MODITIC

Modelling the dispersion of toxic industrial chemicals in urban environments

MODITIC wind tunnel experiments

Harmo’17

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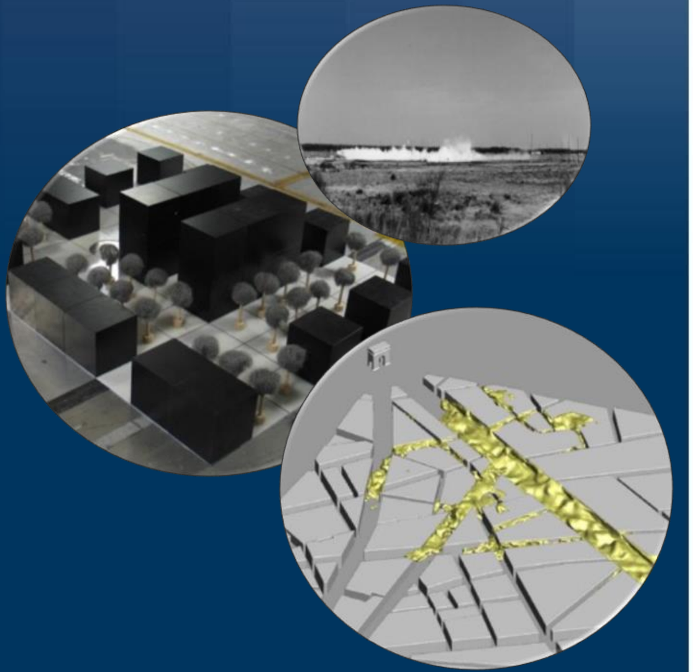

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Test prediction methods for dense gas emissions in conditions of increasing complexity.

Wind tunnel work addresses dispersion processes for

- steady emissions
- finite duration emissions

Strategy

Select operating conditions that generate strong dense gas effects – upwind spread, rapid near-field lateral spread, reduced vertical spread – rather than model specific scenarios.

Limited by choice of dense gas, carbon dioxide, for wind tunnel work.

Six categories of increasing complexity

1 Flat surface

2 Two-dimensional hill

3 Two-dimensional back-step

4 Simple array of obstacles

5 Complex array of obstacles

6 Urban area (central Paris)

Purpose

- to provide data to test computational methods
  - at model scale
  - at equivalent full scale

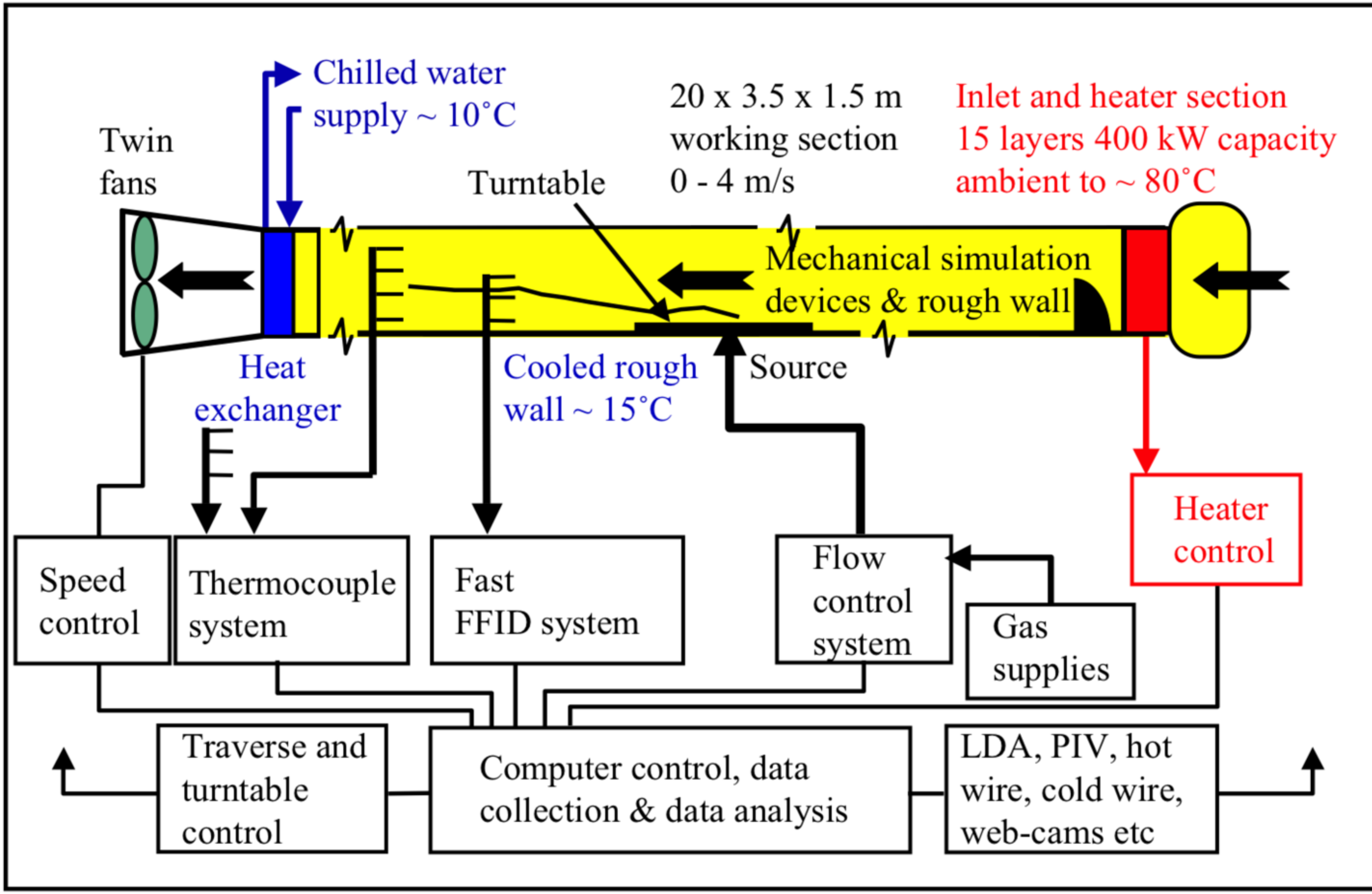
- to provide insight

1. Flat Surface

Data-base compiled from previous EnFlo work

- PERF dense gas studies, reported in Atmos Environ, 2001
- DYCE inverse modelling, reported in Boundary Layer Met., 2012

EnFlo



Chilled water supply ~ 10˚C
20 x 3.5 x 1.5 m working section 0 - 4 m/s
Inlet and heater section 15 layers 400 kW capacity ambient to ~ 80˚C
Twin fans
Turntable
Mechanical simulation devices & rough wall
Heat exchanger
Cooled rough wall ~ 15˚C
Source
Heater control
Speed control
Thermocouple system
Fast FFID system
Flow control system
Gas supplies
Traverse and turntable control
Computer control, data collection & data analysis
LDA, PIV, hot wire, cold wire, web-cams etc

EnFlo

Provide full and joint concentration (FFID) and velocity fields (LDA) for continuous and unsteady releases of air or carbon dioxide (or mixtures of the two) from ground level sources.

EnFlo inflow

Neutral boundary layer generated in standard manner - vorticity generators (Irwin spires) and surface roughness.

Profiles provided of mean velocity, turbulent stresses and length scales.

Summary

- boundary layer depth, H = 1 m
- friction velocity, u^* = 0.055U_{ref}
- surface roughness length, z_o = 0.088 mm.

