Ground-air gas emission rate inferred from measured concentration rise, within a disturbed atmospheric surface layer*

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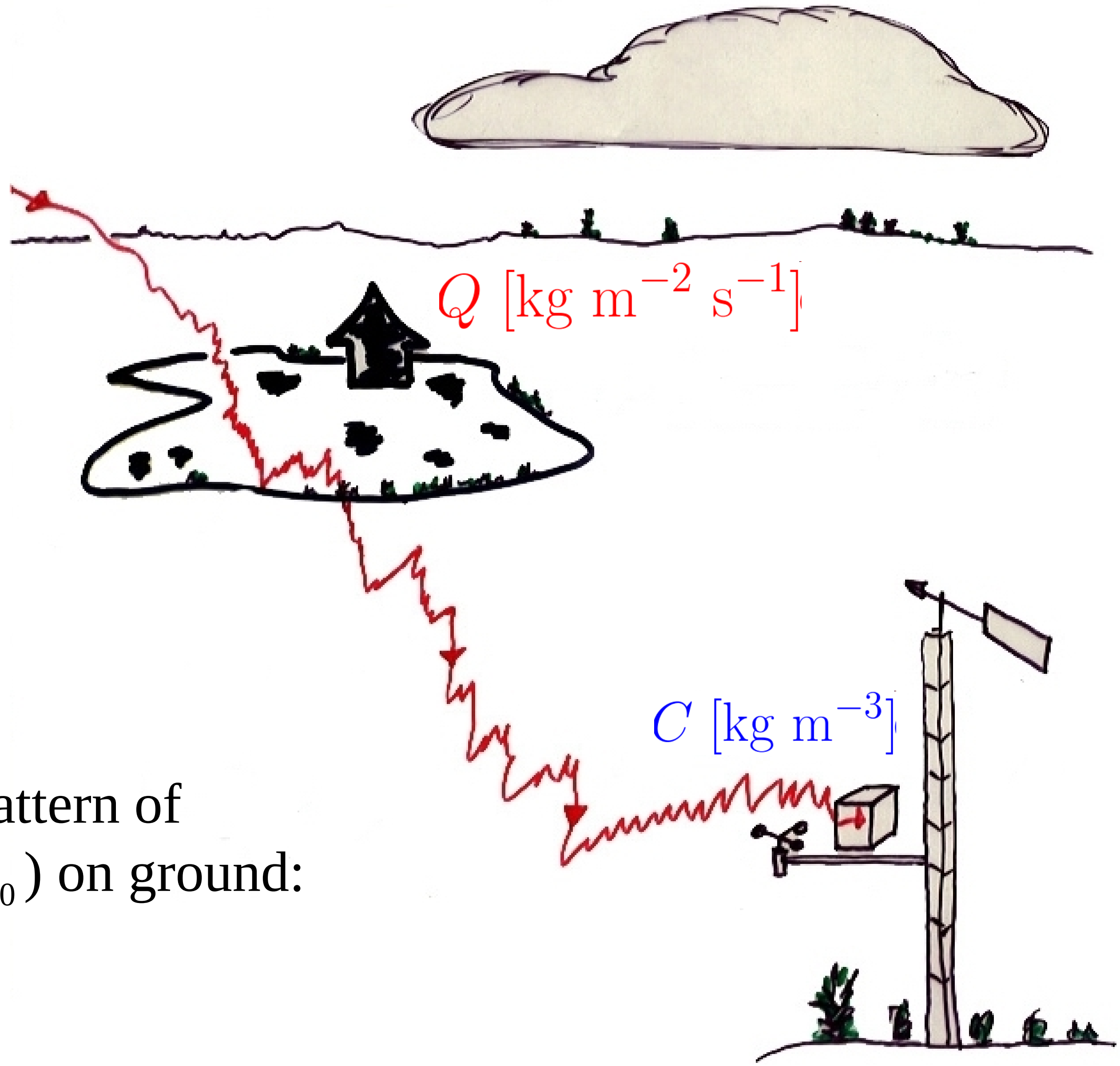
• in undisturbed winds we have a well-tried means to compute an ensemble of forward (f) or backward (b) paths

• this is encoded in WindTrax, which assumes Monin-Obukhov profiles for all needed properties, thus: "**MO-bLS**"



• the ***C*** - ***Q*** rel'n hinges on pattern of "touchdowns" (vert veloc. w_0) on ground:

$$\frac{C}{Q} = \frac{1}{N_P} \sum \frac{2}{|w_0|}$$

• compute NP paths; sum over all touchdowns within source

Inverse dispersion by computing N_P *backward* paths to source(s)

