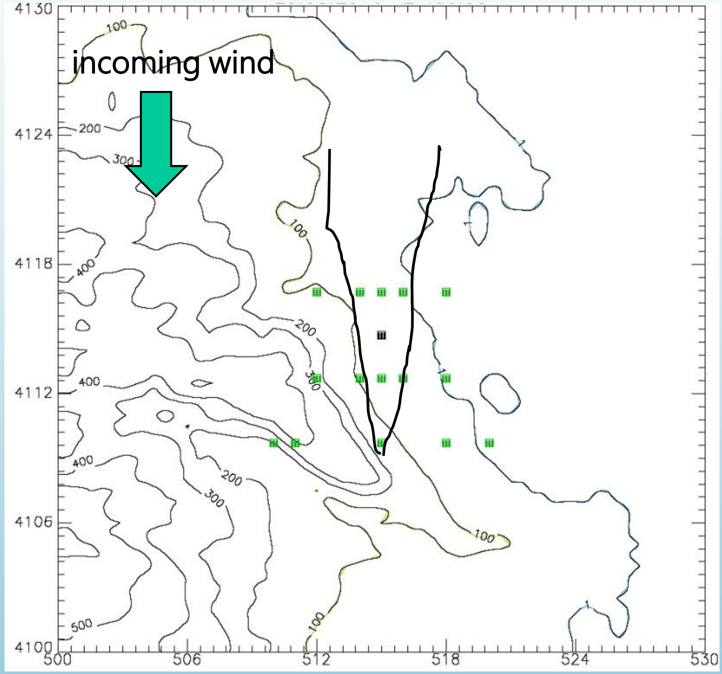

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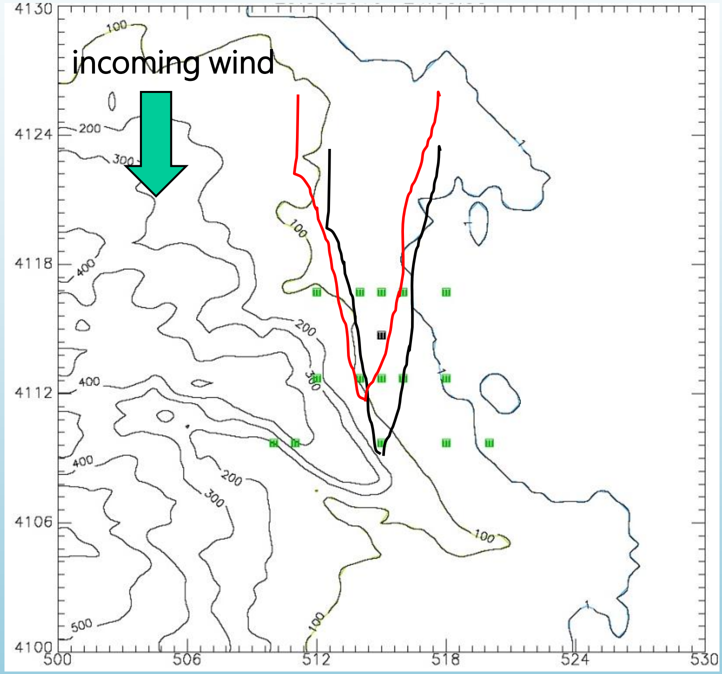

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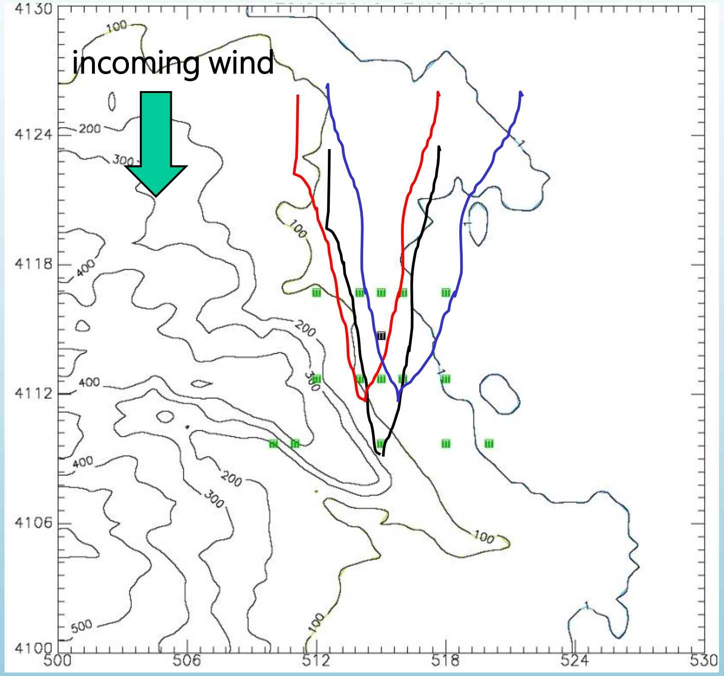

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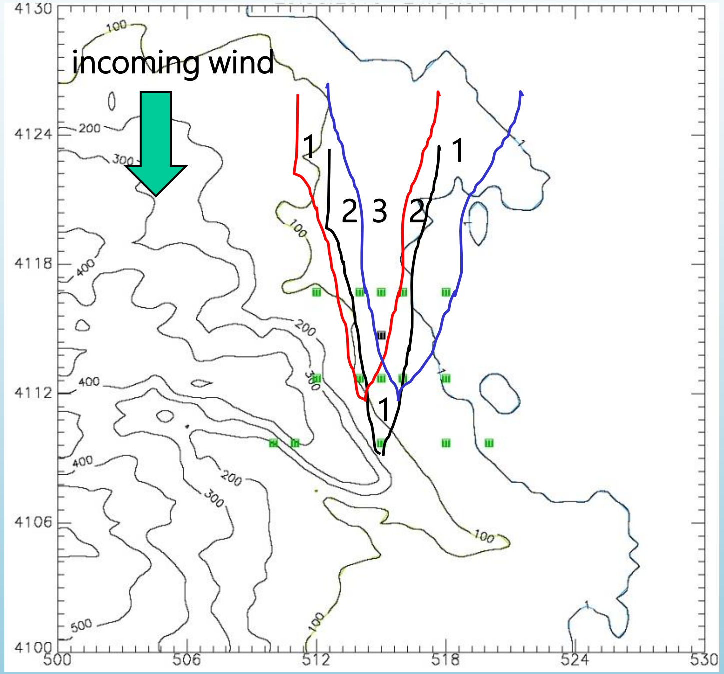

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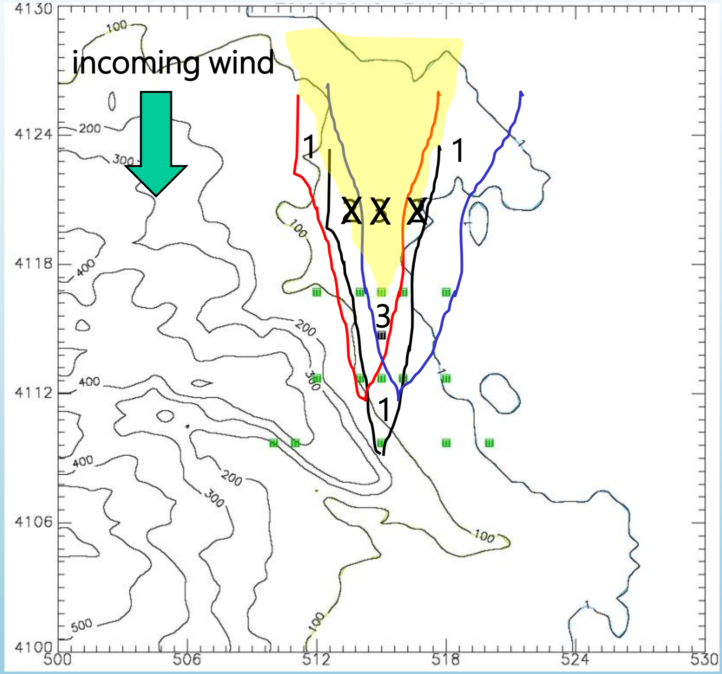

Zero observations (for example those upwind) are used to define ‘exclusion zones’ or zones that cannot include sources, zeroing the counter

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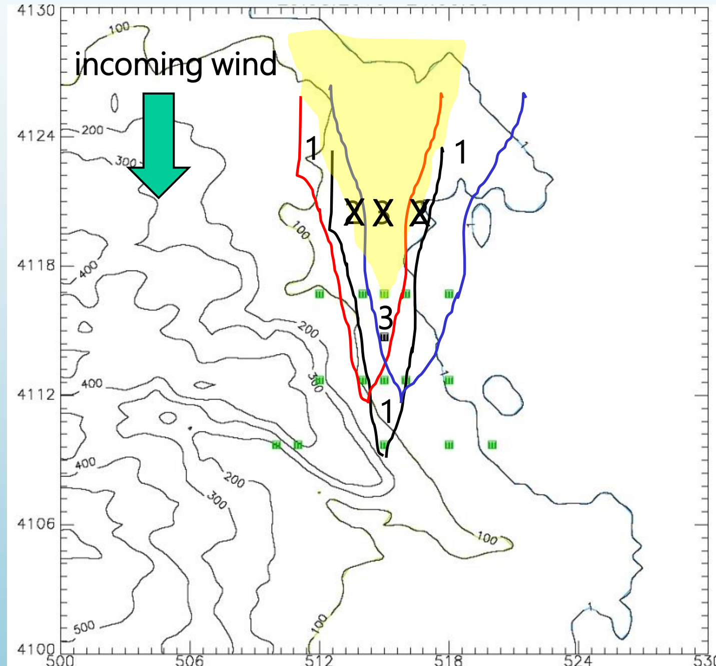
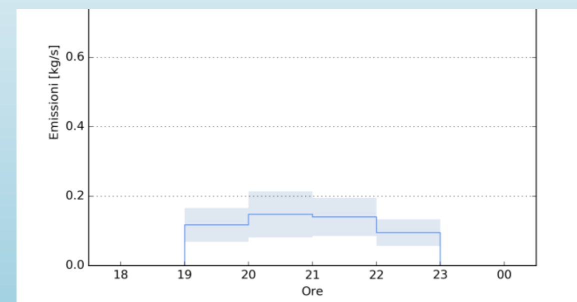


Time by time, the emission flow computed inside the zone of maximum overlap using information from retro-plumes



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VM – a variational method for optimization

