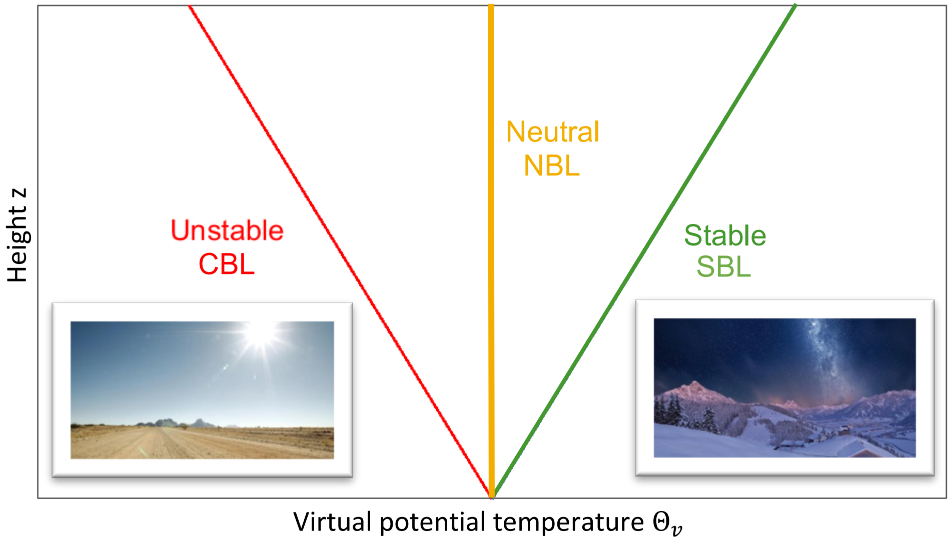
Wind tunnel simulations of urban dispersion in stable and convective conditions

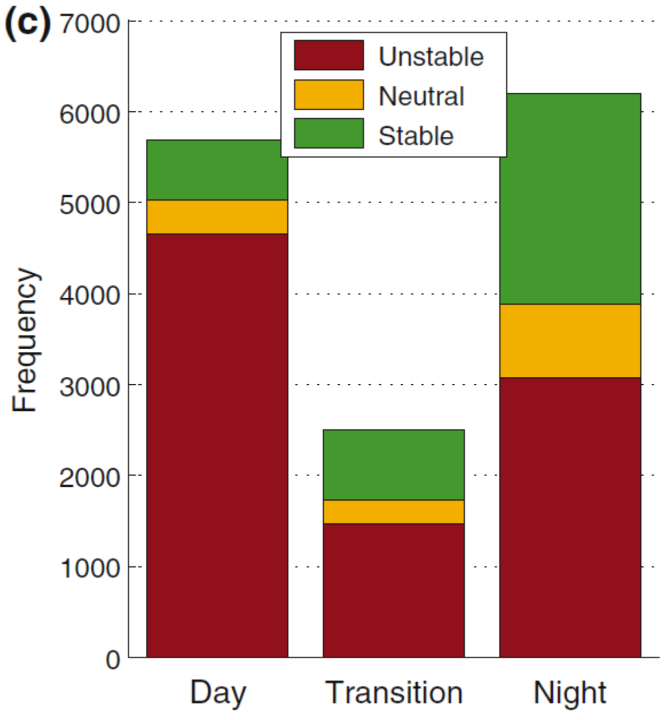
Davide Marucci, Matteo Carpentieri

UNIVERSITY OF SURREY

AMS100, Boston, 14th January 2020

Stratification in urban areas





Wood et al. (2010), "Turbulent Flow at 190 m Height Above London During 2006–2008: A Climatology and the Applicability of Similarity Theory", BLM 137: 77-96

Field measurements?
CFD modelling?
Lack of experimental data:

- Specifically-designed facilities?
- Time-consuming methodologies
- No established methods for SBL
- Artificial thickening not common