bLS applied to determine methane emission from waste lagoons

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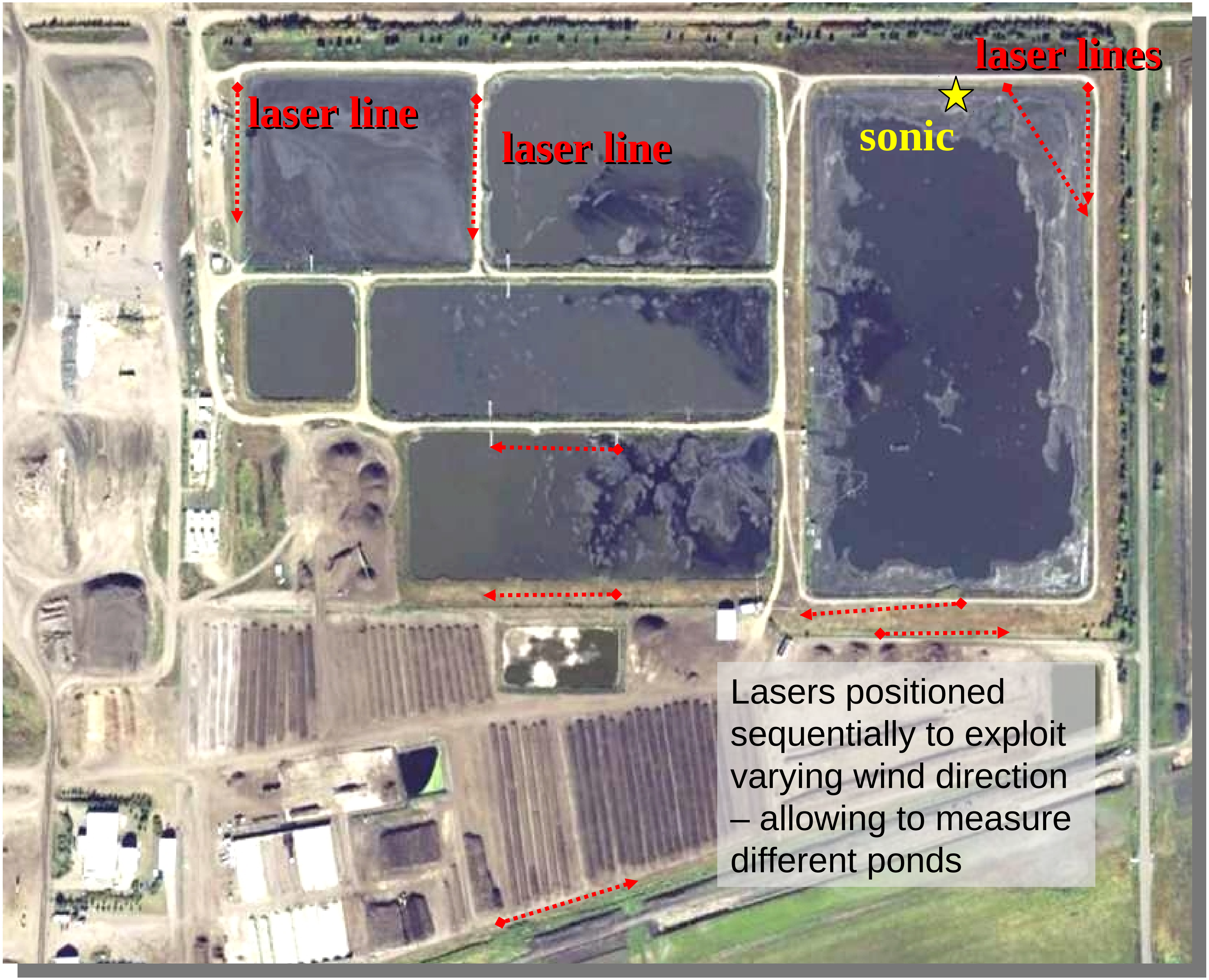
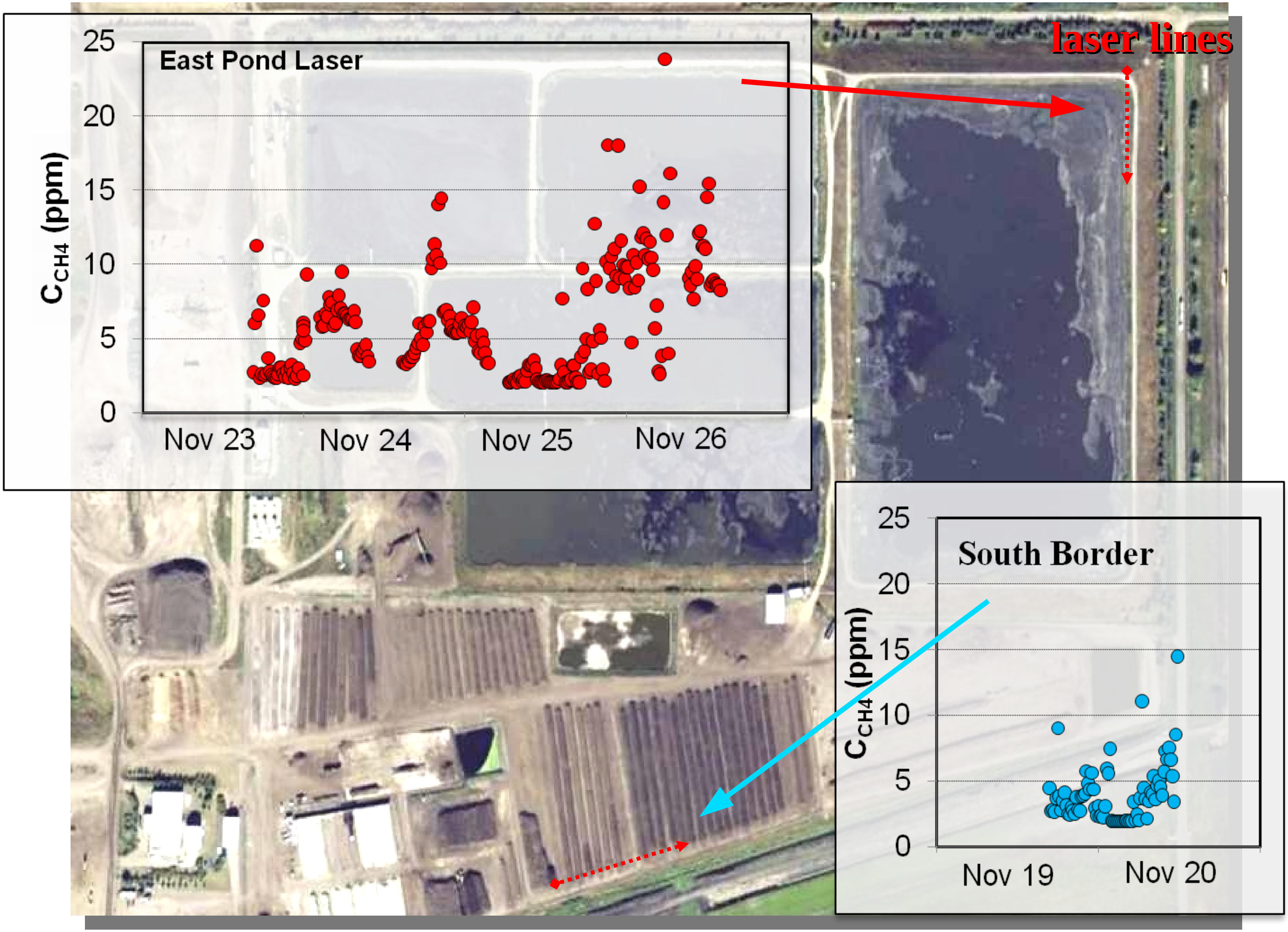
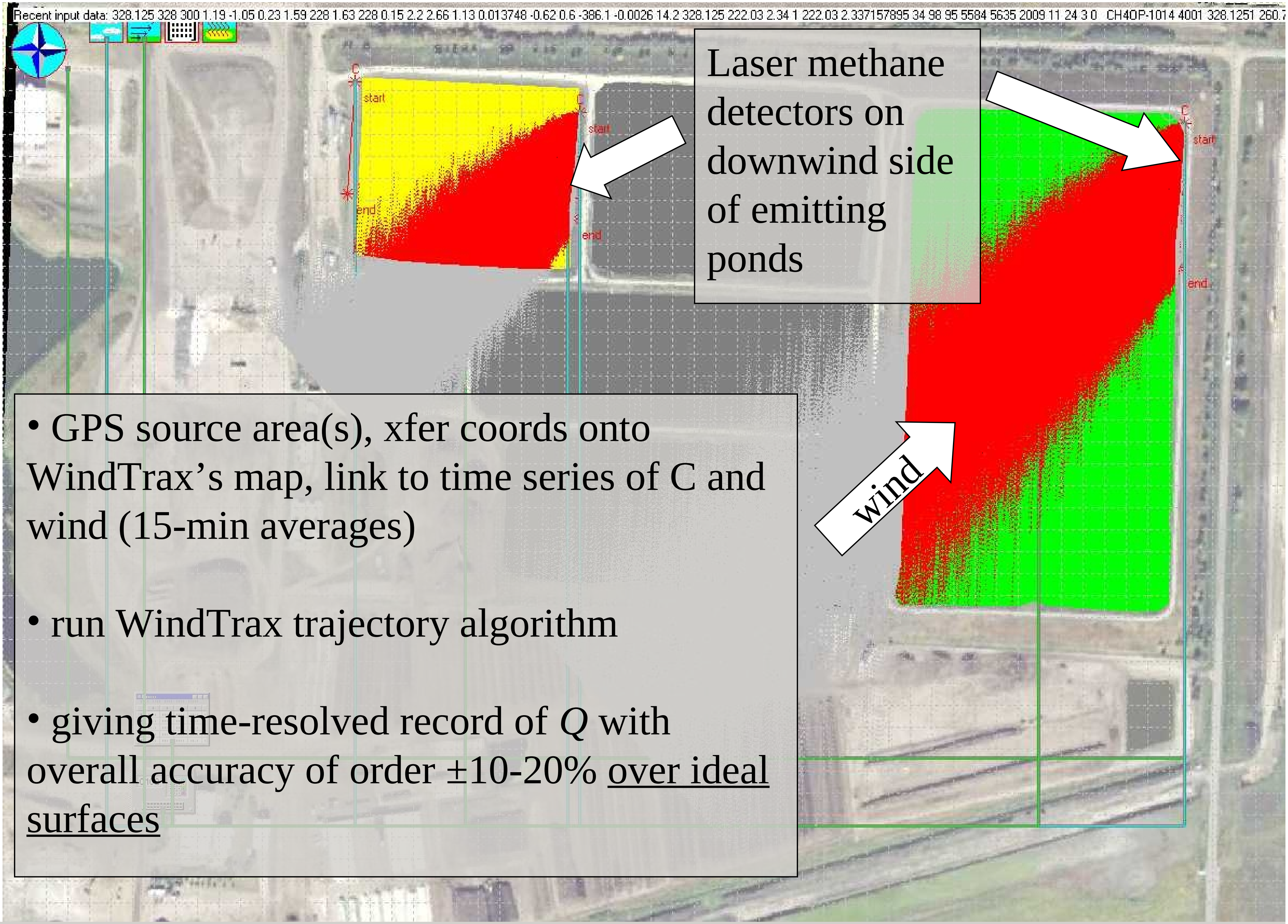