Similarity conditions

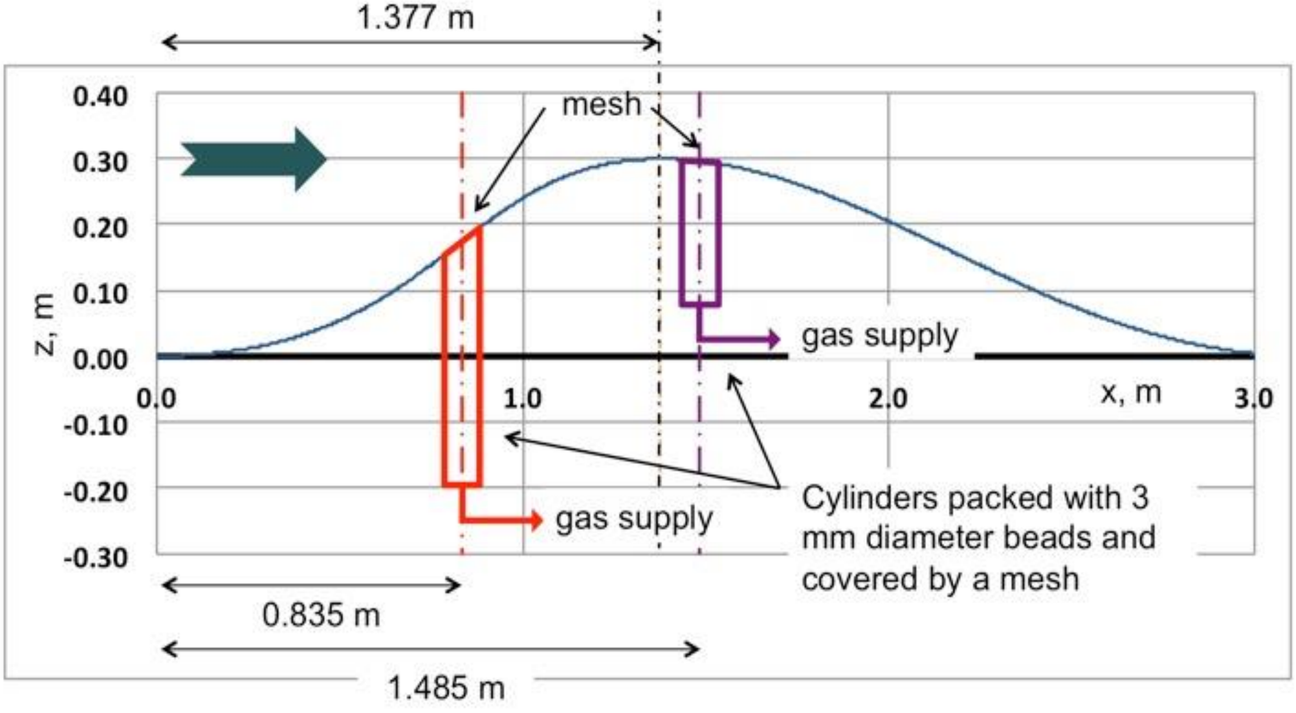
Reynolds numbers - surface and building constraints met.

Scaling of buoyant plume dynamics implies similarity of the emission density ratio, the emission velocity ratio and the Richardson number.

$$e_u = \frac{u*_{fs}}{u*_m} = \frac{U_{ref-fs}}{U_{ref-m}} = \left(\frac{h_{fs}}{h_m} \right)^{1/2} = e^{1/2}$$

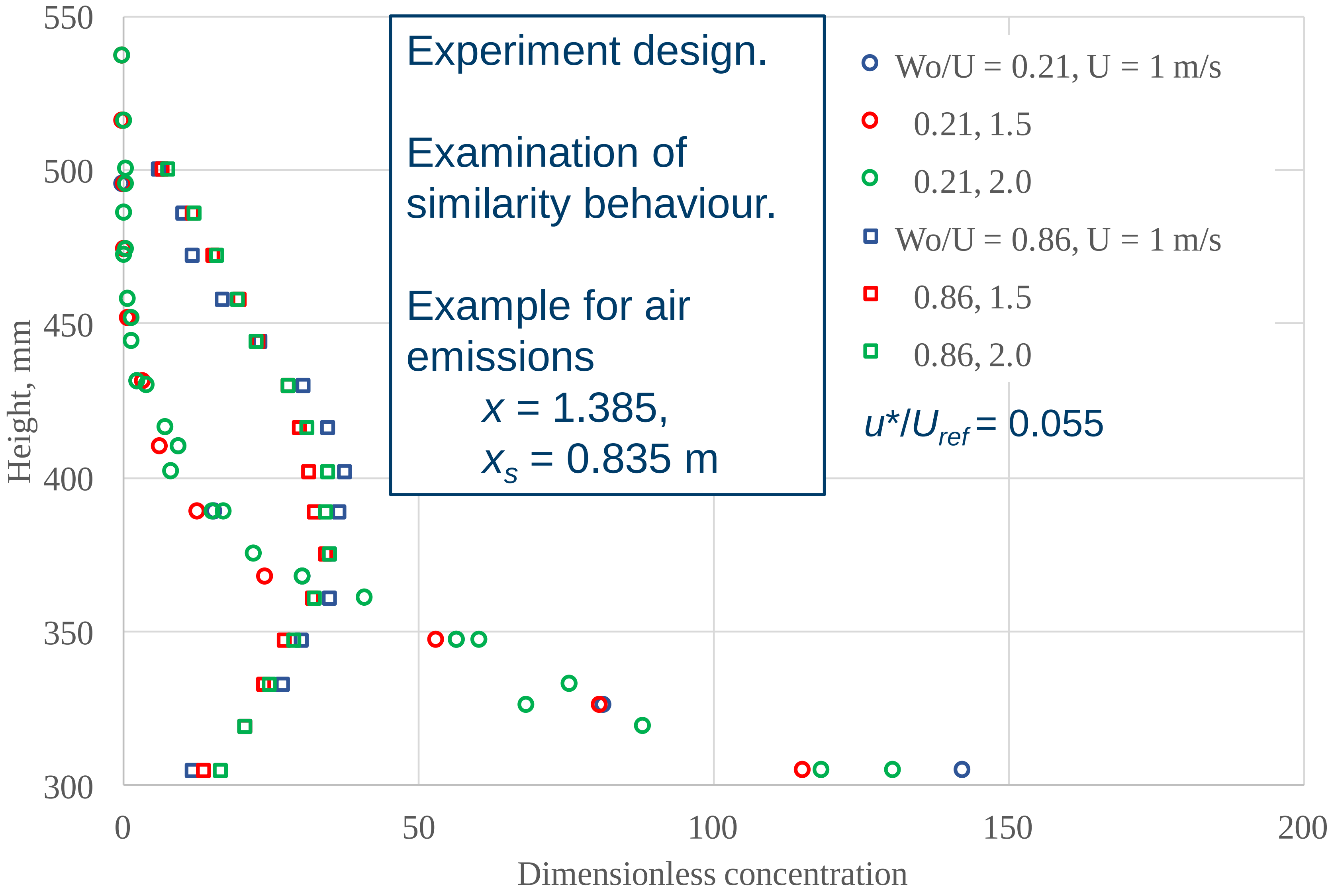
2. Two-dimensional hill

- Shape scaled from WALLTURB 'bump' - designed to generate a small separation bubble on the downwind face - previous LES flow simulations in WALLTURB.



~ 14 m from working section inlet

Two-dimensional hill – experiment design



Experiment design.

Examination of similarity behaviour.

Example for air emissions

x = 1.385,

x_s = 0.835 m

Two-dimensional hill

- Two source positions: upwind face, downwind face.
- Operating conditions: D = 100 mm, U_{ref} = 1 ms^{-1}, $Q_{(CO2)}$ = 100 litre.min^{-1}.
- Simultaneous LDA and FFID measurements (2 sources, 2 gases).

- Buoyancy effects in the dense gas plumes led to local flow deceleration near the upwind source and acceleration near the downwind source.
- Plumes showed significant upwind and greatly enhanced lateral spread (relative to the neutral density cases).