- A **SPRAY** forward integration defines a linear relation $\boldsymbol{\chi} = \mathbf{L}\,\mathbf{q}$

  Where: **q** = emissions (for example number of particles/time)

  $\boldsymbol{\chi}$ = estimated concentrations at obs times and locations

- Backward **RetroSPRAY** integration applies the **transpose** matrix $\mathbf{L}^T$

  the Integration backward in time from obs time and locations enables the explicit computation of all **L** matrix components

- To avoid estimating negative emissions → transformation $\xi=\Phi(q)$, $\eta=\Phi(\chi)$

$$\phi(x) = \begin{cases} ln(x) & x < x_{min} \\ x - 1 & x \geq x_{min} \end{cases}$$

- Estimate emissions by minimizing:

$$J(\xi) = \frac{1}{2}[\eta(\xi) - \eta^o]^T[\eta(\xi) - \eta^o] = \text{MIN}$$

...at each gridbox → (minimized) objective function map

A comparison
FFT07 – Trial 54

Fusion Field Trial 2007 (Platt and Deriggi, 2012)

Experiments in Utah, U.S.A., 2009

Tracer (propylene) released in prescribed quantities from a source located upstream of 100 concentration detectors set in a regular array, flat orography

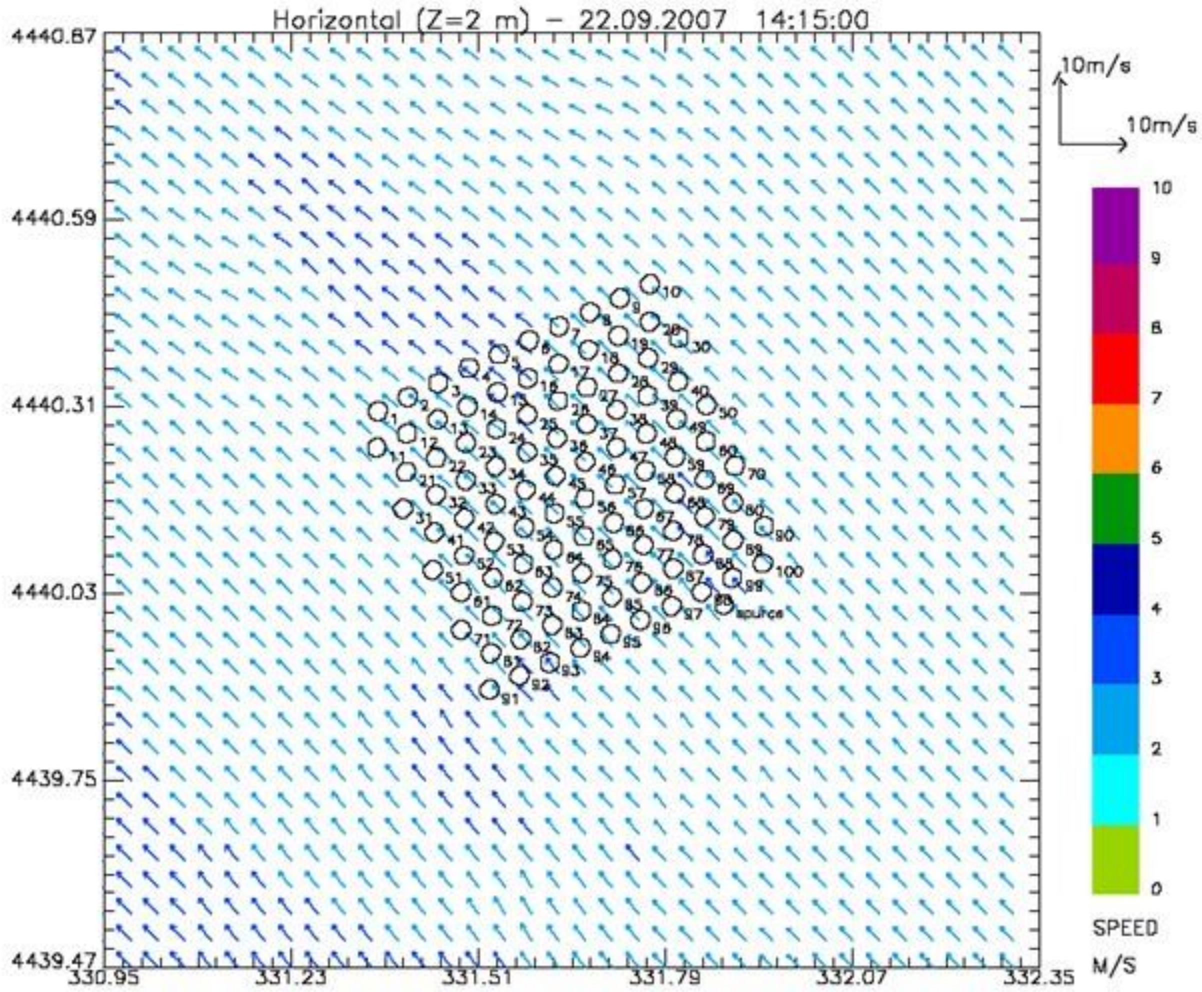
Experiment chosen Trial 54: steady wind from SE

Experiment duration: 12 minutes from 14:15 to 14:27 of 2009/09/22

Platt N., DeRiggi D (2012) Comparative investigation of Source Term Estimation algorithms using FUSION field trial 2007 data: linear regression analysis, IJEP, 48 (1-4), pp. 13-21