Concentration signals – not necessarily time-continuous





Laser methane detectors on downwind side of emitting ponds

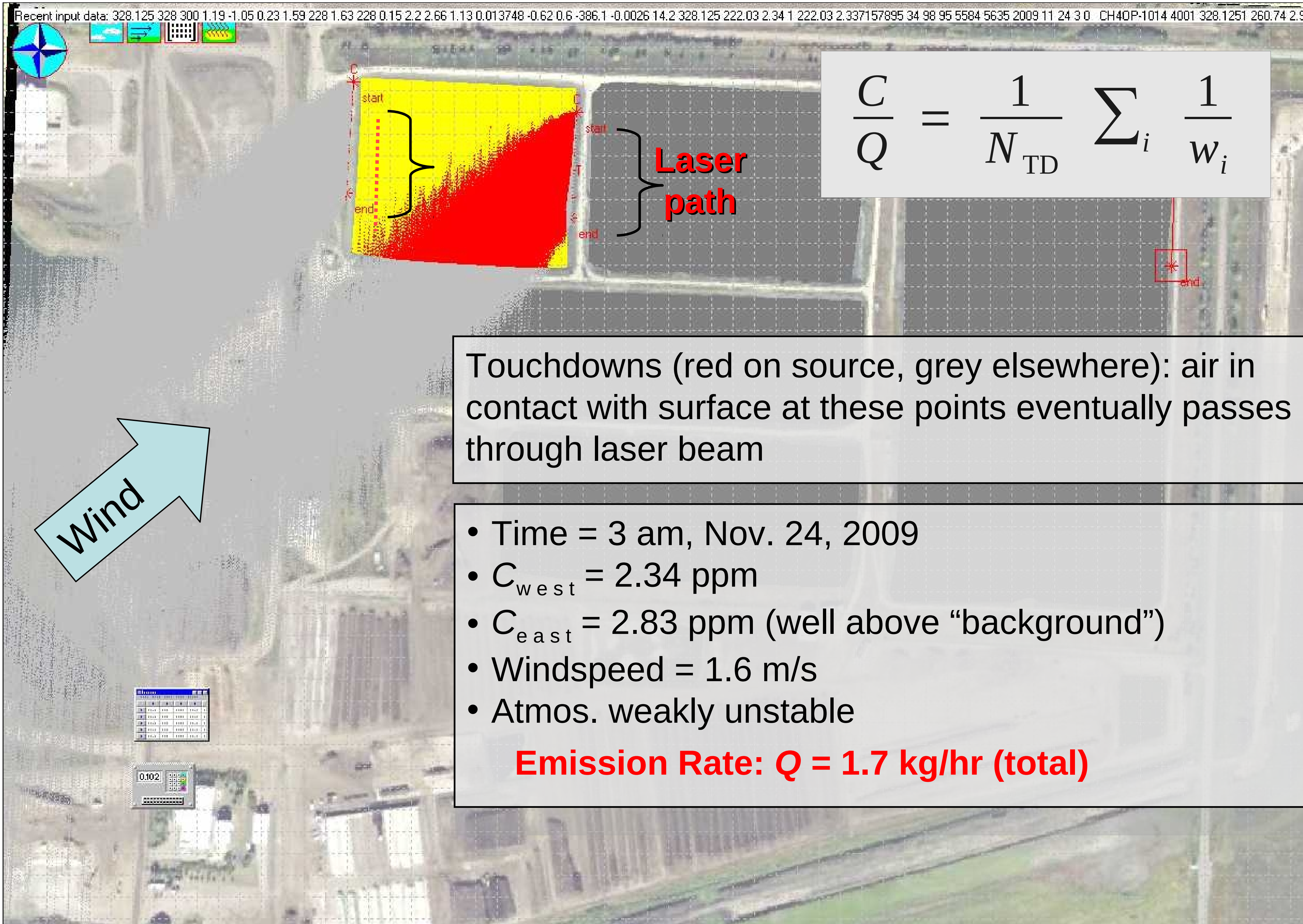
- GPS source area(s), xfer coords onto WindTrax's map, link to time series of C and wind (15-min averages)

- run WindTrax trajectory algorithm

- giving time-resolved record of *Q* with overall accuracy of order ±10-20% <u>over ideal surfaces</u>

WindTrax facilitates **<u>MO-bLS</u>** – here showing "touchdown clouds"

Converting concentration (*C*) to emission rate (*Q*) using WindTraX



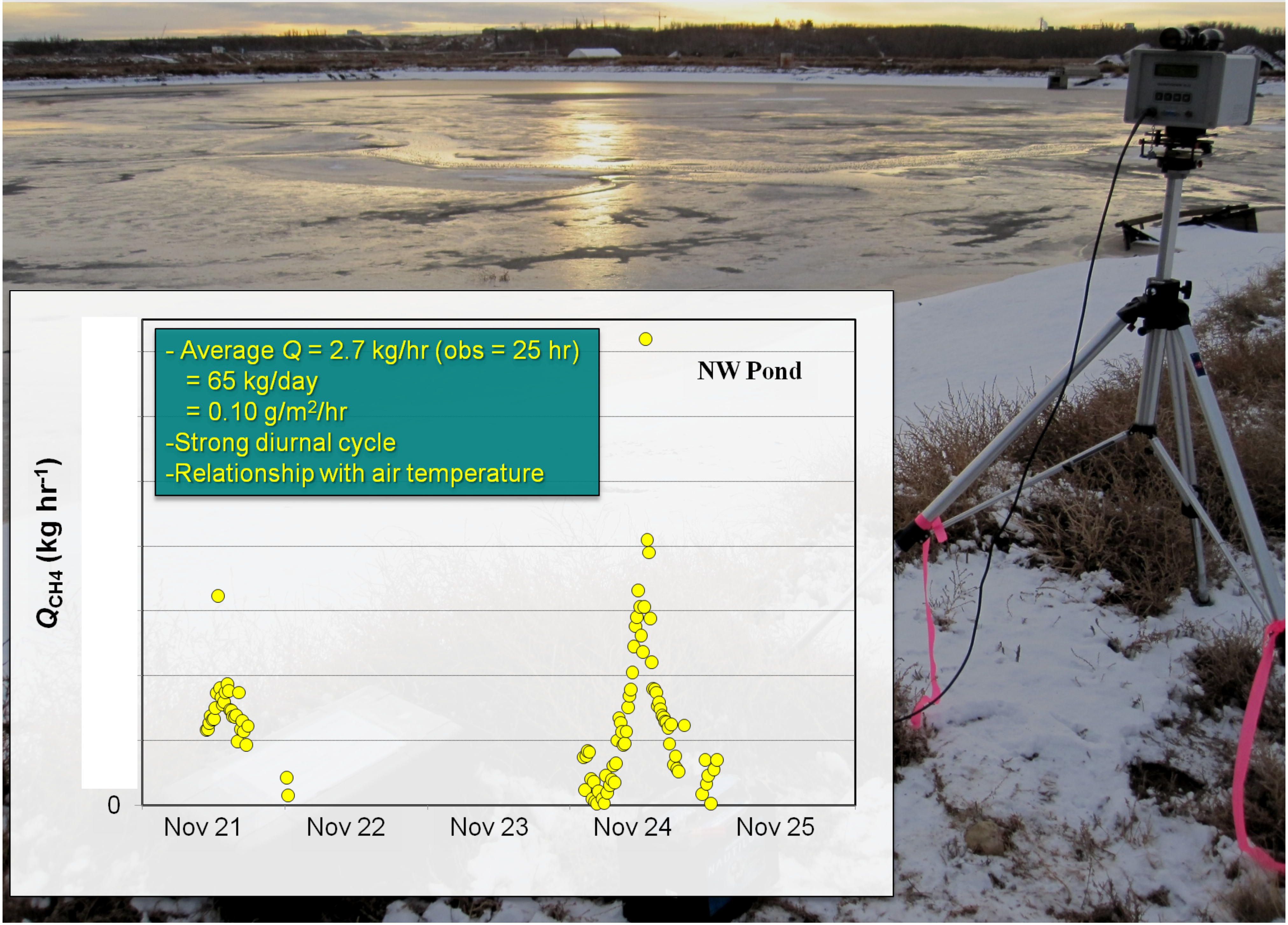
$$\frac{C}{Q} = \frac{1}{N_{\mathrm{TD}}} \sum_i \frac{1}{w_i}$$

Touchdowns (red on source, grey elsewhere): air in contact with surface at these points eventually passes through laser beam

- Time = 3 am, Nov. 24, 2009
- C_{west} = 2.34 ppm
- C_{east} = 2.83 ppm (well above “background”)
- Windspeed = 1.6 m/s
- Atmos. weakly unstable

Emission Rate: *Q* = 1.7 kg/hr (total)

Inferred CH4 emission rate



MO-bLS method for inferring emission rate

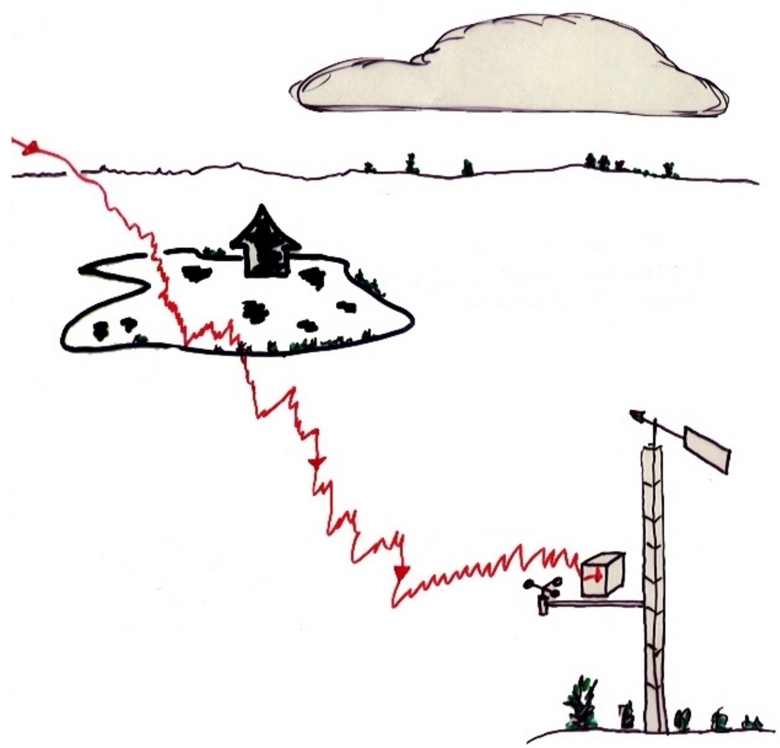
- convenient; provides a time-resolved (but typically non-continuous) record with overall accuracy that should be of order +/- 10%

- provides an average of emission rate over a large surface area

- requires

  - well defined background (use a second sensor to determine this?)