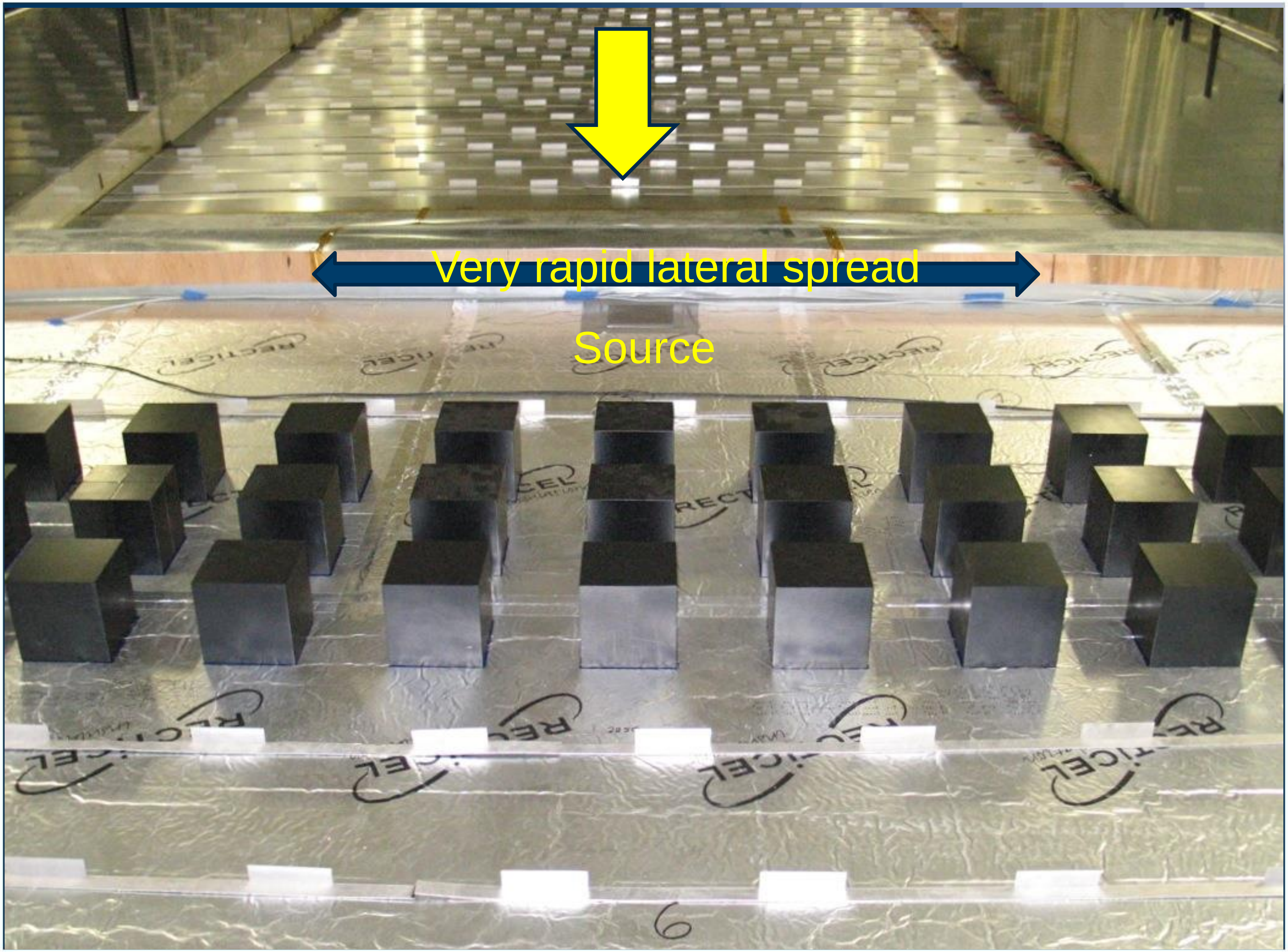
3. Two-dimensional back-step

Separating the hill at the crest gave a step aspect ratio, *W*/*h*, of 10, which was too small.
Floor level downwind of the step was built-up to reduce the step height to 0.1m, increasing *W*/*h* to 30 with W/L_R ~ 5.

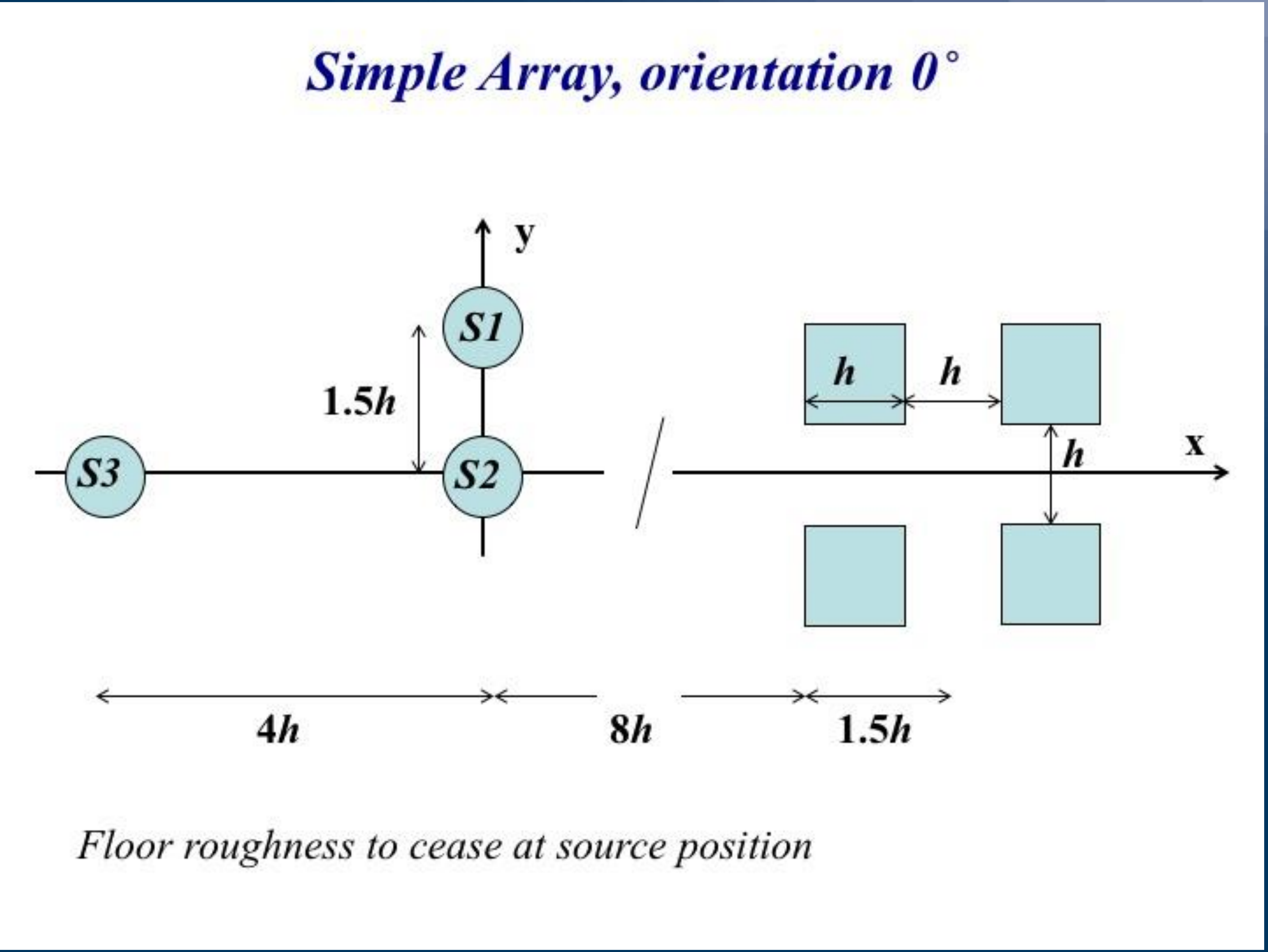
Source centre 0.1m from the step.
Floor downwind of the step either smooth or covered in the roughness elements.
Run conditions, *D*, U_{ref} and *Q*, as used with the hill model.

Dense gas plumes effectively two-dimensional.