FFT07 – Trial 54

Wind flow

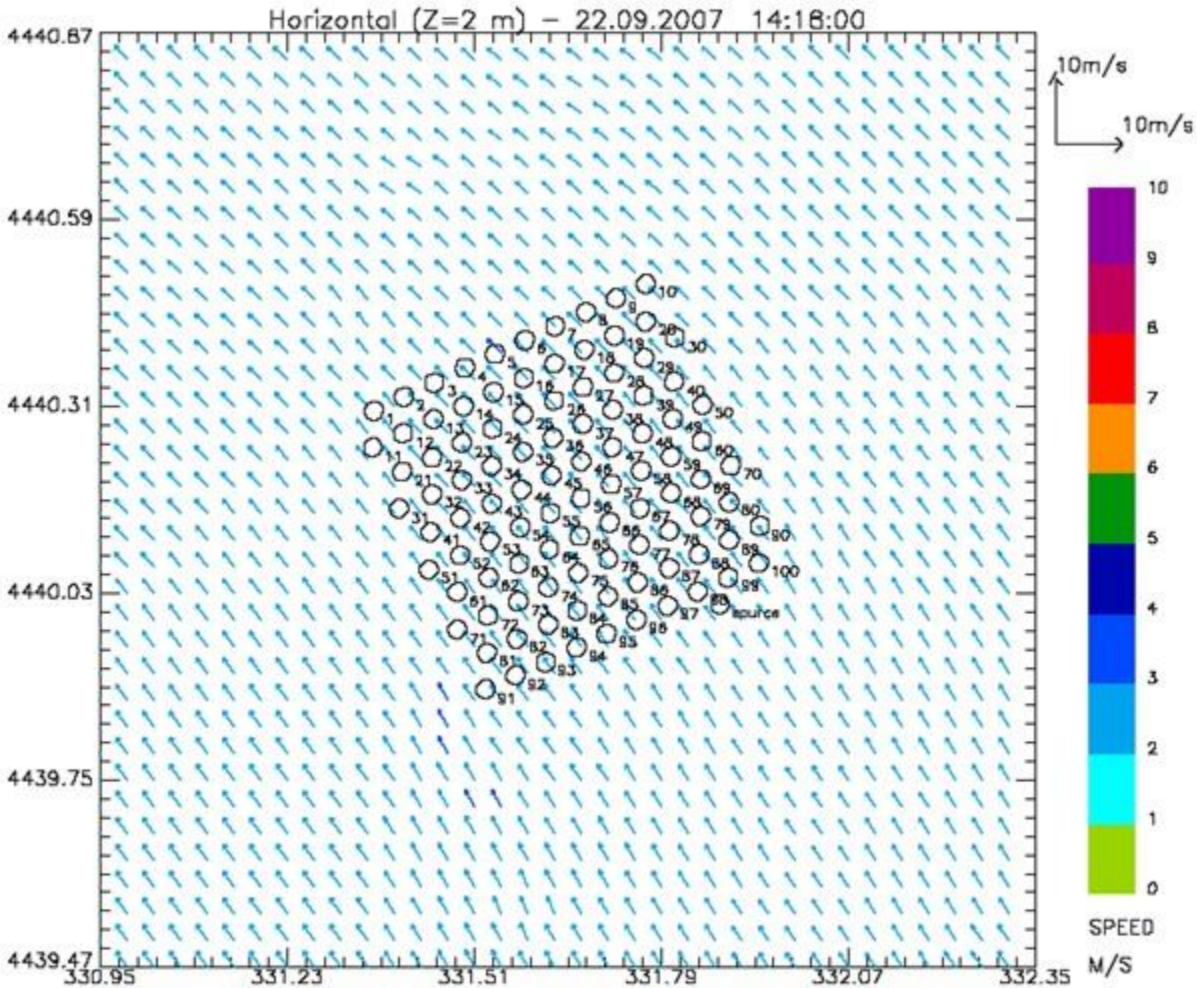


14:15

Ground level wind – 3 min averages from 14:15 to 14:27 diagnostic reconstruction

FFT07 – Trial 54

Wind flow

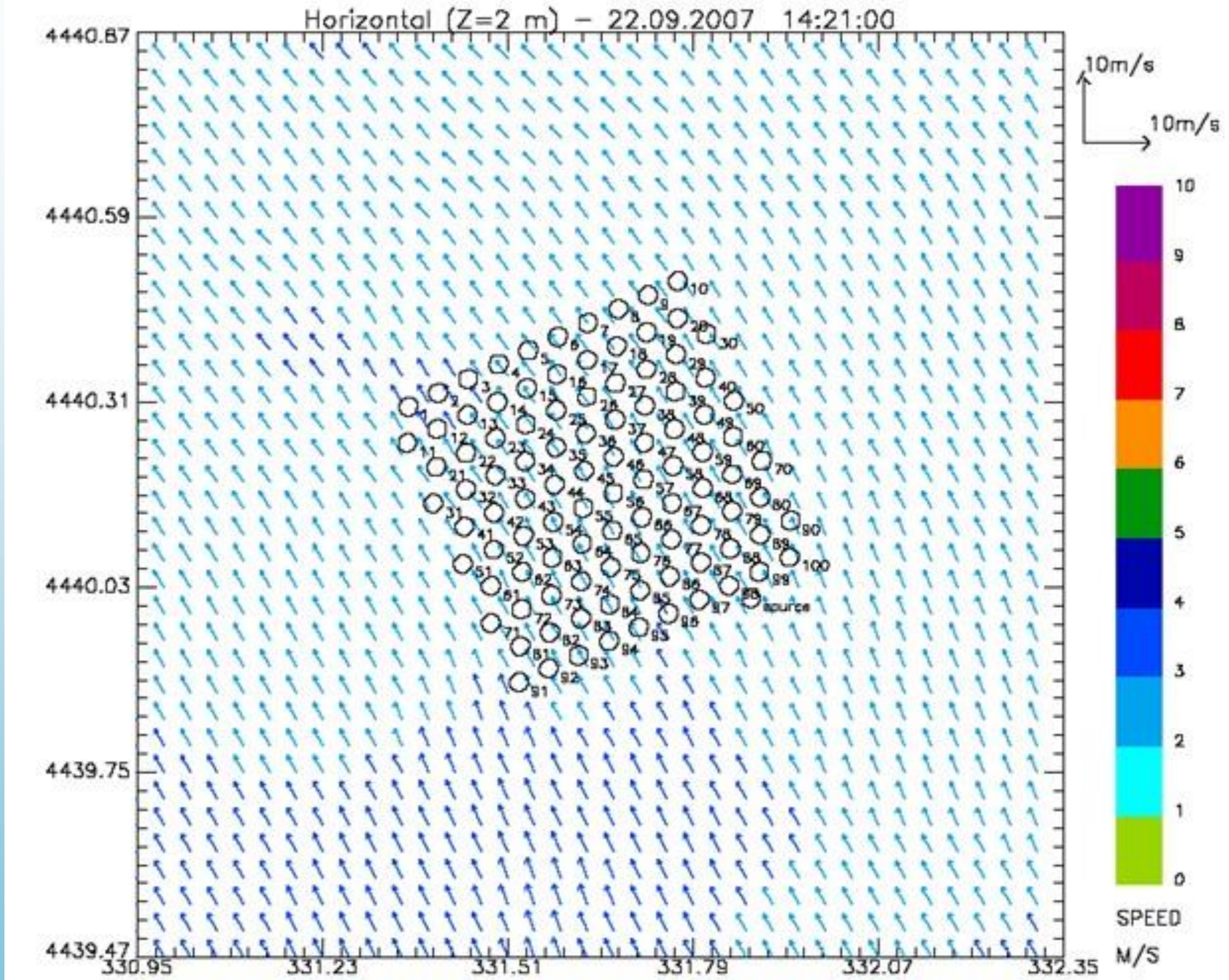


14:18

Ground level wind – 3 min averages from 14:15 to 14:27 diagnostic reconstruction

FFT07 – Trial 54

Wind flow

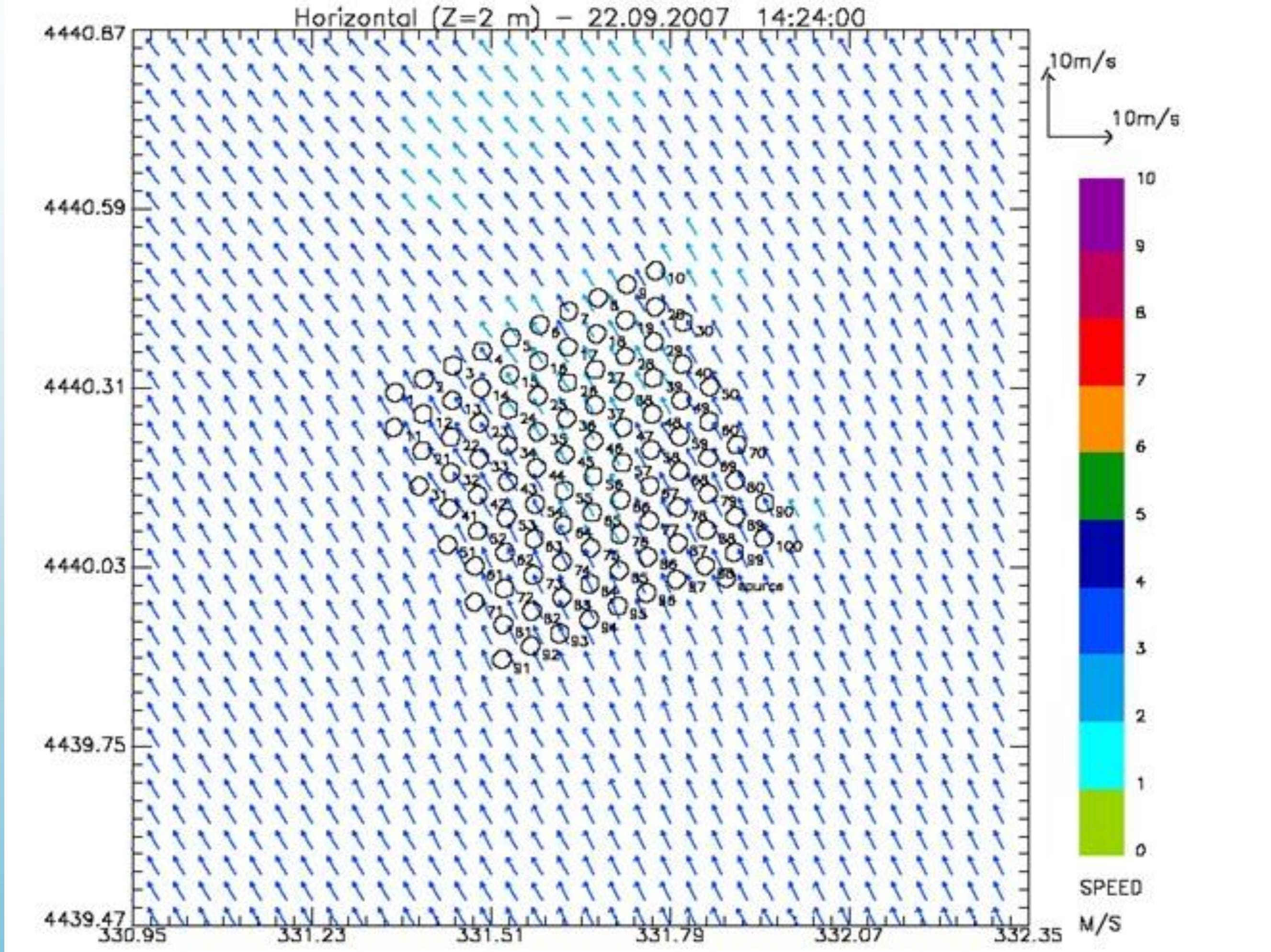


14:21

Ground level wind – 3 min averages from 14:15 to 14:27 diagnostic reconstruction

FFT07 – Trial 54

Wind flow

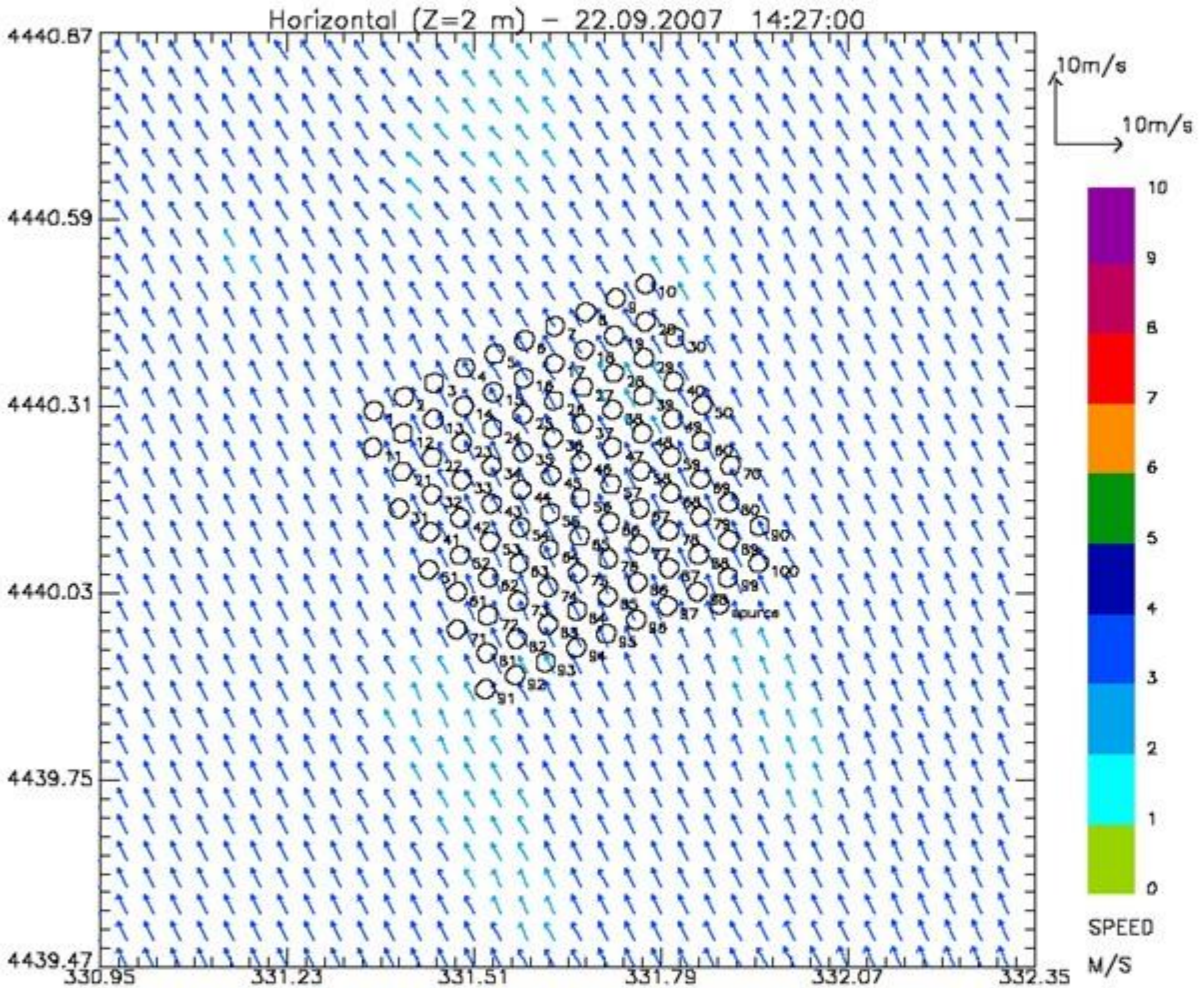


14:24

Ground level wind – 3 min averages from 14:15 to 14:27 diagnostic reconstruction