View of London from BT Tower

The EnFlo wind tunnel

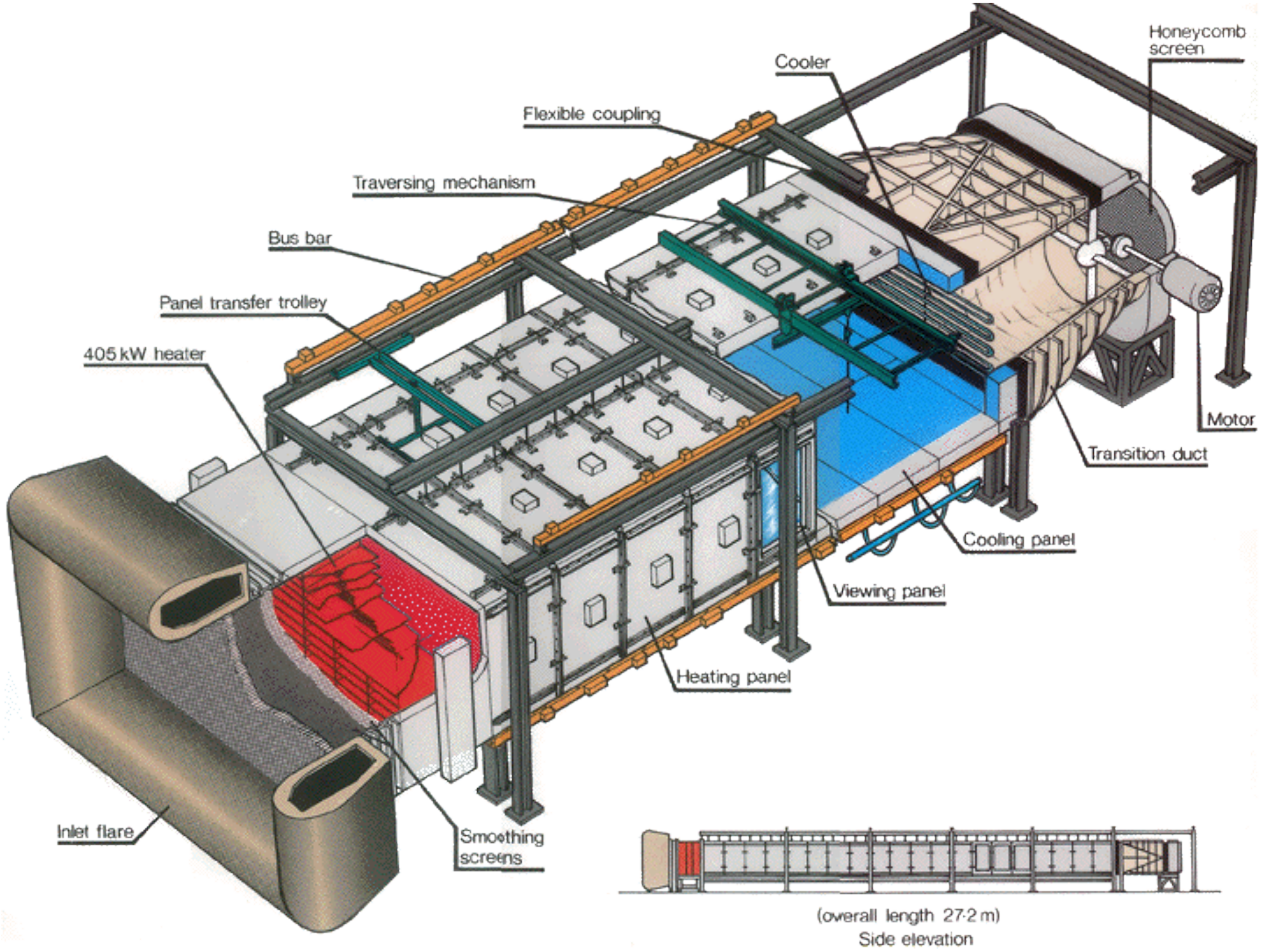
Open-return meteorological wind tunnel