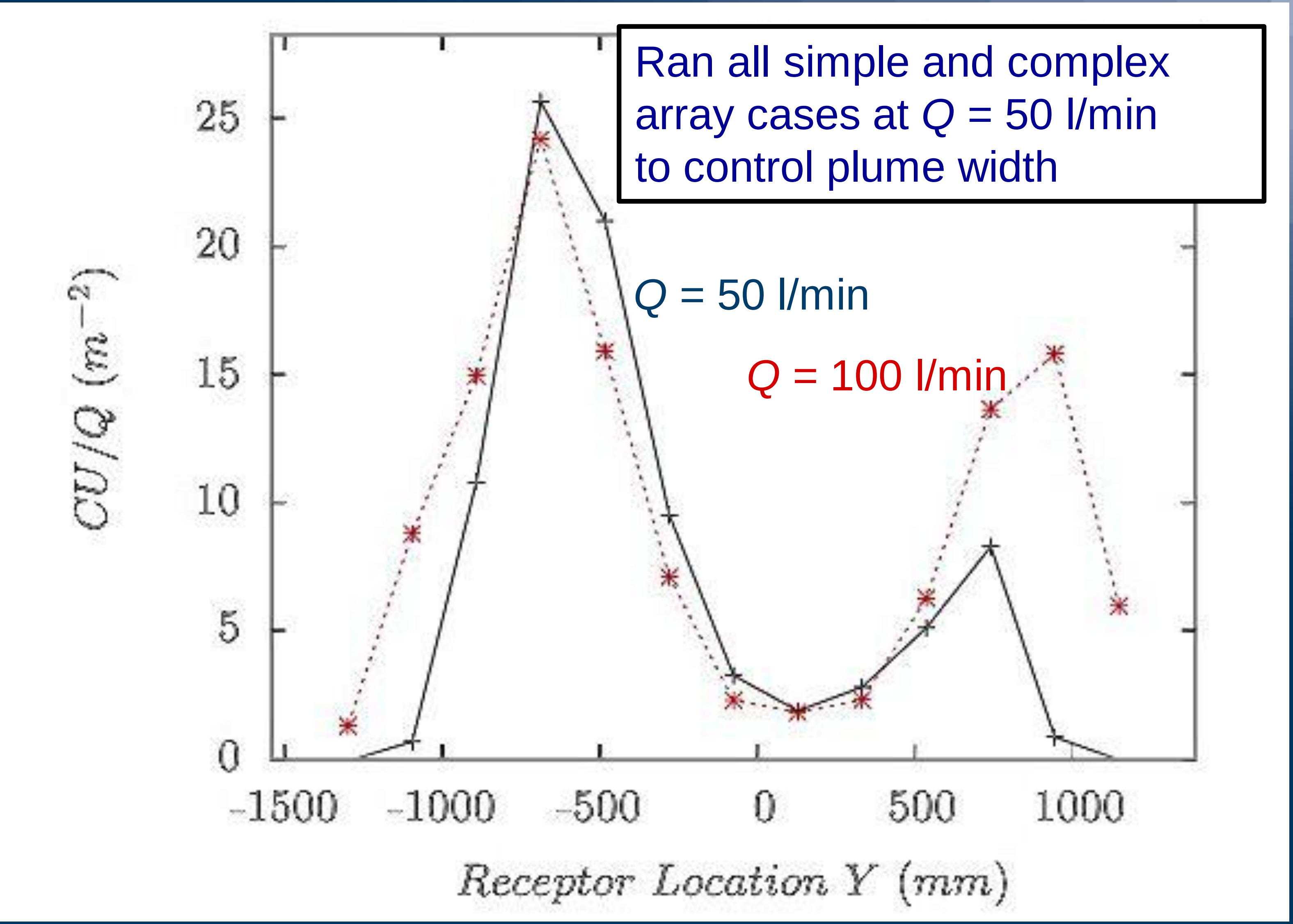
Variants on the basic experiments saw arrays of cubical obstacles installed on the downstream surface.