FFT07 – Trial 54

Wind flow

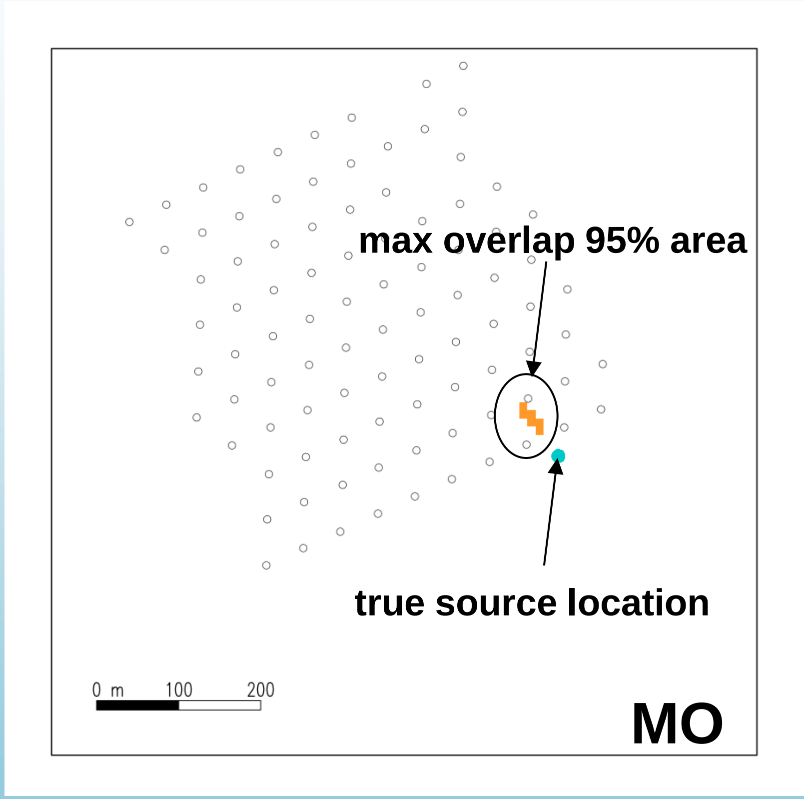


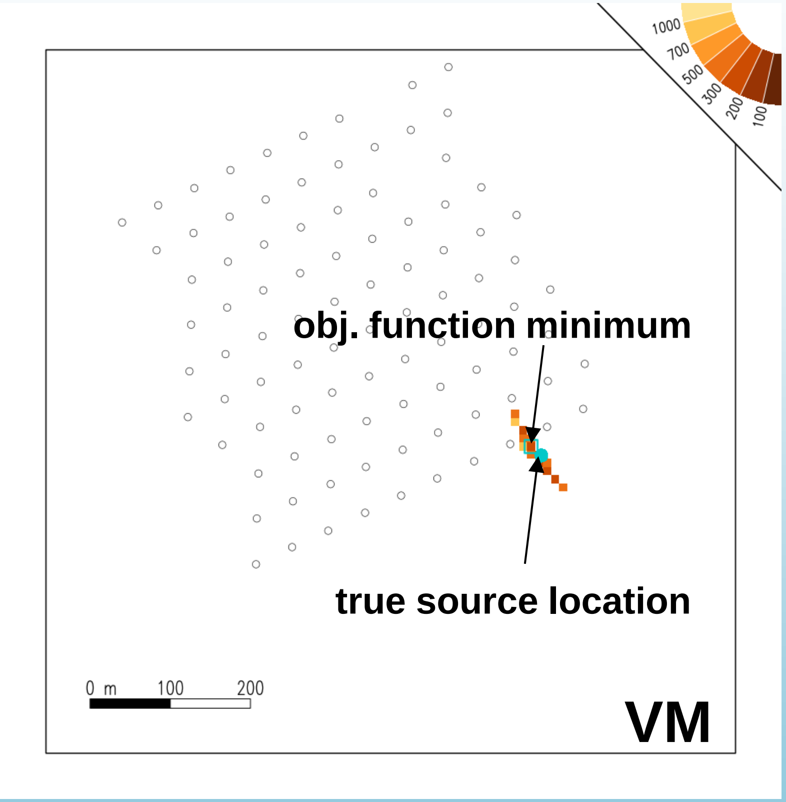
14:27

Ground level wind – 3 min averages from 14:15 to 14:27 diagnostic reconstruction

FFT07 – Trial 54

Source position - estimation

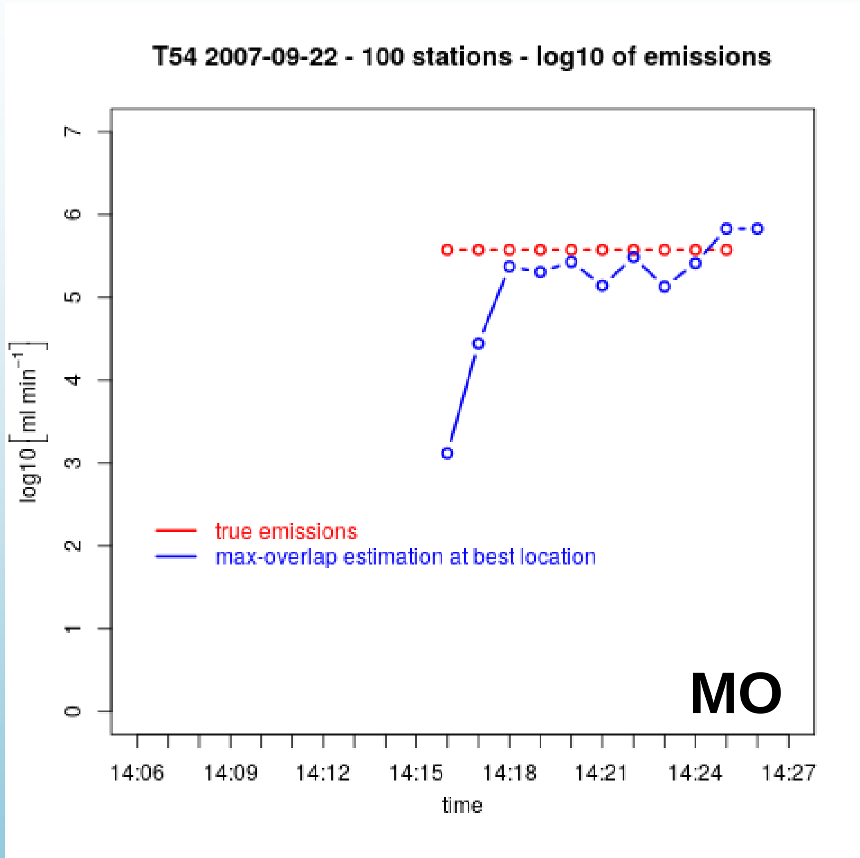


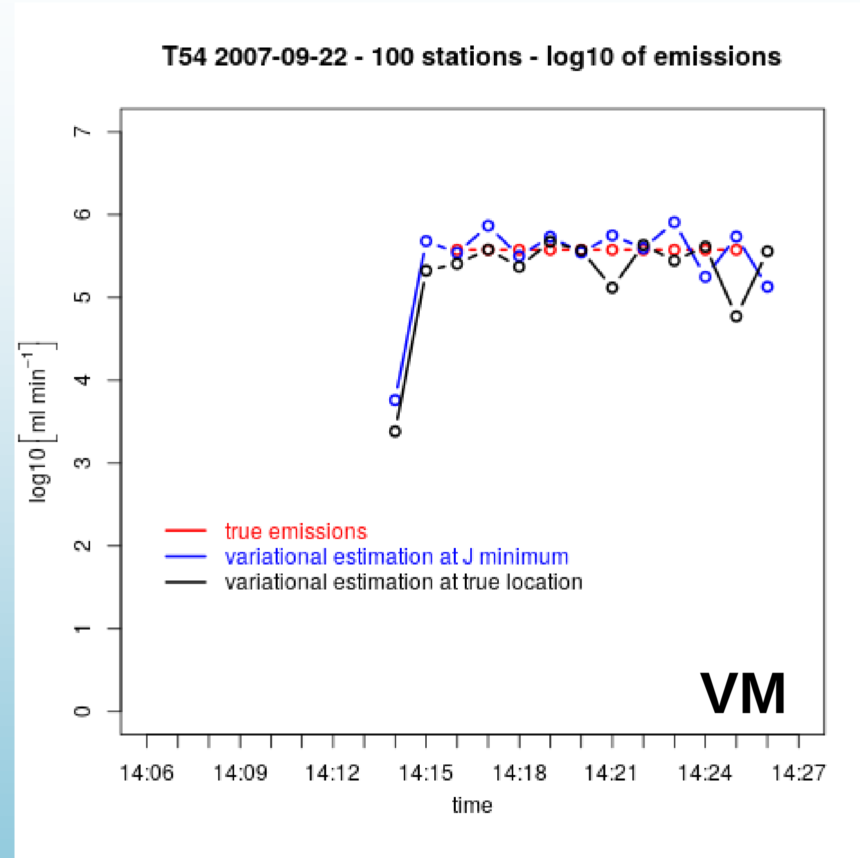


Plot of the objective function

FFT07 – Trial 54

Emission flow estimation





Cumulated emissions:
MO estimation at best location: 2.940×10^6 ml

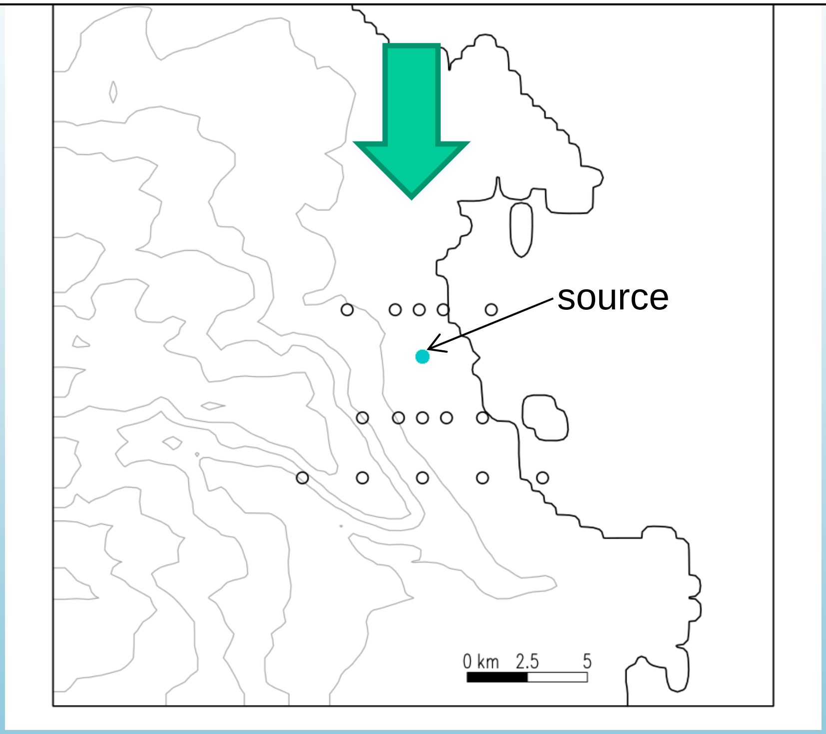
Cumulated emissions:
VM estimation at true location: 3.606×10^6 ml
VM estimation in minimum of J: 5.405×10^6 ml