Test section dimensions (m): 20 x 3.5 x 1.5

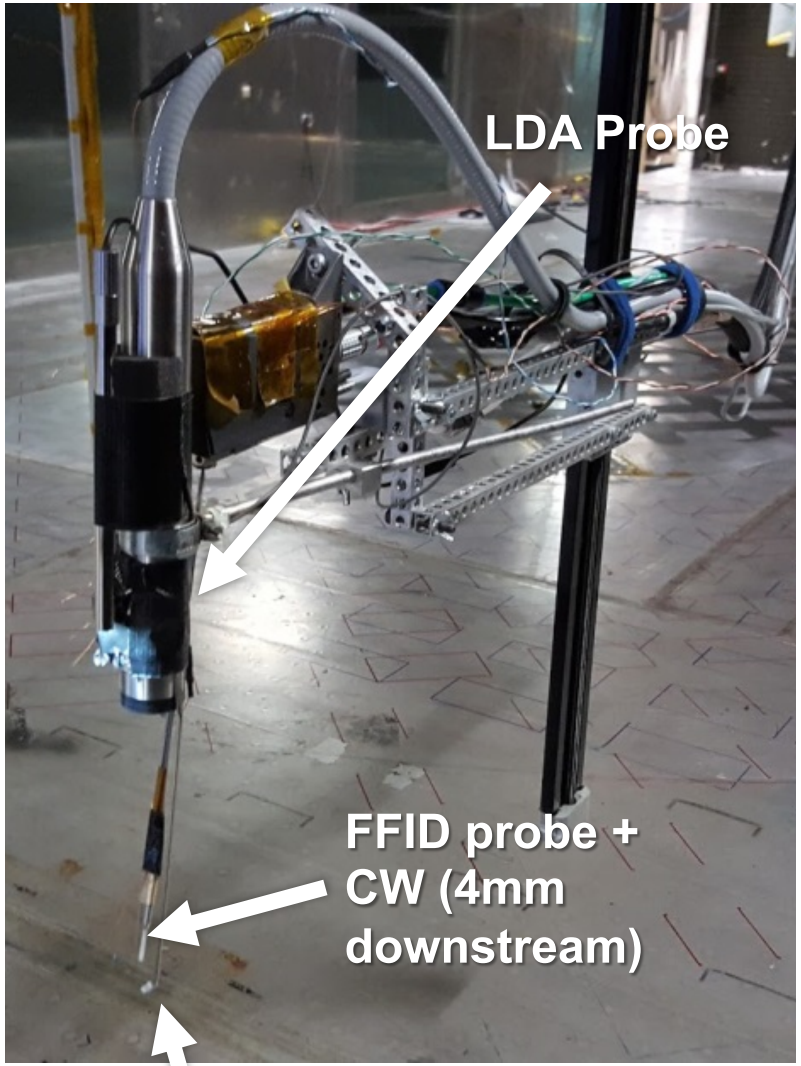
Air speed range: 0.3 - 2.5 m/s

Temperature range: 10 – 110 °C