Very rapid lateral spread
Source

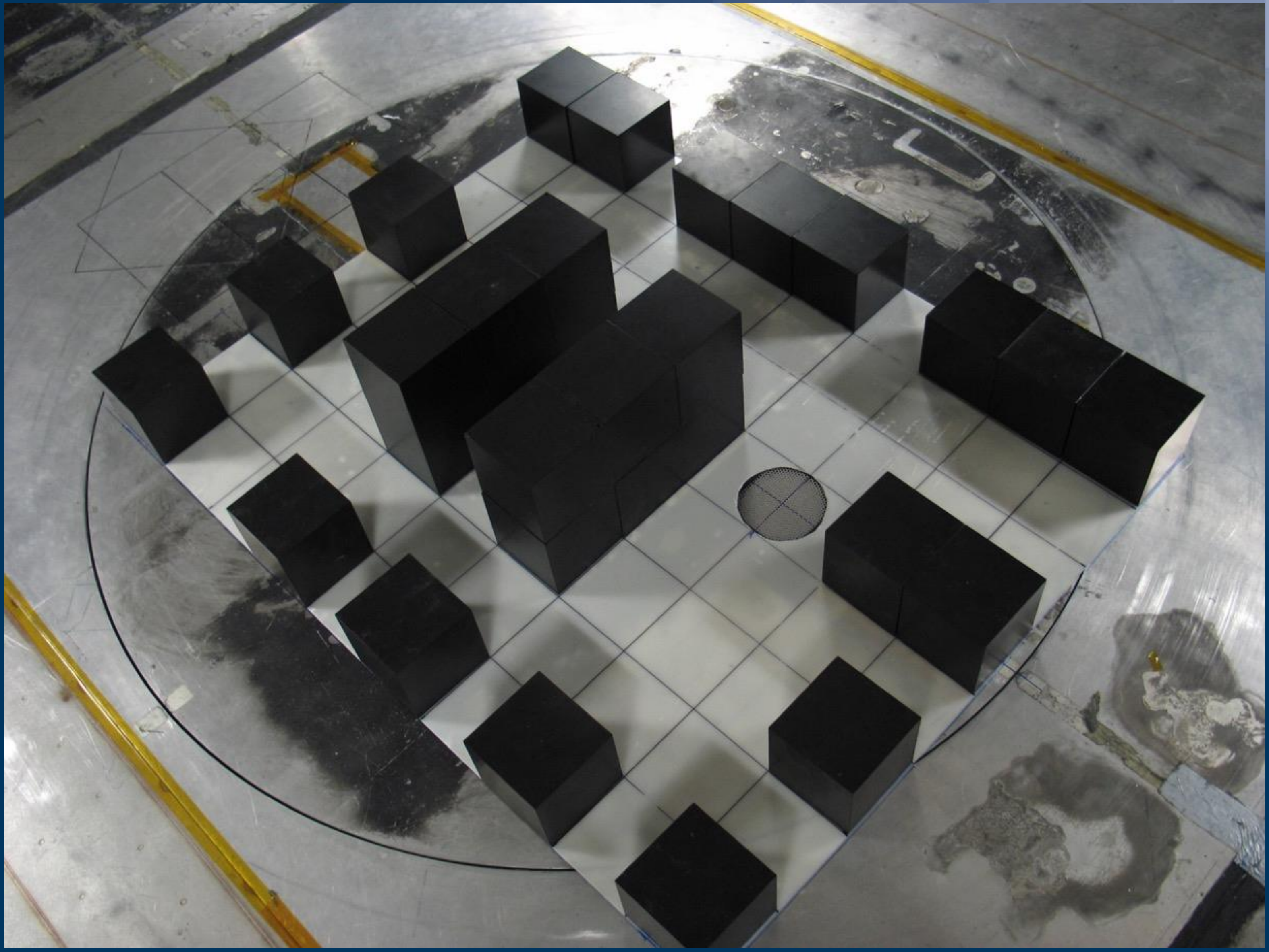
4. Simple obstacle array, 0 and 45°

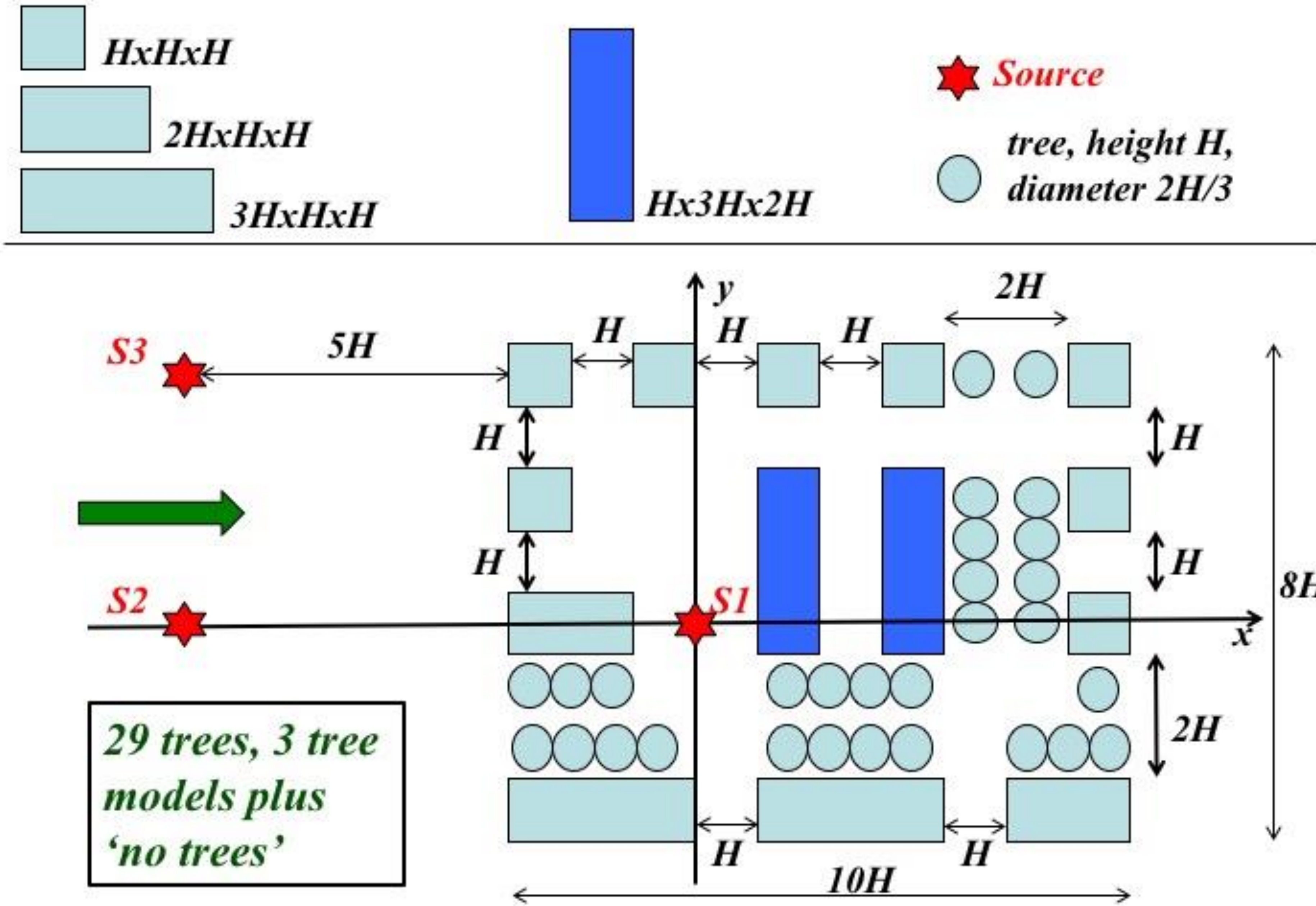


CO_2, x = 3.0 m, z = 0.025 m, U_{ref} = 1 ms^{-1}



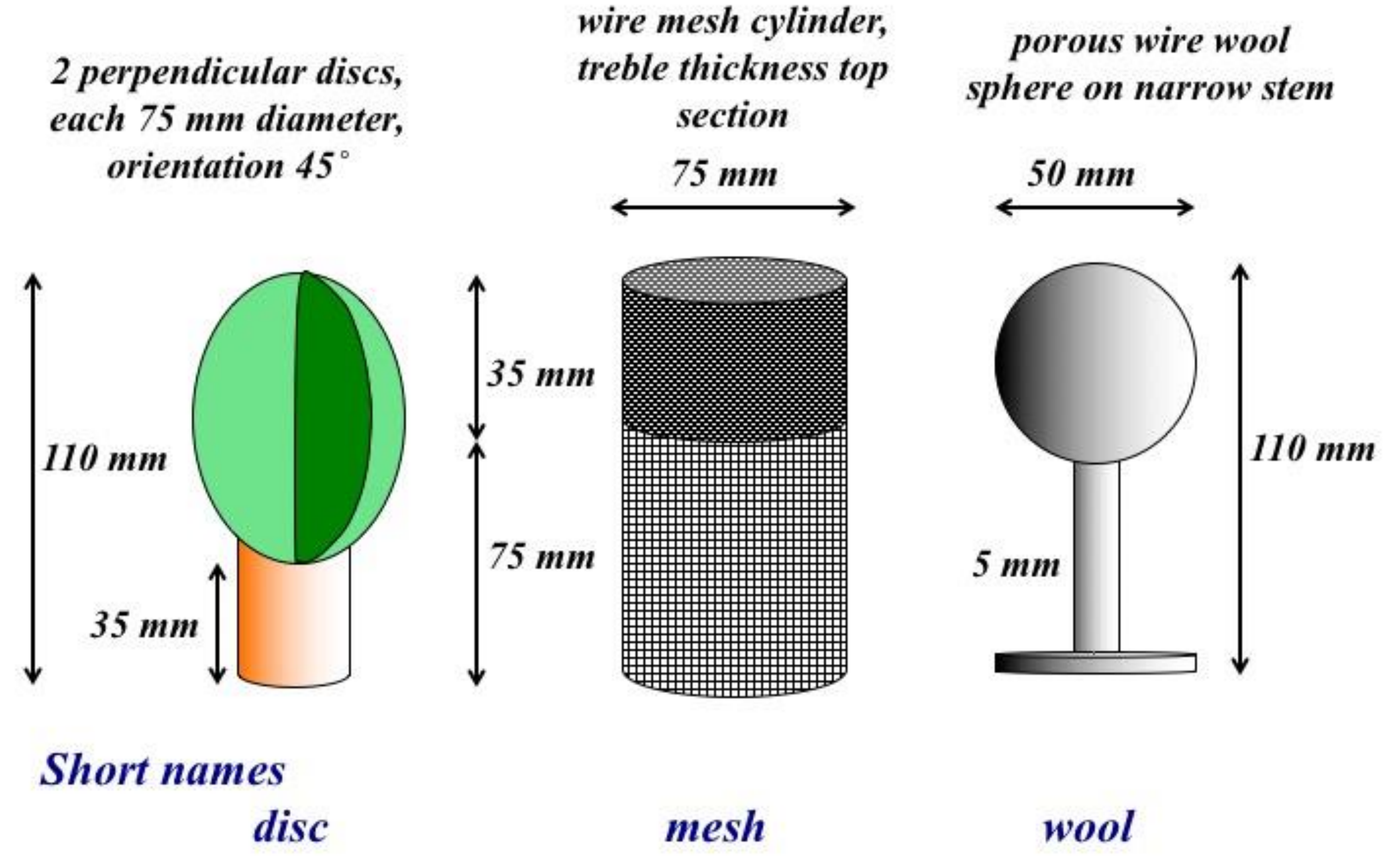
5. Complex obstacle array





HxHxH
2HxHxH
3HxHxH
Hx3Hx2H
Source
tree, height H,
diameter 2H/3
y
2H
H
H
H
5H
S3
H
H
H
H
S2
S1
x
8H
2H
29 trees, 3 tree
models plus
'no trees'
H
H
10H

Trees … ?



2 perpendicular discs, each 75 mm diameter, orientation 45°
wire mesh cylinder, treble thickness top section
porous wire wool sphere on narrow stem
75 mm
50 mm
110 mm
35 mm
35 mm
75 mm
110 mm
5 mm
Short names
disc
mesh
wool