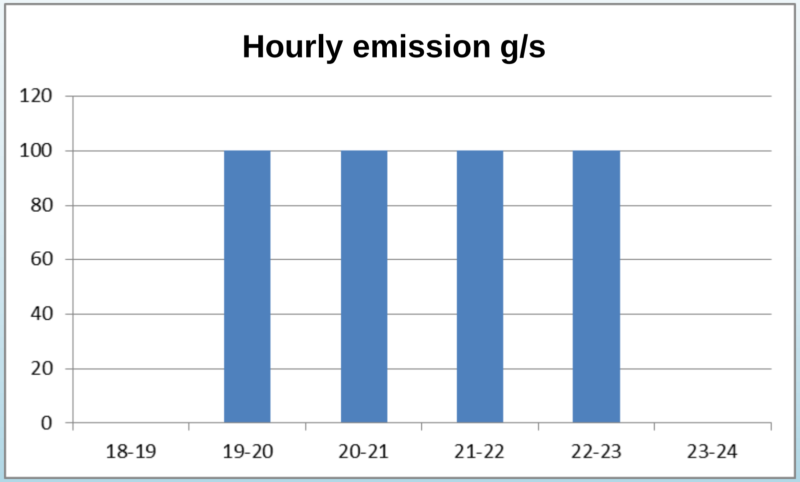
True emissions at true source: 3.775×10^6 ml

Synthetic case 1

Real domain 30x30 km^2 coastal industrial site, complex terrain

Stationary flow from North (19:00 – 24:00) 2 m/s





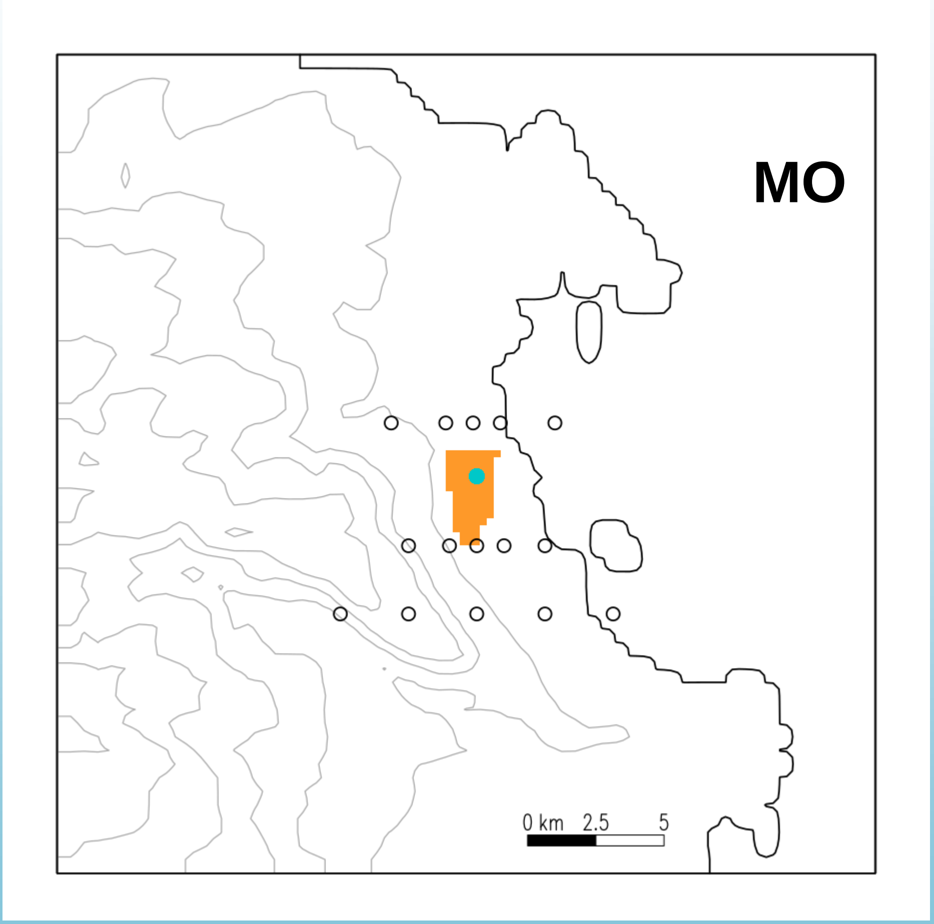
Stationary emission flow
100 g/s from 19:00 – 23:00

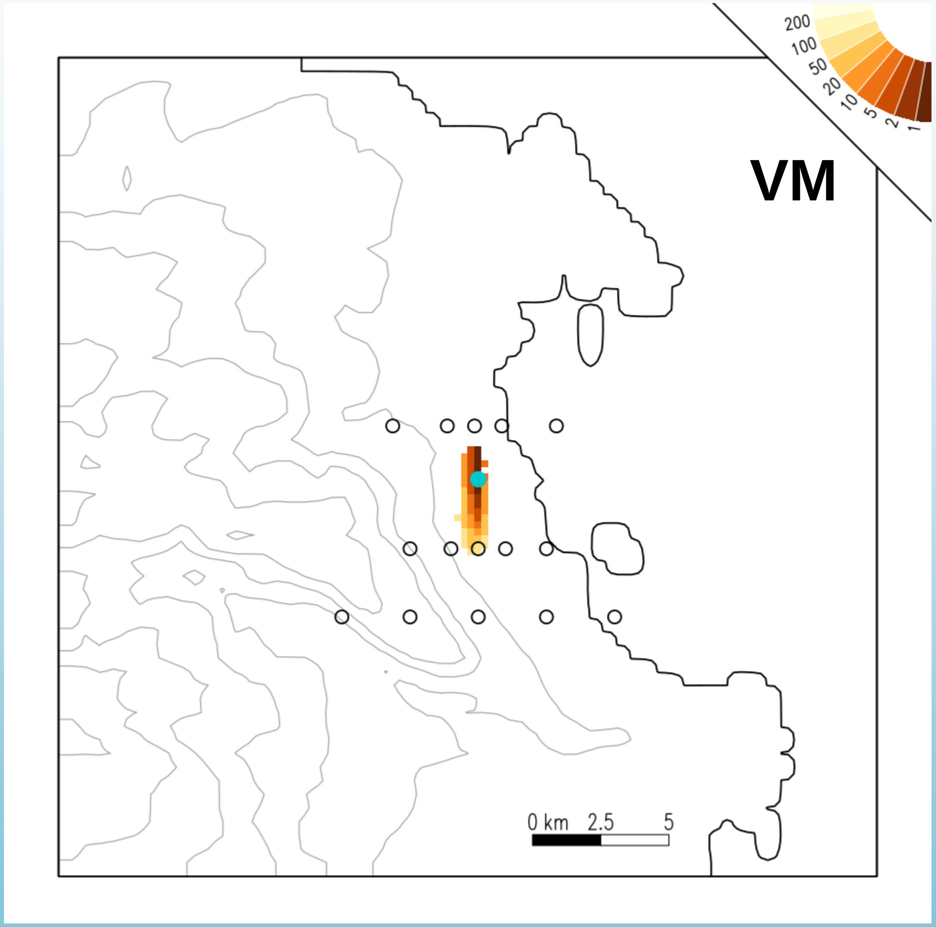
5 upwind samplers
5 downwind samplers 2 km to the source
5 downwind samplers 4 km to the source