Max heating power: 800 kW



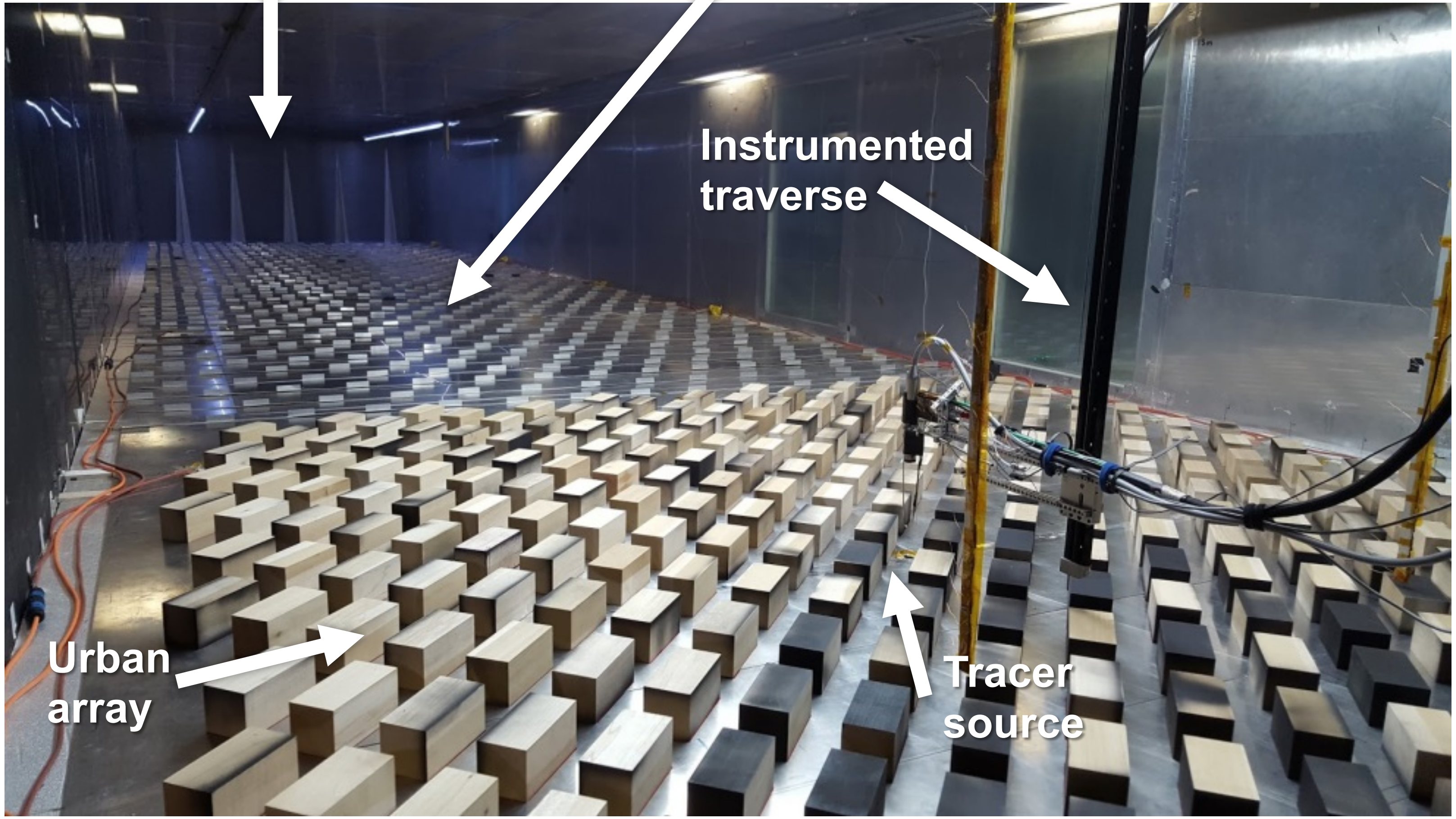
Wind tunnel setup



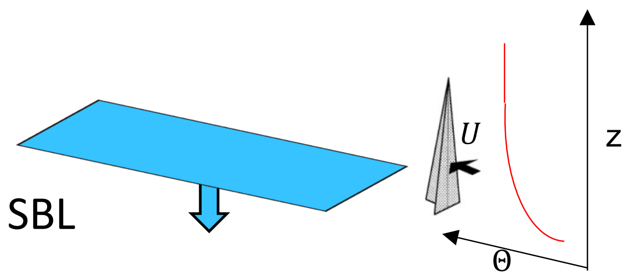
LDA Mirror (UW setup only)