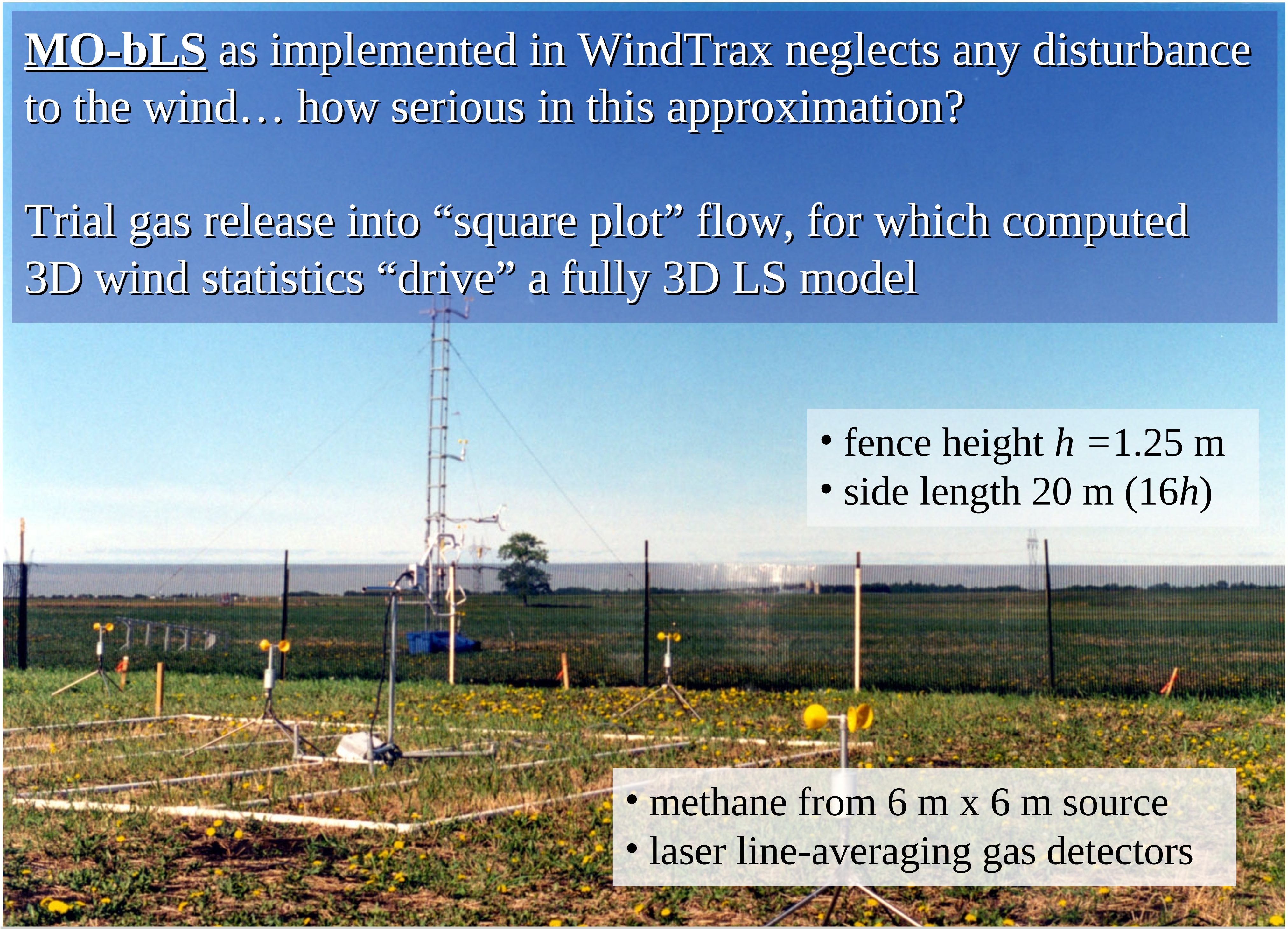
  - that source area(s) can be delineated from non-source




Estimating Gas Emissions from Multiple Sources Using a Backward Lagrangian Stochastic Model
Estimating gas emissions from a farm with an inverse-dispersion technique
ATMOSPHERIC ENVIRONMENT
Estimating Tracer Emissions with a Backward Lagrangian Stochastic Technique
Methane emissions from beef cattle – a comparison of paddock- and animal-scale measurements
European Journal of Agronomy
The evaluation of a backward Lagrangian stochastic (bLS) model to estimate greenhouse gas emissions from
AGRICULTURAL AND FOREST METEOROLOGY
Measuring methane emission rates of a dairy cow herd (II): results from a backward-Lagrangian stochastic model
Atmospheric monitoring and verification technologies for CO2 geosequestration
Energy Procedia
Atmospheric Monitoring for the Pembina Cardium CO2 Monitoring Project using Open Path Laser Technology
Atmospheric Environment
Testing Lagrangian atmospheric dispersion modelling to monitor CO2 leakage from geosequestration
Agricultural and Forest Meteorology
Assessment of the backward Lagrangian Stochastic dispersion technique for continuous measurements of CH4 emissions
The Effect of Biofuel Production on Swine Farm Methane and Ammonia Emissions

<u>**MO-bLS**</u> as implemented in WindTrax neglects any disturbance to the wind… how serious in this approximation?

Trial gas release into "square plot" flow, for which computed 3D wind statistics "drive" a fully 3D LS model