Use of forward Spray to build concentrations at pseudo-samplers

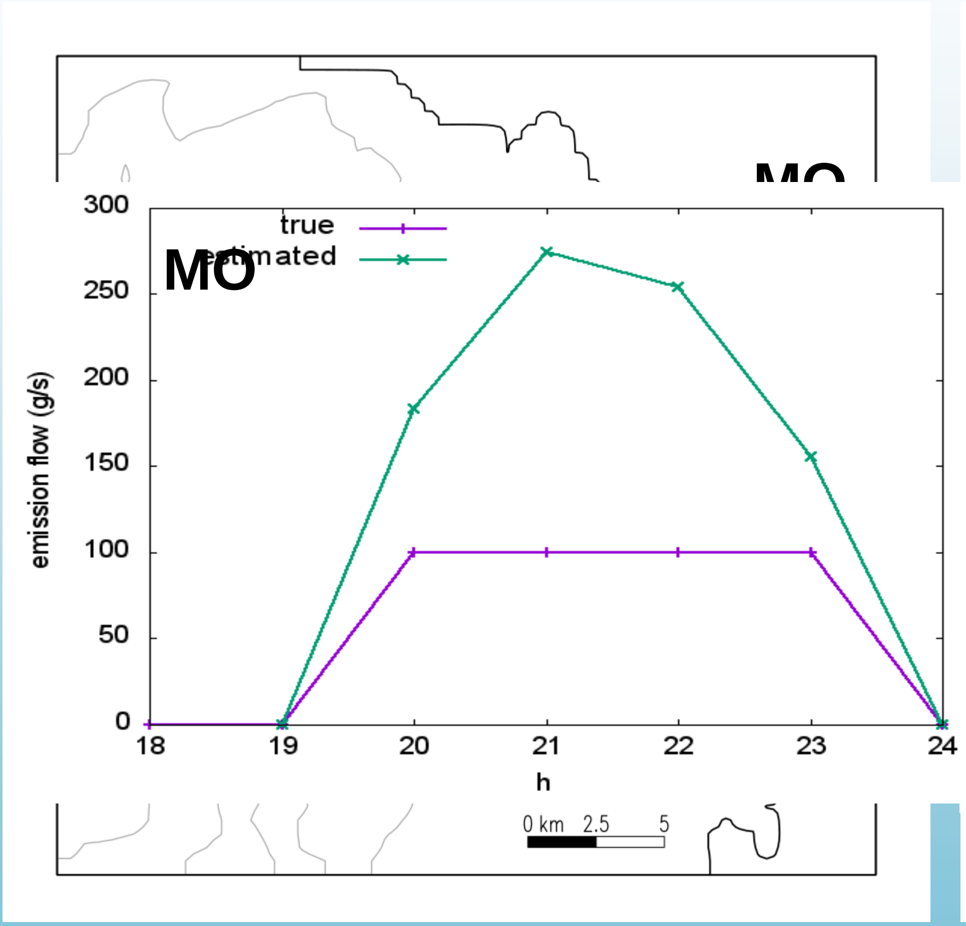
Synthetic case 1

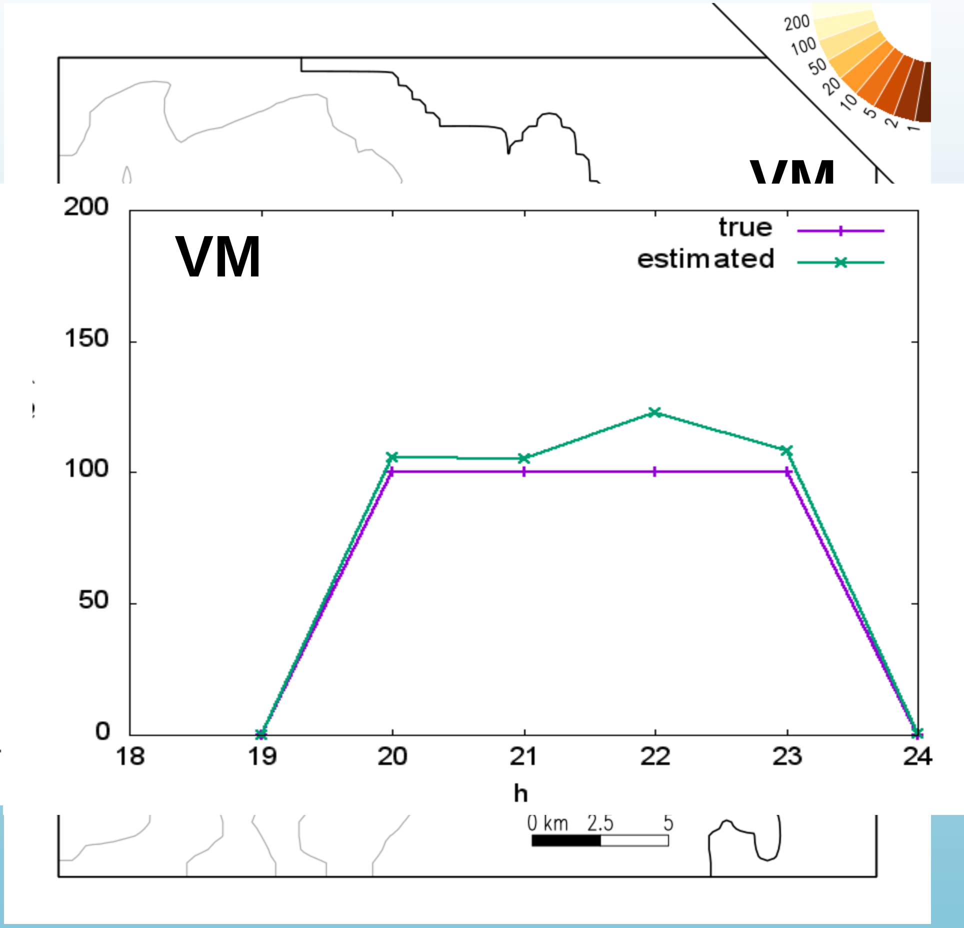
Source position - estimation





Synthetic case 1
Emission flow

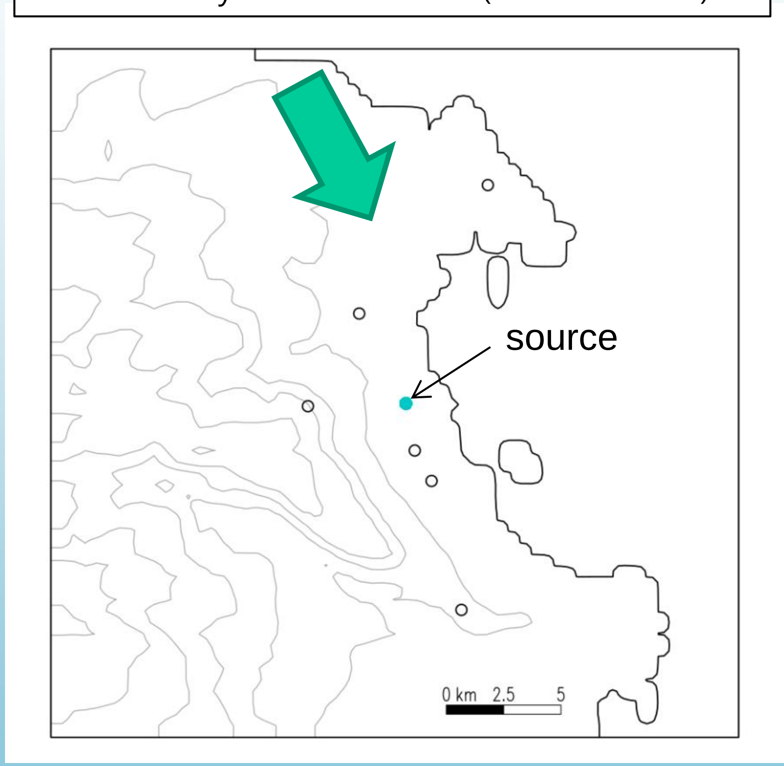




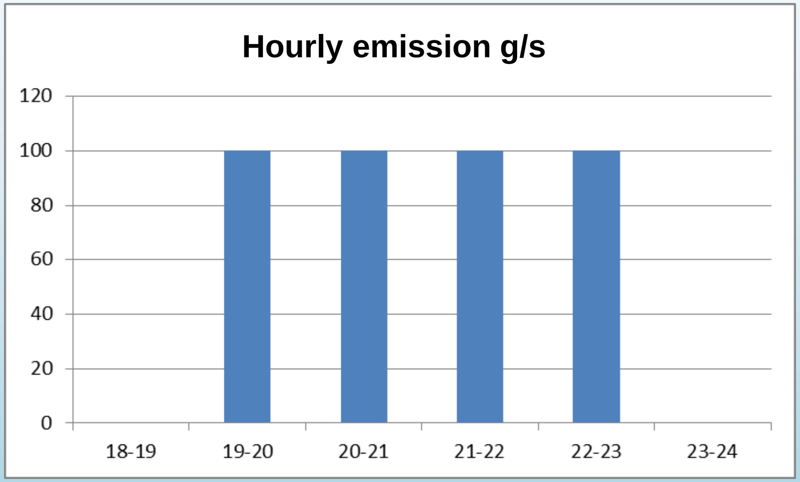
Synthetic case 2

Same domain as in case 1, but samplers as in the local existing network and realistic wind direction

Stationary flow from NW (19:00 – 24:00)



6 sparse samplers, mainly along the coast



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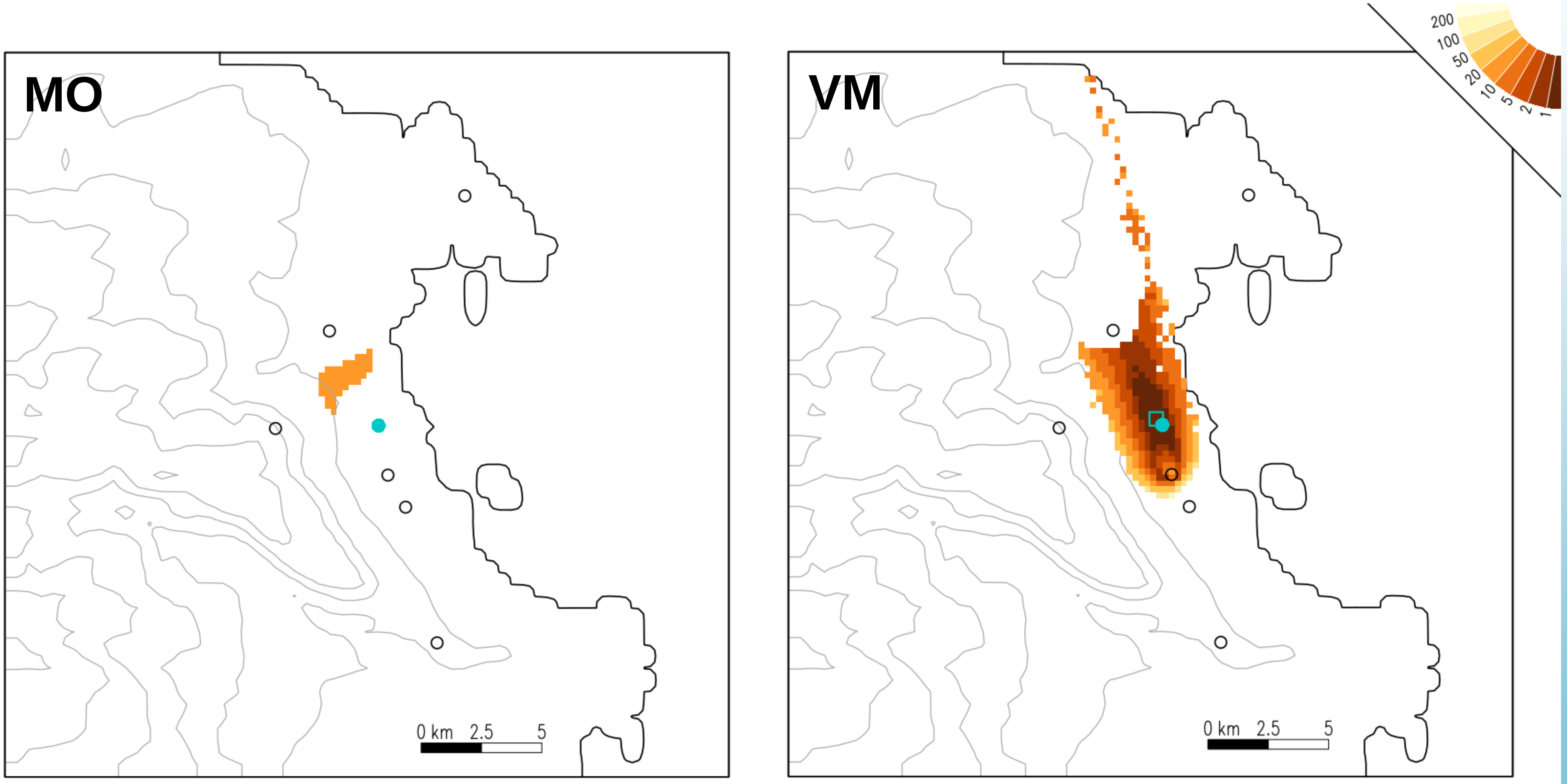