Irwin spires

Roughness elements



Generating a SBL in the wind tunnel

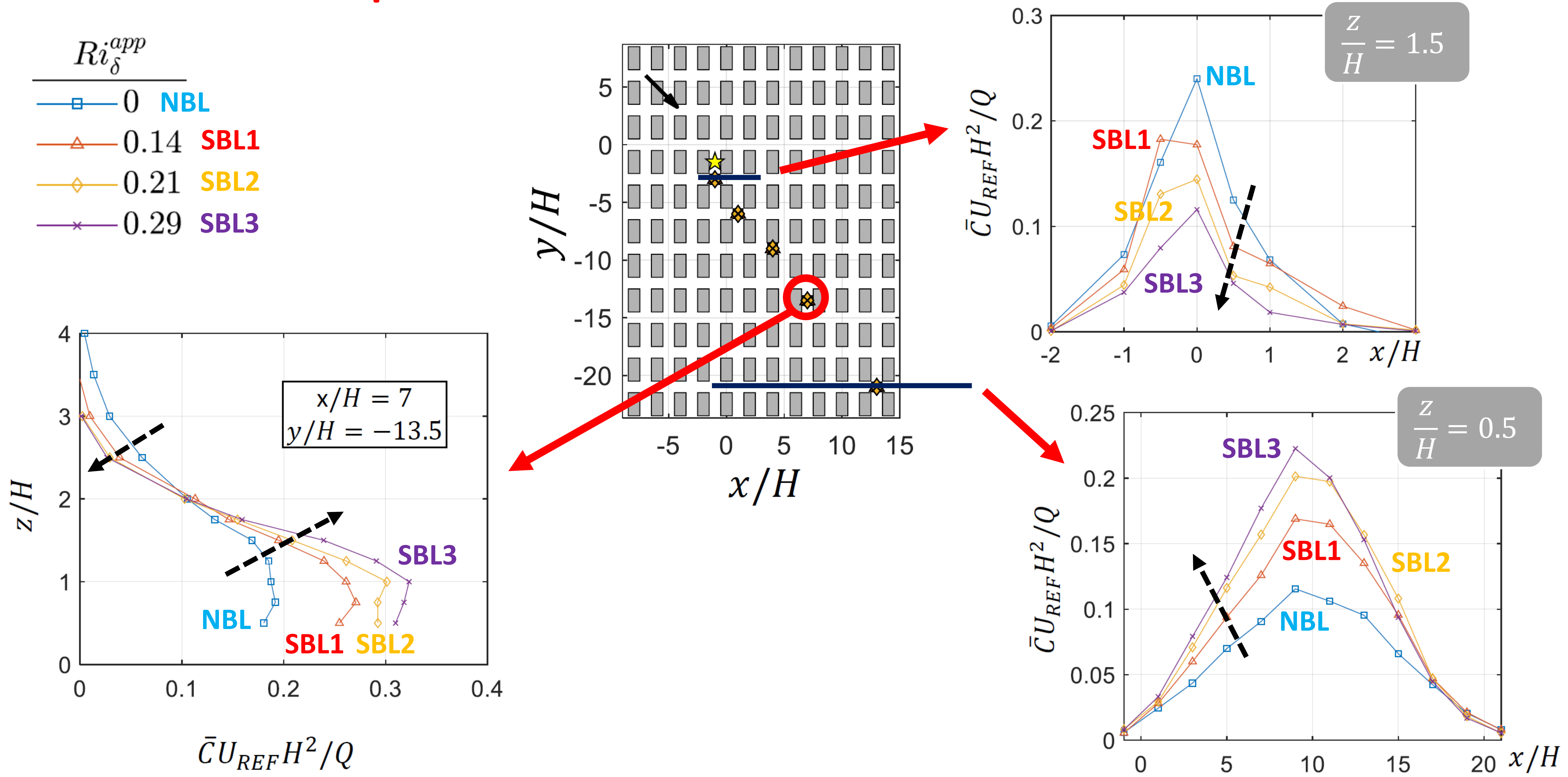


Bulk Richardson number:

$$Ri_b = \frac{g(\Theta_\delta - \Theta_0)\delta}{\Theta_0 U_\delta^2}$$

	NBL (ref)	SBL 1	SBL 2	SBL 3
U_{ref} (m/s)	1.25	1.25	1.25	1.15
$\Delta\Theta_{\mathrm{max}}$ (°C)	0	10.8	16	17.8
δ (mm)	850	850	850	850
u_*/U_{ref}	0.078	0.063	0.061	0.059
z_0 (mm)	3.45	2.5	2.6	2.9
d (mm)	52.5	53.5	54.5	55.0
Ri_b^{app}	0	0.14	0.21	0.29
Ri_b	0	0.12	0.19	0.24
L (mm)	∞	2105	1365	965

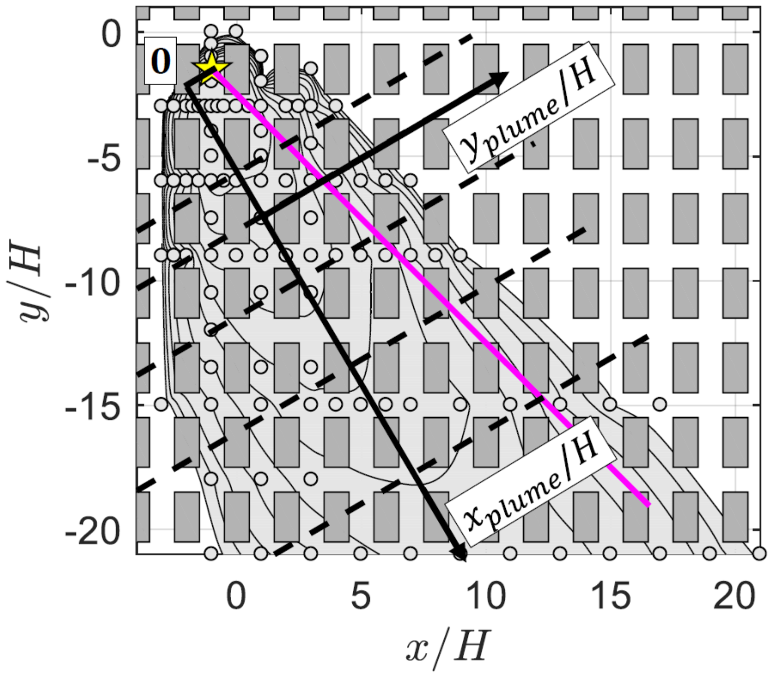
Plume development and concentrations in a SBL