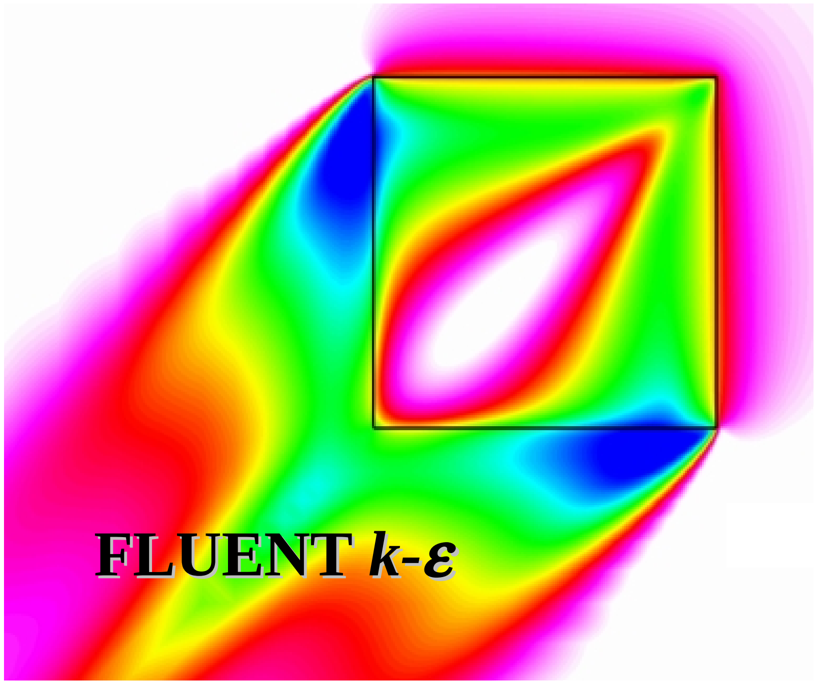


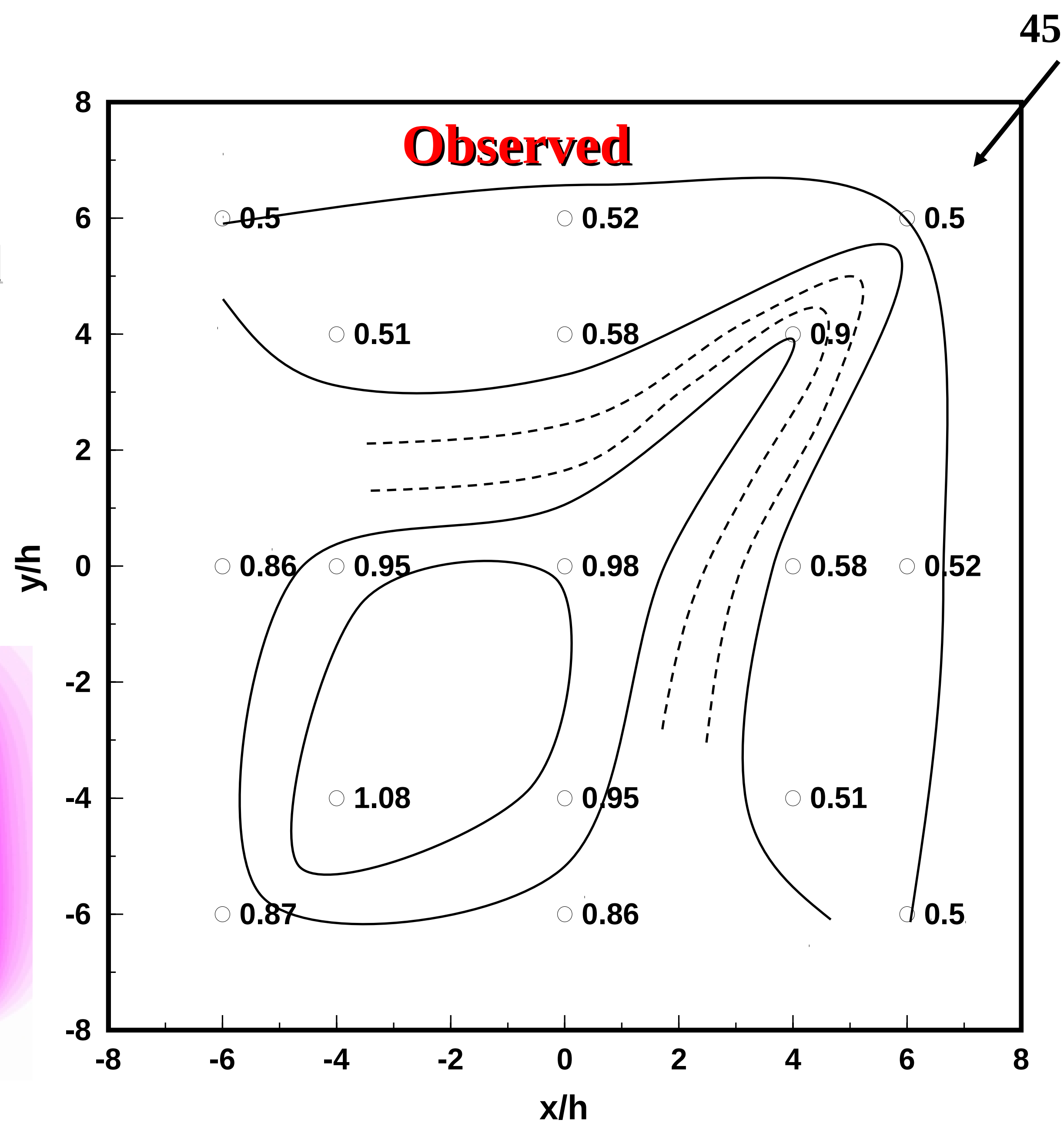
- fence height *h* =1.25 m
- side length 20 m (16*h*)

- methane from 6 m x 6 m source
- laser line-averaging gas detectors

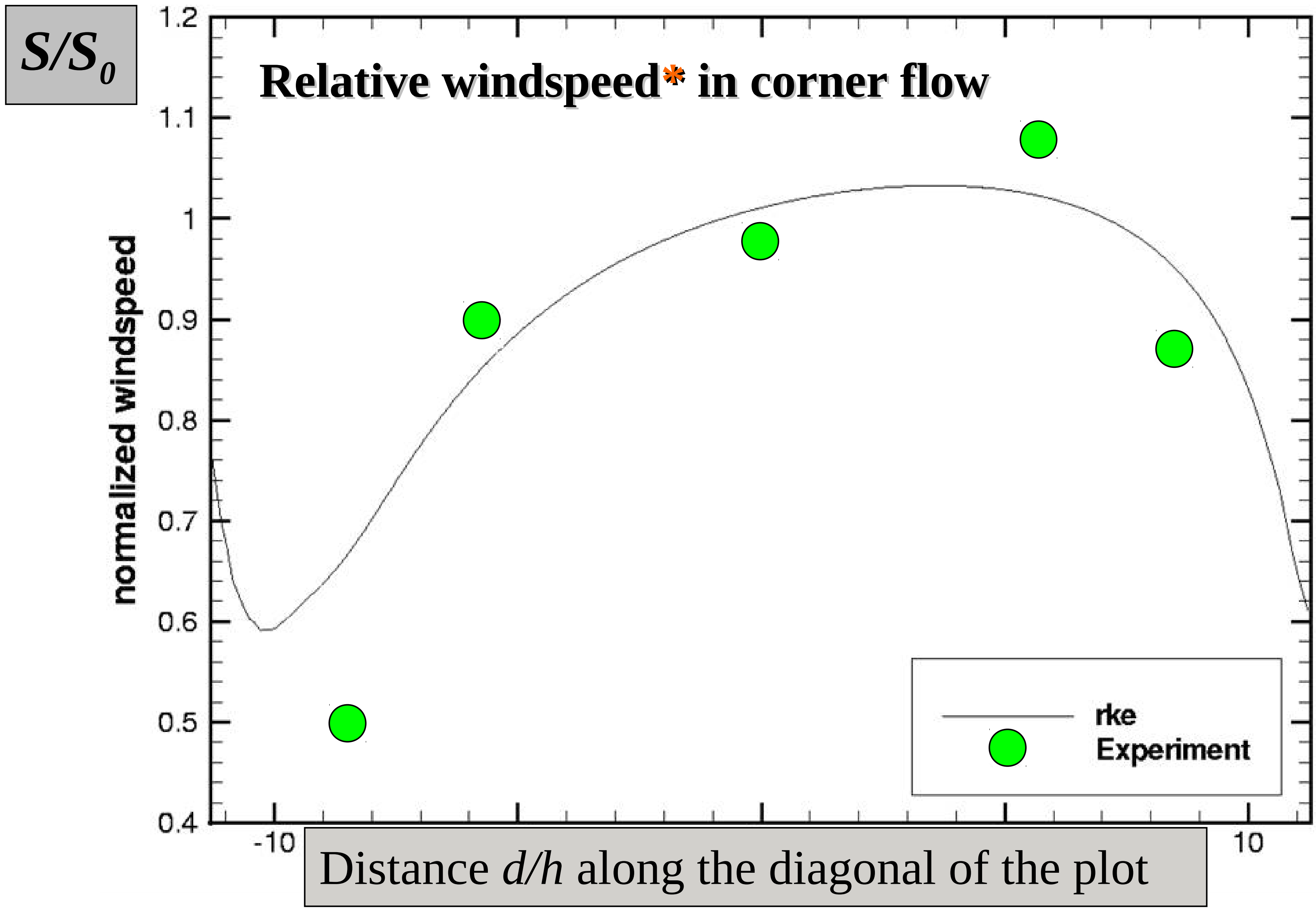
The square plot tracer dispersion trials