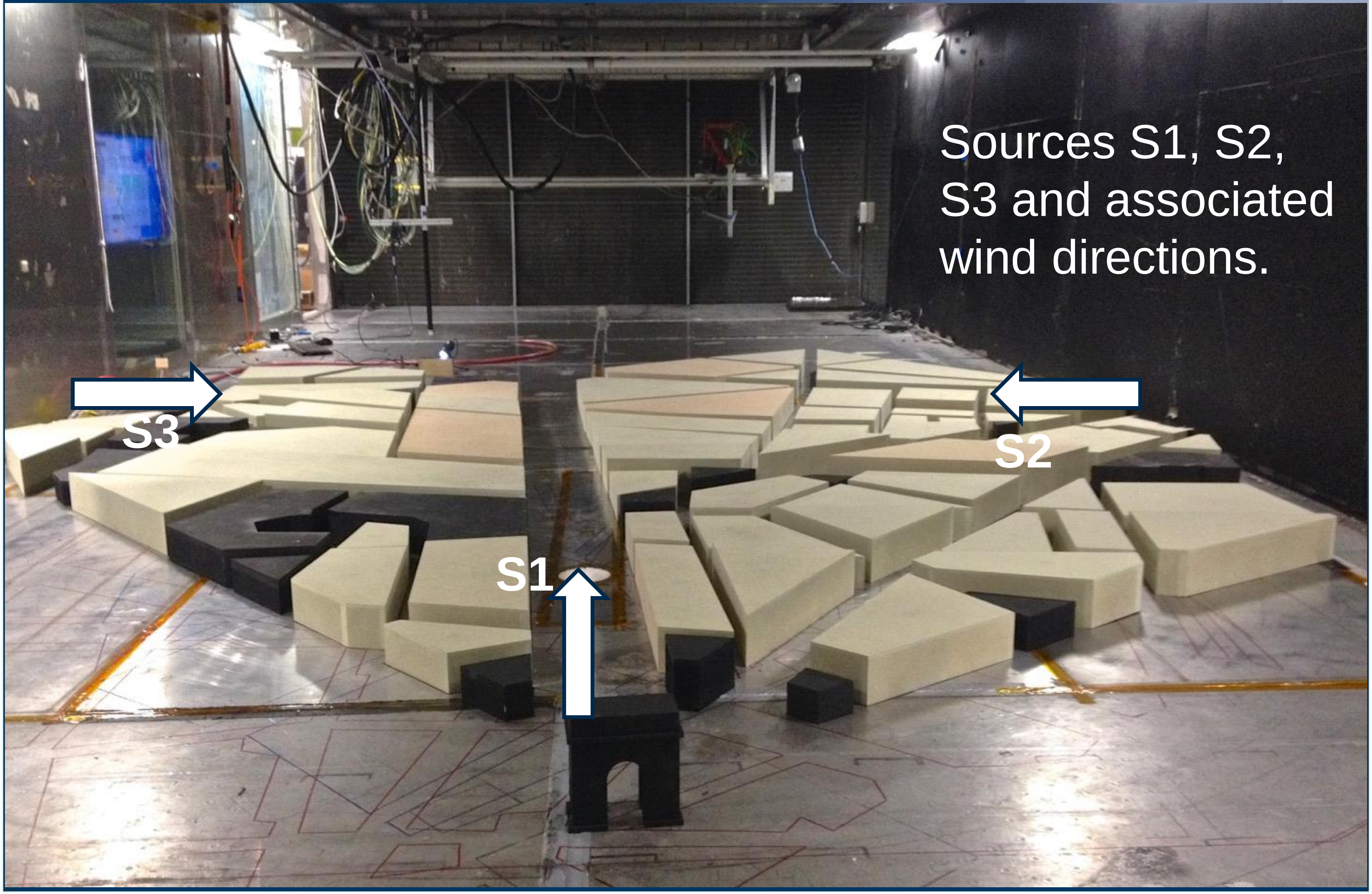
Data for inverse modelling studies

- Four FFIDS operated simultaneously to generate long concentration time series.
- Experiments ran for 16 minutes, off-on-off, with 13 minutes of steady emission.
- Data for unobstructed flow, simple array, complex array; air and CO2.

- Both the raw data, sampled at 400 Hz, and equivalent full scale data made available
- Geometrical scale of 1:200 assumed in converting the results to full scale, data first down-sampled to 100 Hz.

6. Urban area – central Paris

Paris - EnFlo



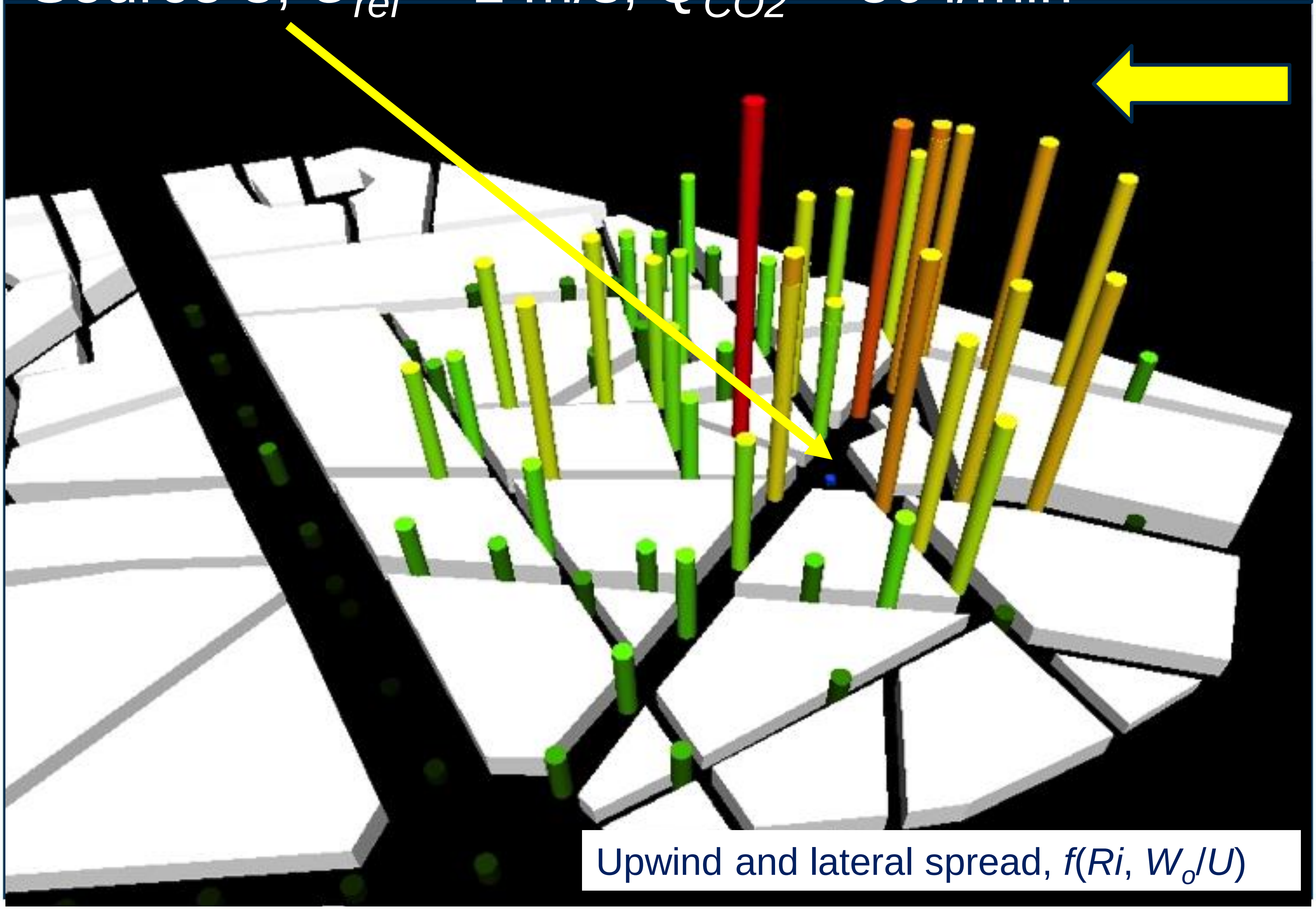
Paris experiments

- Model comprised almost a hundred blocks.
- 1:350 scale implied that the ratio of full scale and model wind speeds was $\sqrt{350} = 18.7$.
- 1ms^{-1} wind tunnel reference speed equivalent to 18.7ms^{-1}, or more usefully 9ms^{-1} at 10m height and 11.6ms^{-1} at the average building block height of 27m.