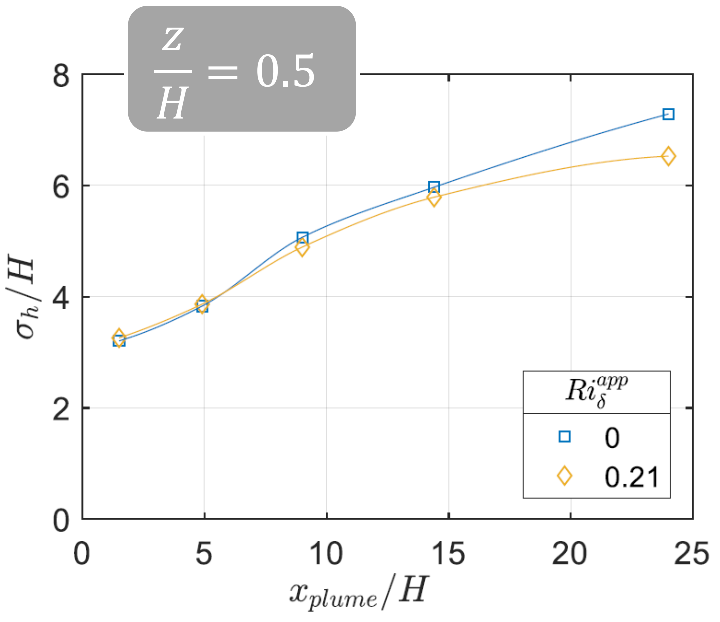


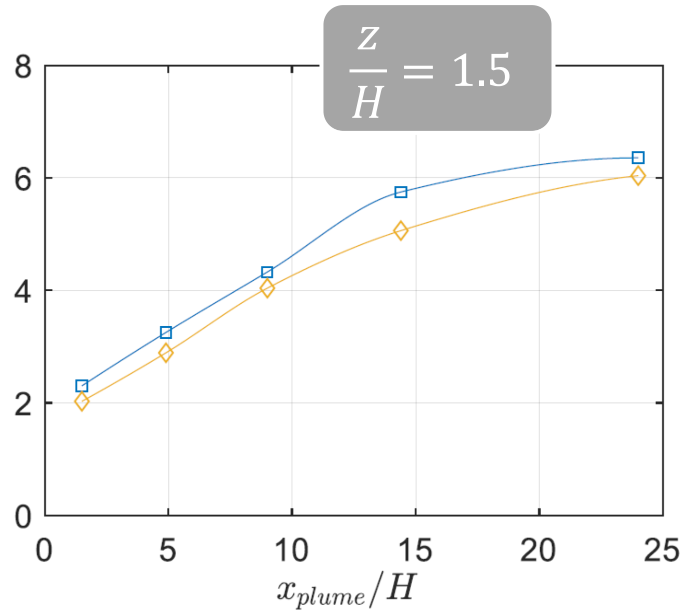
Plume development and concentrations in a SBL