Contoured ratio S/S_0 of speed in plot at $h/2$ to speed at same height in open



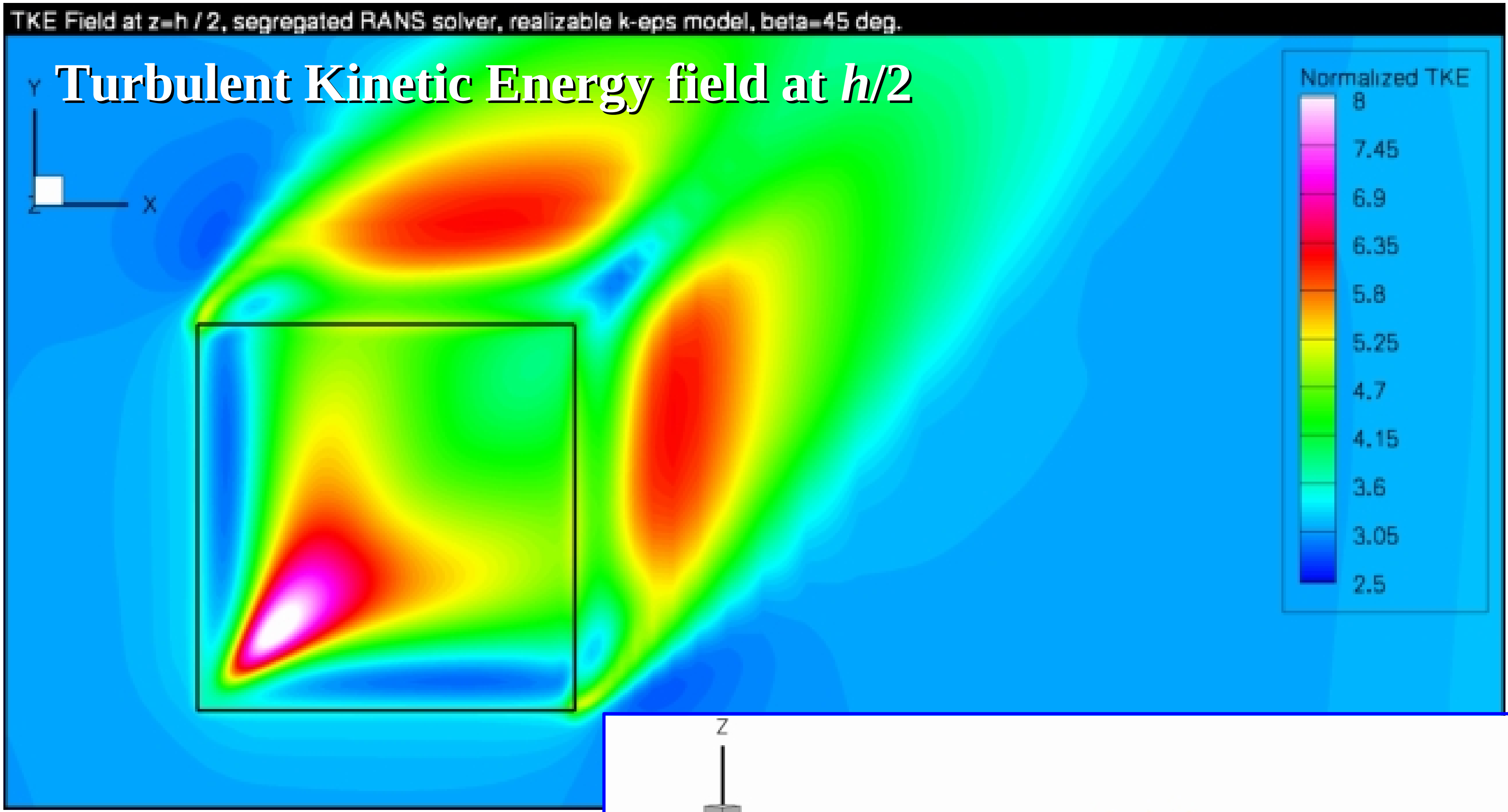


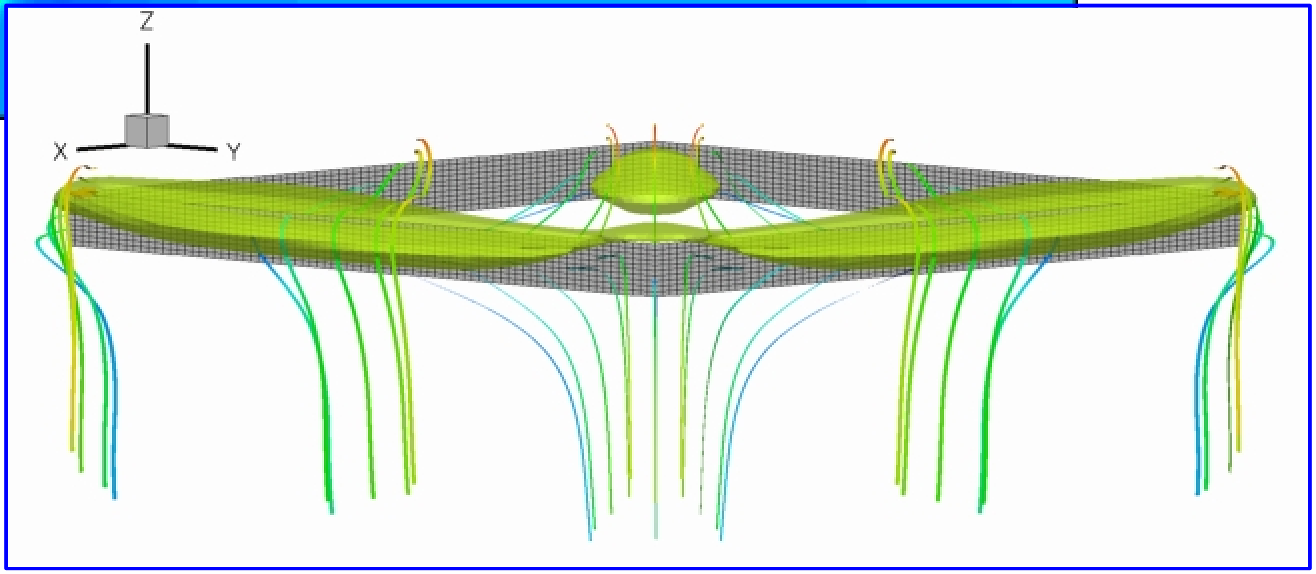
Winds in the square plot *highly* disturbed



***ratio of speed in plot at *h/2* to speed at same height in open**

Quantitative comparison of FLUENT computation with measurements



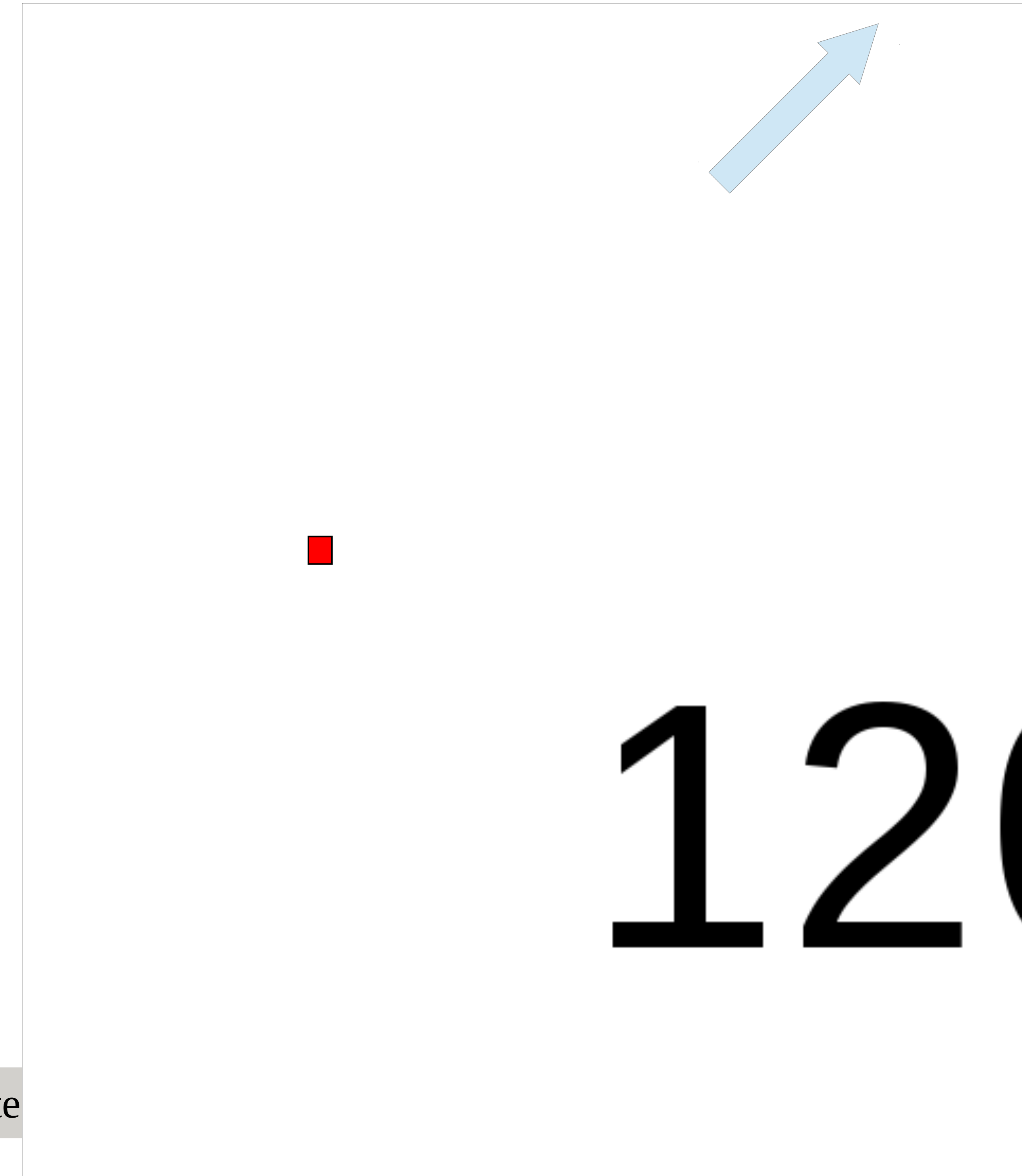


Computed pattern of TKE during corner flow

■ Tracer gas source

—— Line-averaging laser gas detector

y (m)