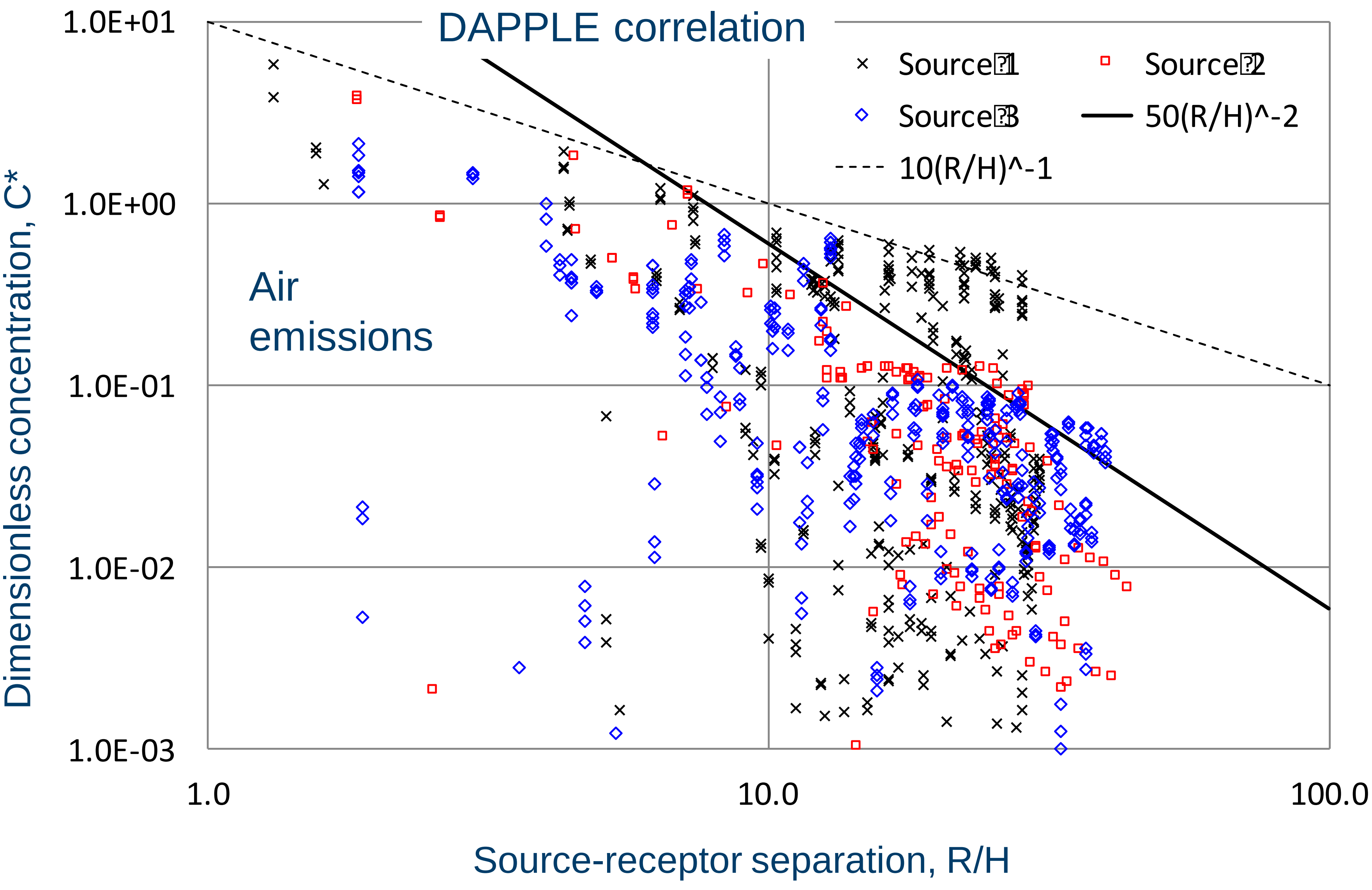
- Additional experiments were carried out with reduced emission rates and lower tunnel speeds to provide data for more realistic full scale conditions - dense gas effects were much reduced but not absent in these cases.
- Upwind spread ceased but vertical spread remained much reduced in all cases.

- Experiments were conducted with both continuous and short duration emissions.

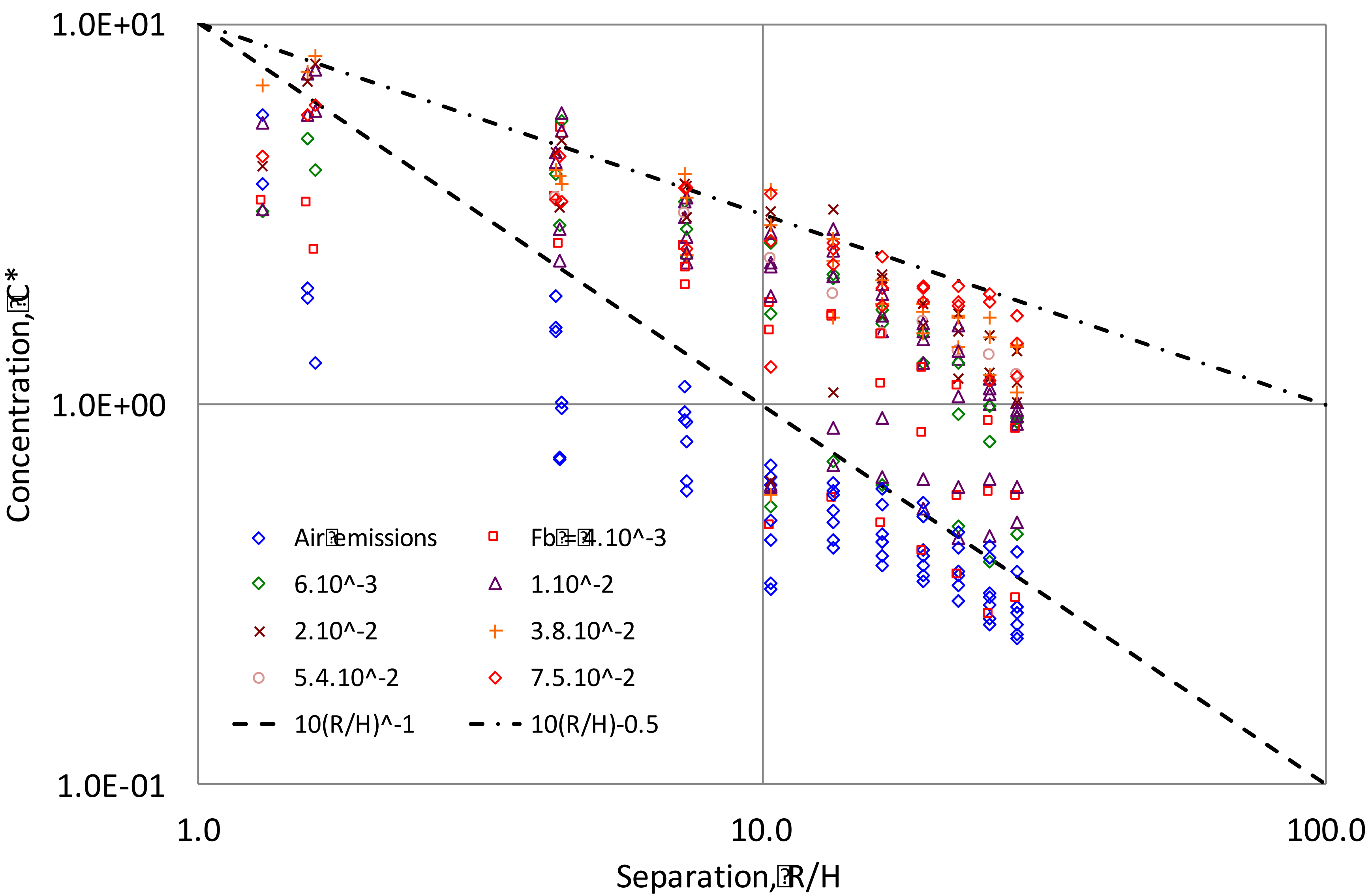
Source 3; U_{ref} = 1 m/s, Q_{CO2} = 50 l/min