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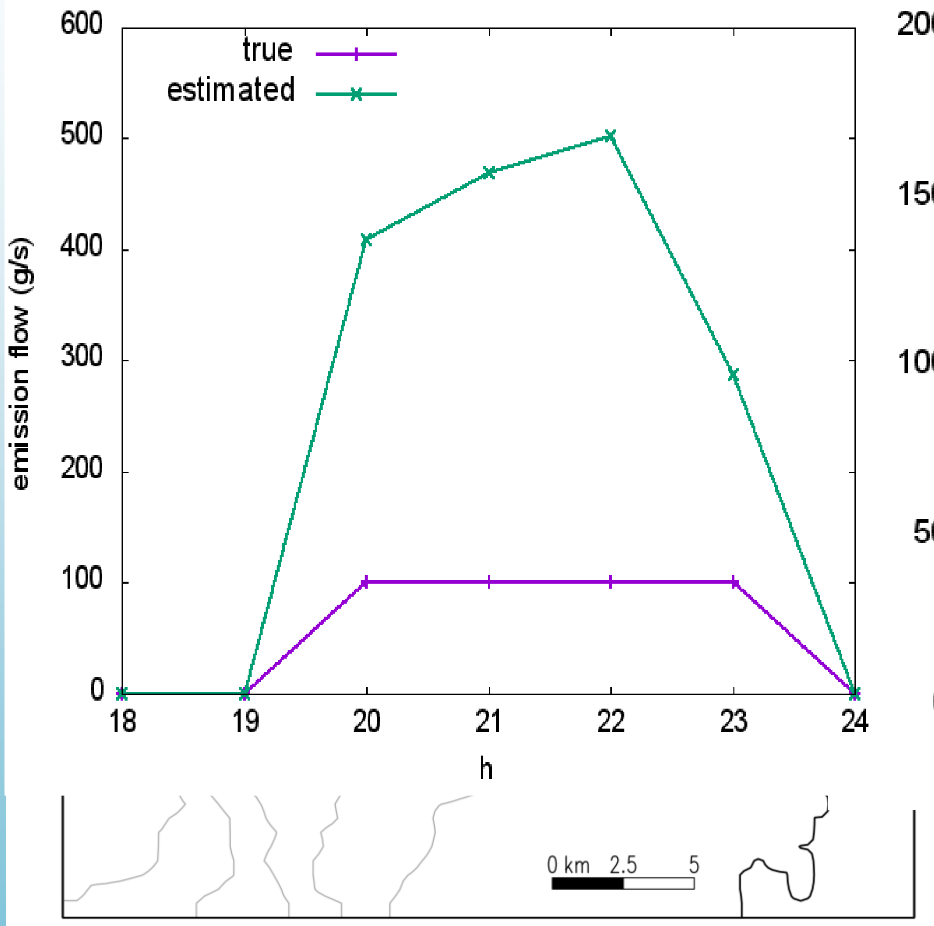
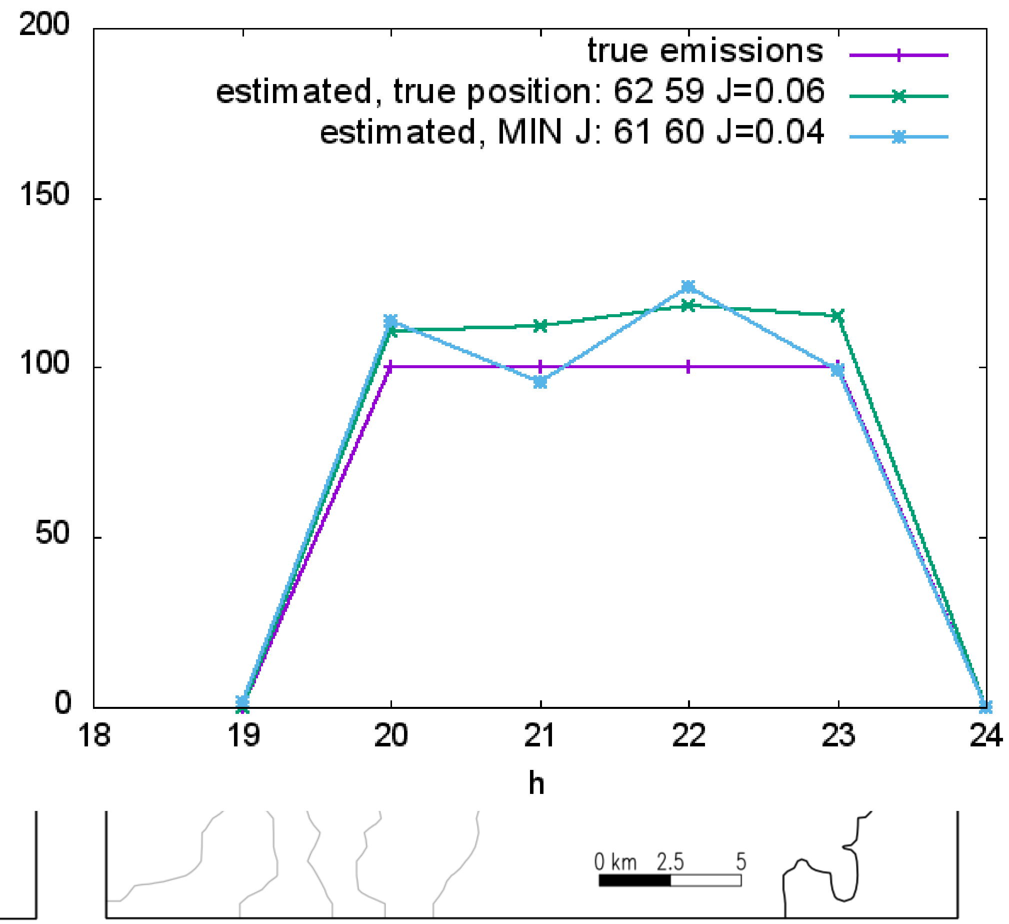
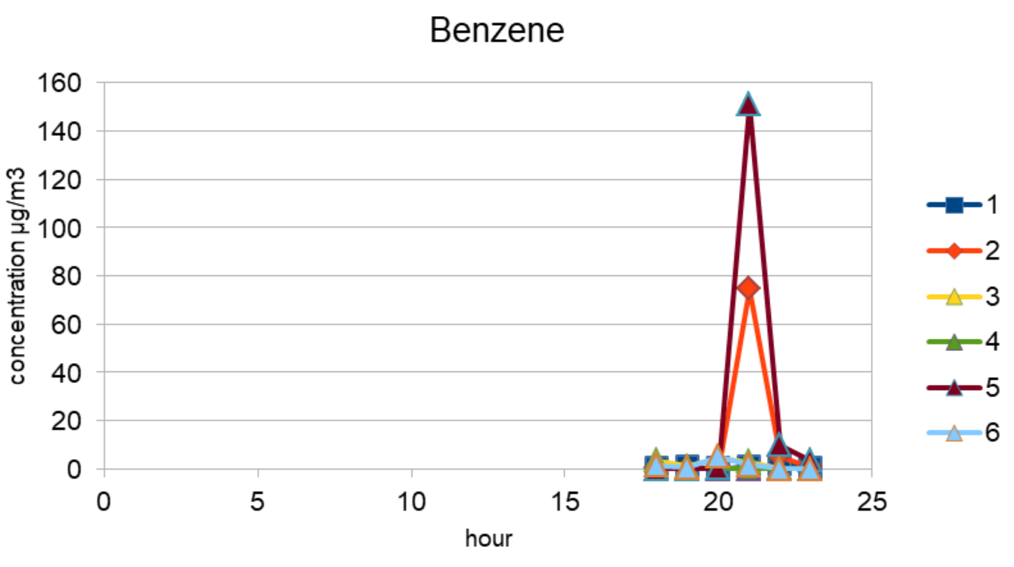
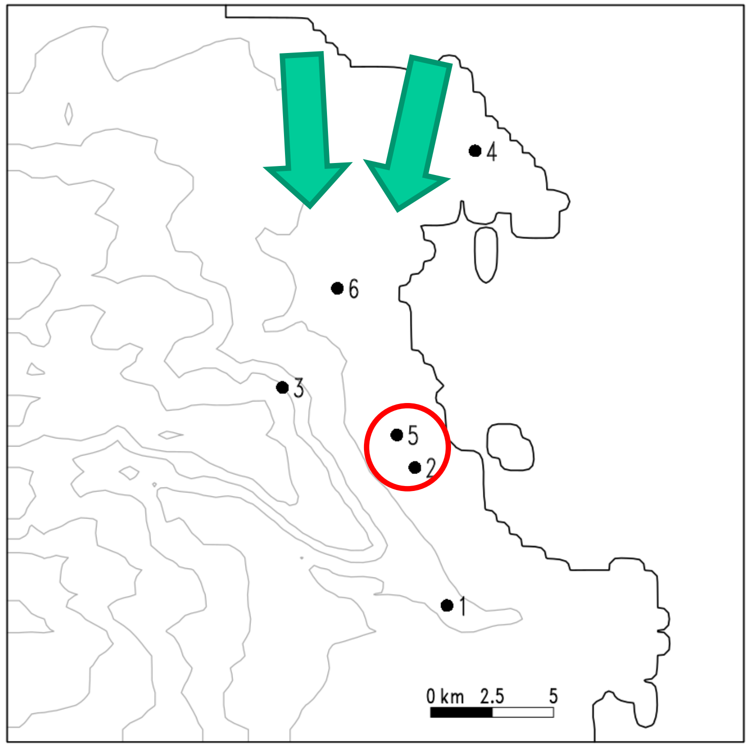