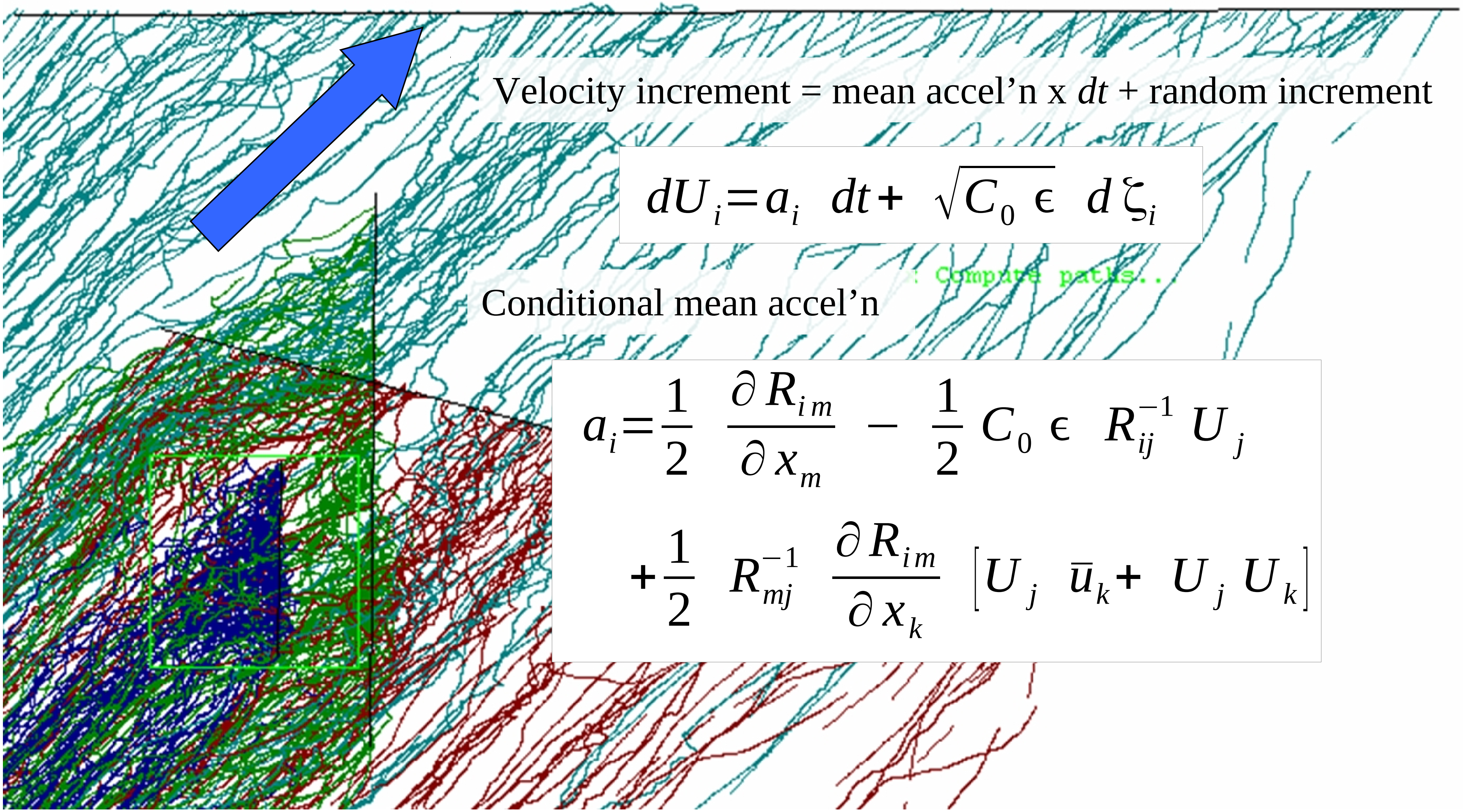


- release rate ***Q*** controlled and known

- many trials for each configuration

Configurations of laser methane dete

Compute *C/Q* ratio using 3D-bLS model (driven by computed wind)



Velocity increment = mean accel'n x *dt* + random increment

$$dU_i = a_i \; dt + \sqrt{C_0 \, \epsilon} \; d\zeta_i$$

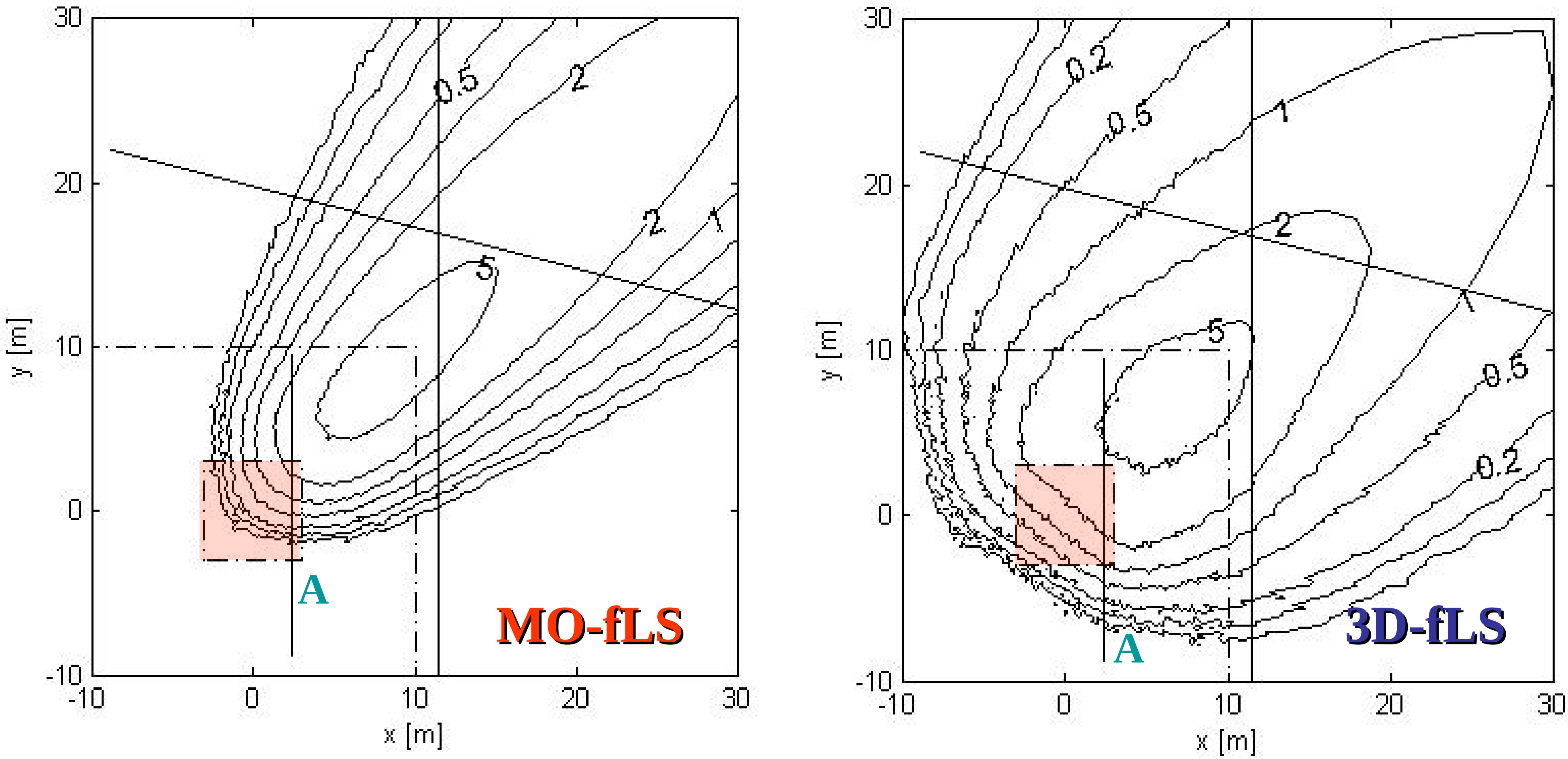
Conditional mean accel'n

$$a_i = \frac{1}{2} \frac{\partial R_{im}}{\partial x_m} - \frac{1}{2} C_0 \, \epsilon \; R_{ij}^{-1} \, U_j + \frac{1}{2} \, R_{mj}^{-1} \frac{\partial R_{im}}{\partial x_k} \left[U_j \; \bar{u}_k + U_j \, U_k \right]$$

- $R_{ij} = \overline{u'_i u'_j}$ the Reynolds stress tensor, provided by Fluent along with $\bar{u}_i$, ϵ