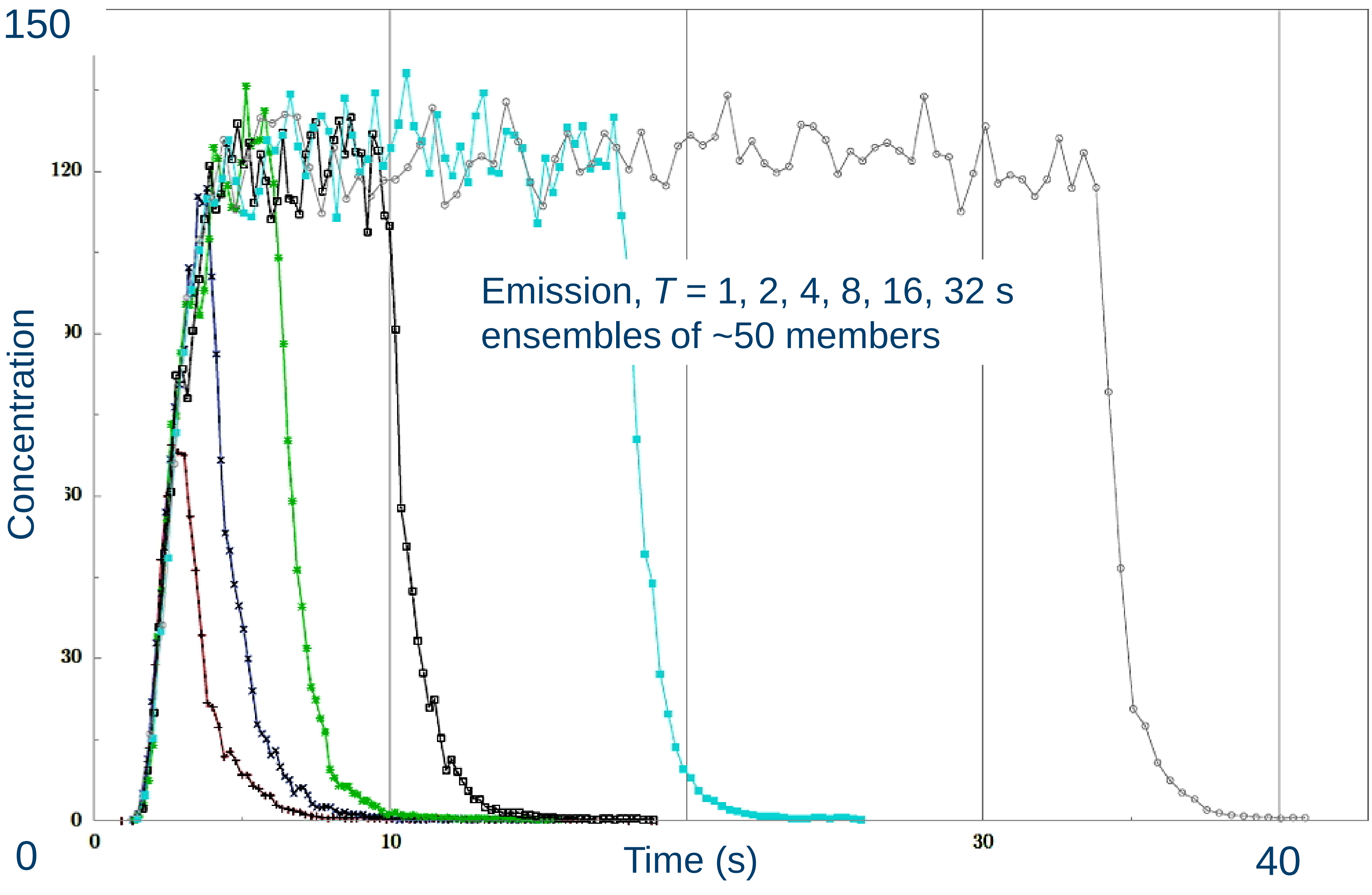
Paris and DAPPLE, C* decay correlation



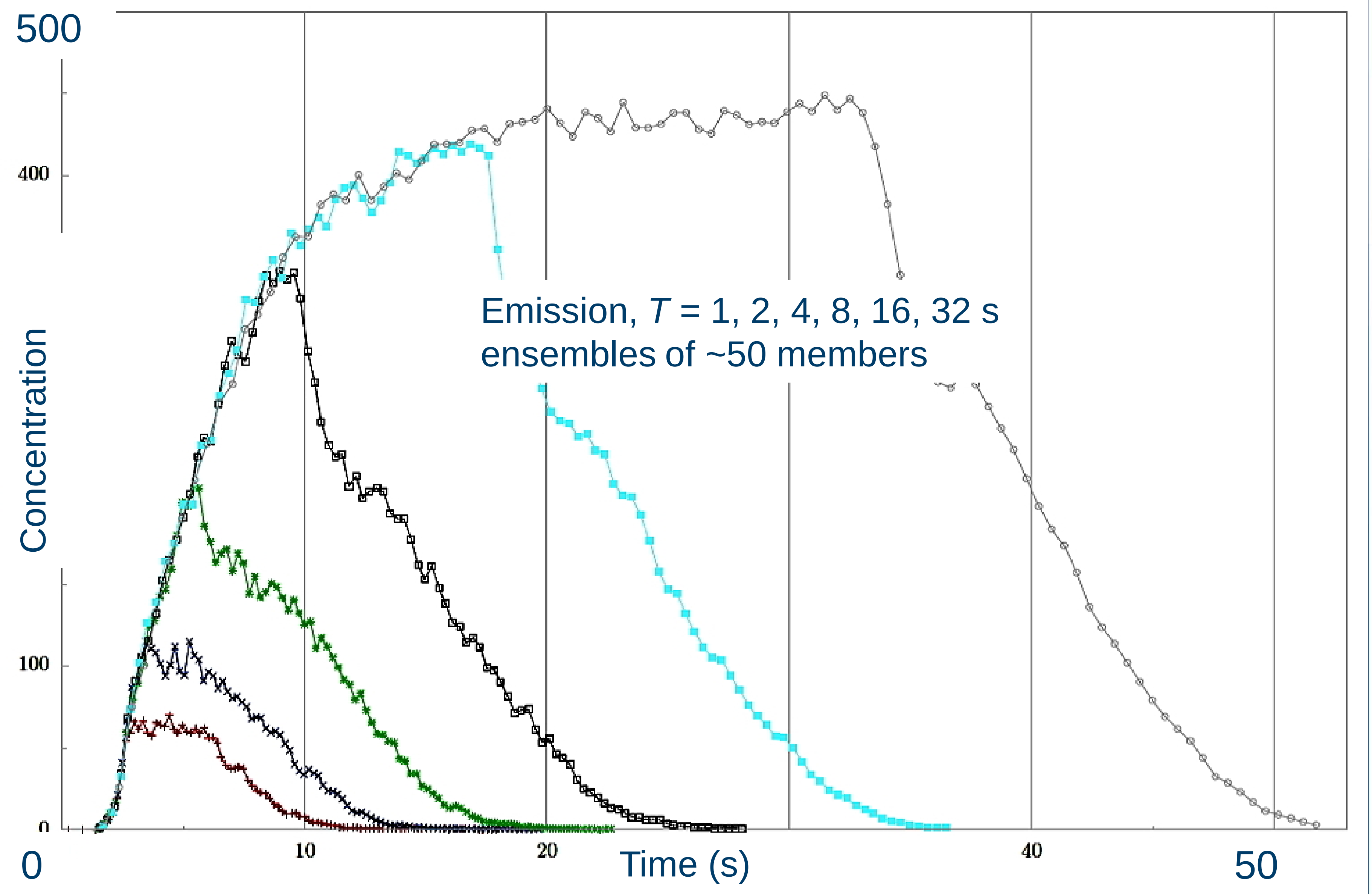
Av des Champs Elysees, Source S1, CO2



Source S1, U_{ref} = 0.8 m/s Q = 35 l/min, Air



Source S1, U_{ref} = 0.8 m/s Q = 35 l/min, CO2



Raw Data Fi	<DATA_ROOT>:\2014\EnFlo_Tunnel\Joe_Batten\Raw_Measurements\04-2014\4FFID_Long_Array_3_xls\4FFID_Lon

*****This is a many rows per single point file*****

Case							Y (m)	Z (m)	Raw Data Filename
None							3	5	<DATA_RO
None							3	5	<DATA_RO
None							3	5	<DATA_RO
None							3	5	<DATA_RO

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Data:

C, c, U_i, $u_i u_j$, $u_i c$

with associated standard errors

3 minute averaging (Quality A),

1 minute averaging (Quality B).

Time (s)	FF (C1)	FF (C2)	FF (C2)	FF (C4)	RV (V)
0.053	4	5.3	5.3		
0.1945	3.8	4.3	4.3		
0.3359	4.2	4.4	4.4		
0.4773	4.5	4.6	4.6		
0.6187	4	4.8	4.8		
0.7601	3.8	4.5	4.5		
0.9016	4.3	4.9	4.9		
1.043	4.1	4.4	4.4		
1.1844	4.1	4.7	4.7		
1.3258	3.5	5	5		
1.4672	4.1	5.4	5.4		
1.6087	4.8	4.5	4.5		
1.7501	4	4.9	4.9		
1.8915	4.2	5.4	5.4		
2.0329	3.7	5.1	5.1		

All data available as simple text or spreadsheet files with full metadata.

Release to third parties limited to collaborative use for the time being.

Full third party availability is intended – precisely when to be agreed.