Real case

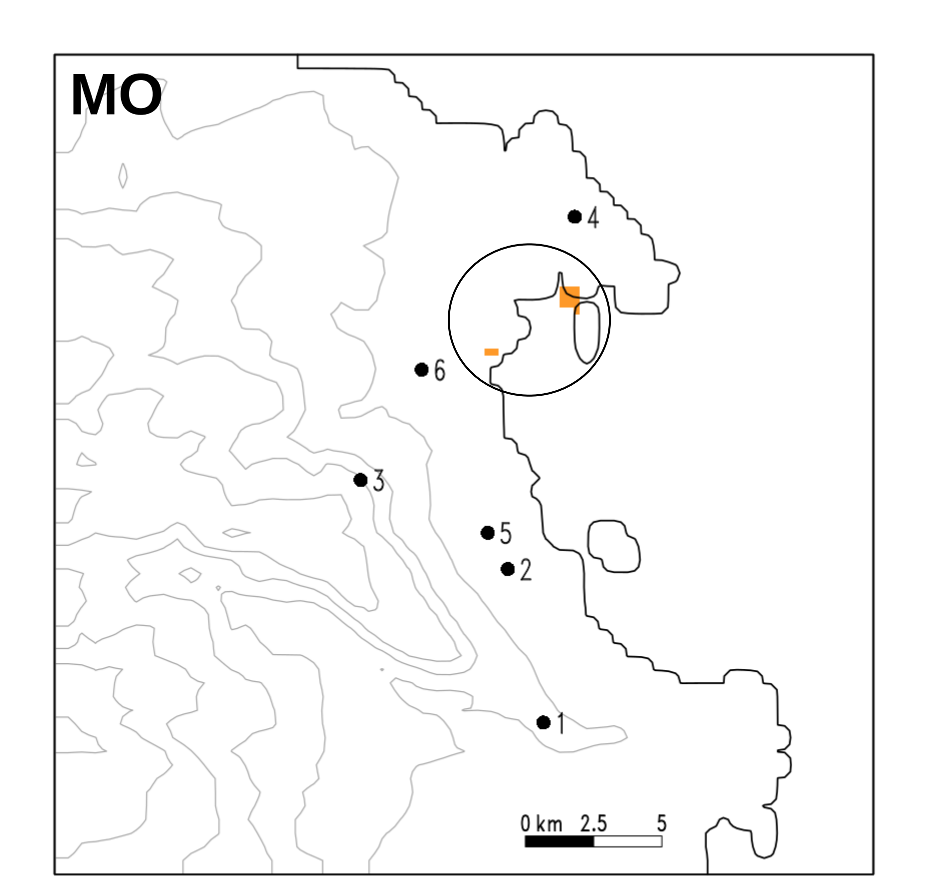
Benzene peak at 21:00
Weak wind (1-2 m/s) mainly from N and NNE

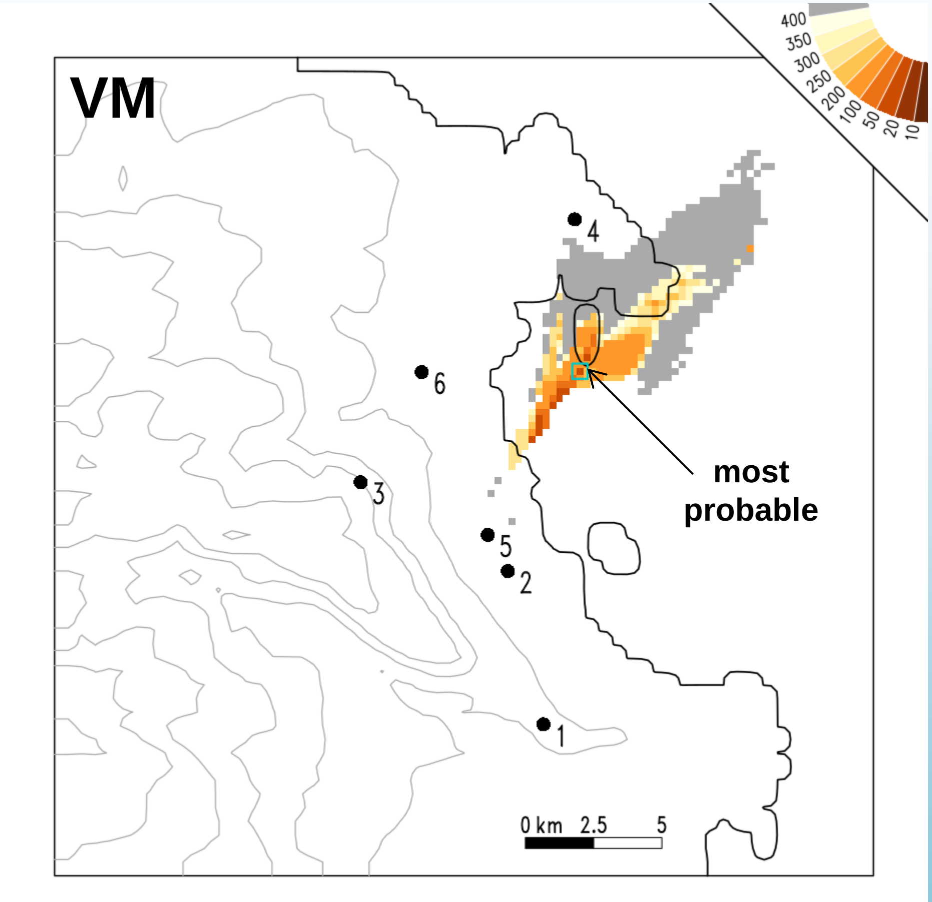




only two samplers
are substantially measuring the peak

Real case – source position





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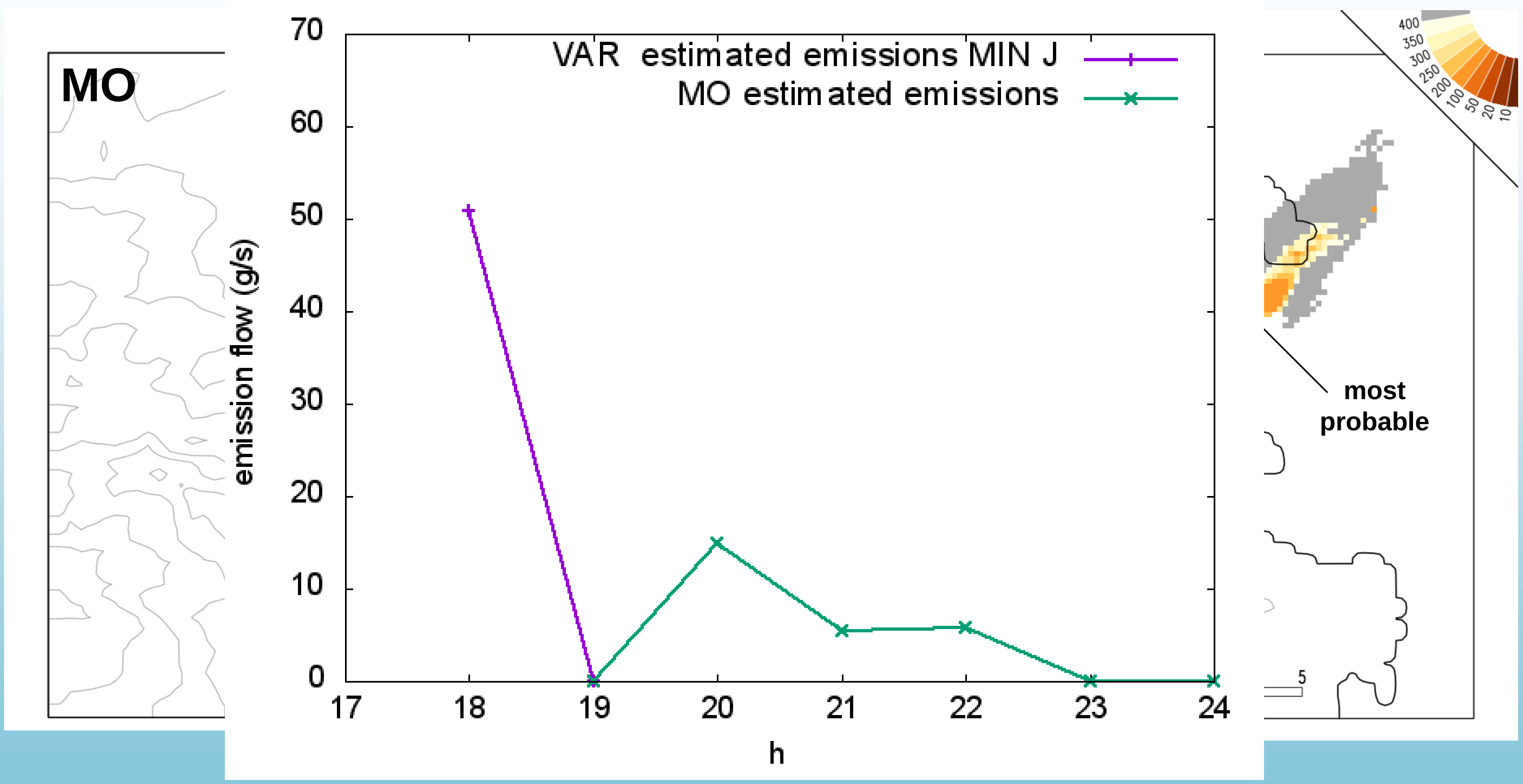

Conclusions

- Two **Source Term Estimation** (STE) algorithms, based on **retroSPRAY results have been tested**
- **Real and synthetic test cases and on real operational cases with different spatial and temporal time scales**

- Critical point 1: definition of the **wind** field: advection and transport
- Critical point 2: **Station spatial distribution**, particularly with respect to main wind directions
- **ZERO observations** are useful to exclude impossible, or very unlikely, source locations, particularly if upwind to the source

When 1) **wind uncertainty** is **small** and 2) **observational information** is **sufficient**, both method locate the **source position** with acceptable accuracy

The **variational method** seems to provide a more accurate estimate of the source position and in particular of the emitted quantities**,** even if in an operational environment, for a rapid response, the **maximum overlap** method gives reasonable results