Thomson 3D LS model … and computed backward trajectories

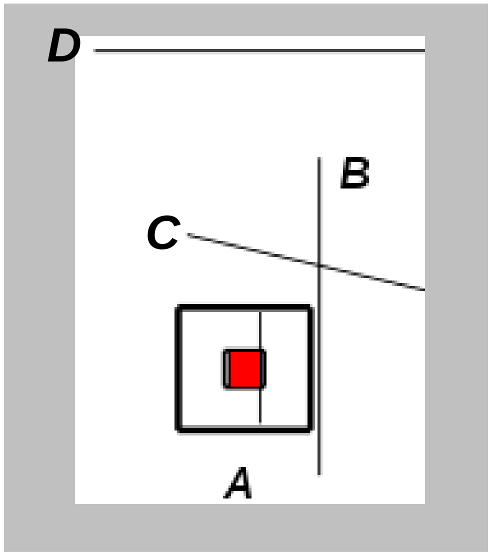
Computed concentration contours

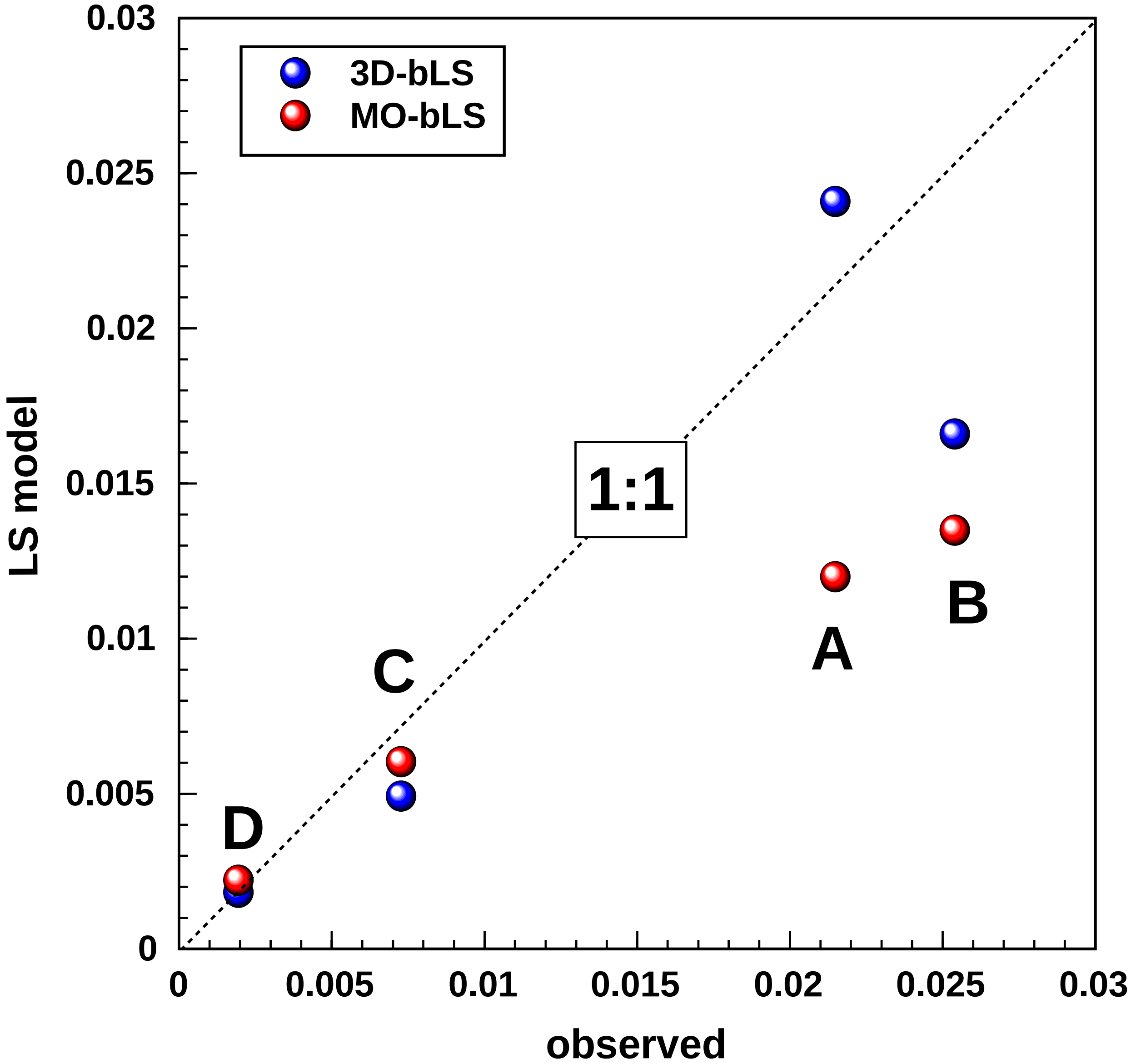


- (100 x) normalized concentration *SC/Q* at height of lasers
- narrow, elongated plume in (fictitious) undisturbed MO flow
- fatter plume in the “real” flow (or Fluent’s approx. to it)

Computed versus measured *UC/Q* ratio at four laser positions

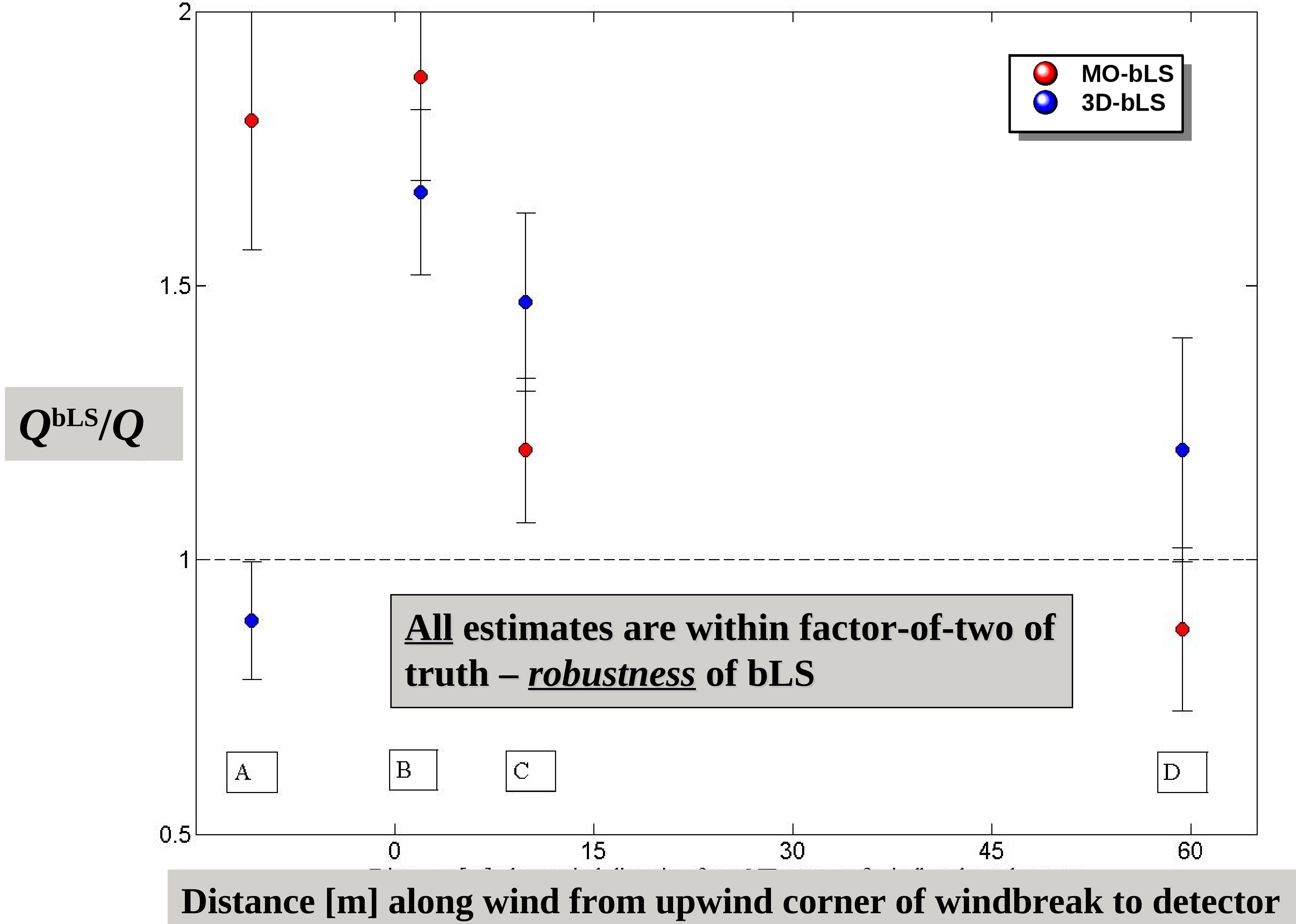
- A inside shelter
- B just outside
- D most distant





- perfect performance would be 1:1 line

Ratio of inferred to true source strength



Conclusion

• estimates are within factor-of-two both for MO-bLS and 3D-bLS

• basing bLS inverse-dispersion on an approximation to the disturbed wind field (“3D-bLS”) advantageous if detection point is in highly disturbed flow

• however “3D-bLS” very cumbersome relative to “MO-bLS” (which approximates the winds as being undisturbed)

• no advantage of 3D-bLS over MO-bLS if detection point far from source