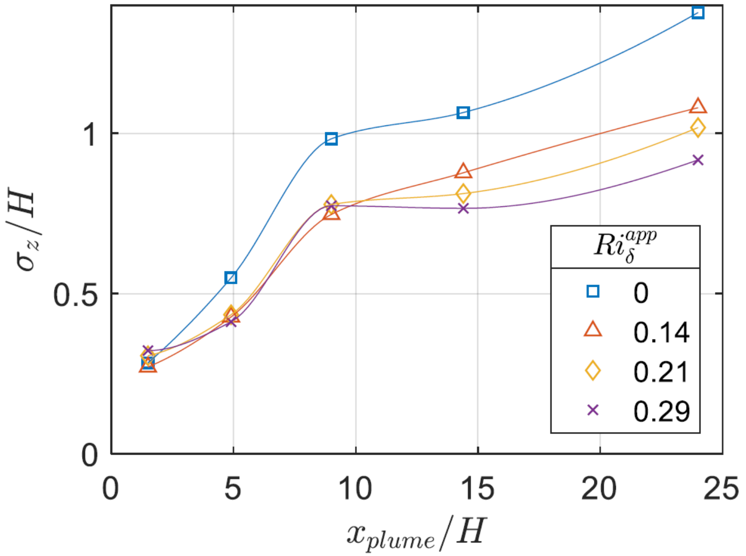
Gaussian fit

$$\overline{C} = Ae^{-\frac{(y_{plume}-\mu)^2}{2\sigma_h^2}}$$







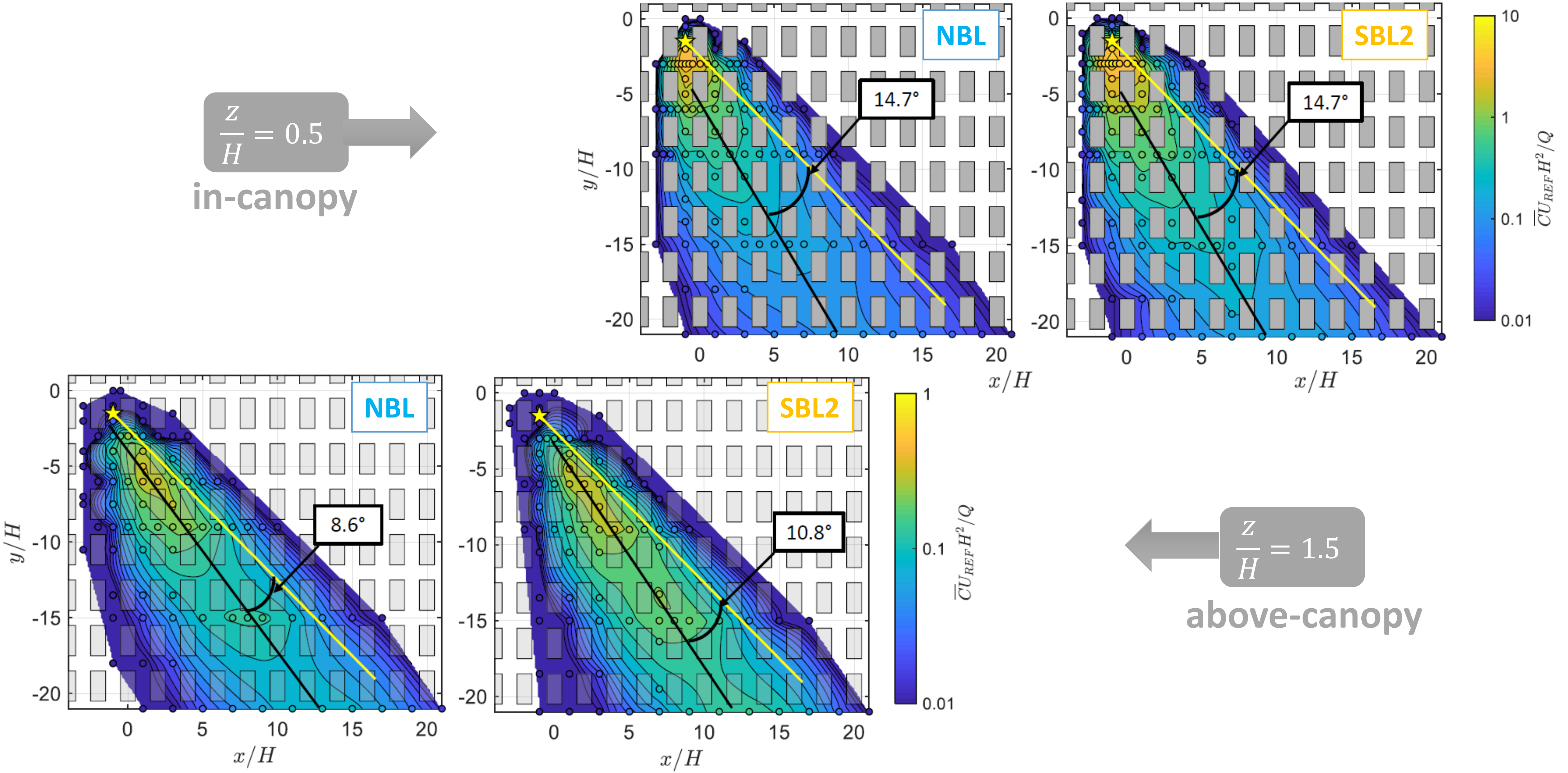


$$\overline{C} = Ae^{-\frac{(z-\mu)^2}{2\sigma_z^2}}$$

Plume channelling in a SBL

$\frac{z}{H} = 0.5$

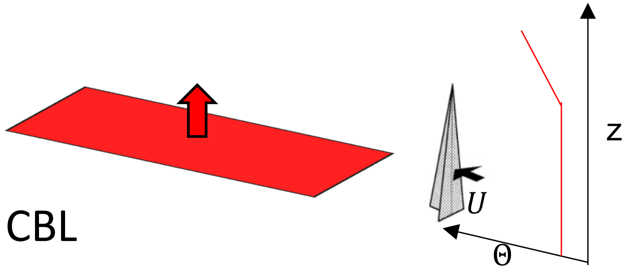
in-canopy



$\frac{z}{H} = 1.5$

above-canopy

Generating a CBL in the wind tunnel

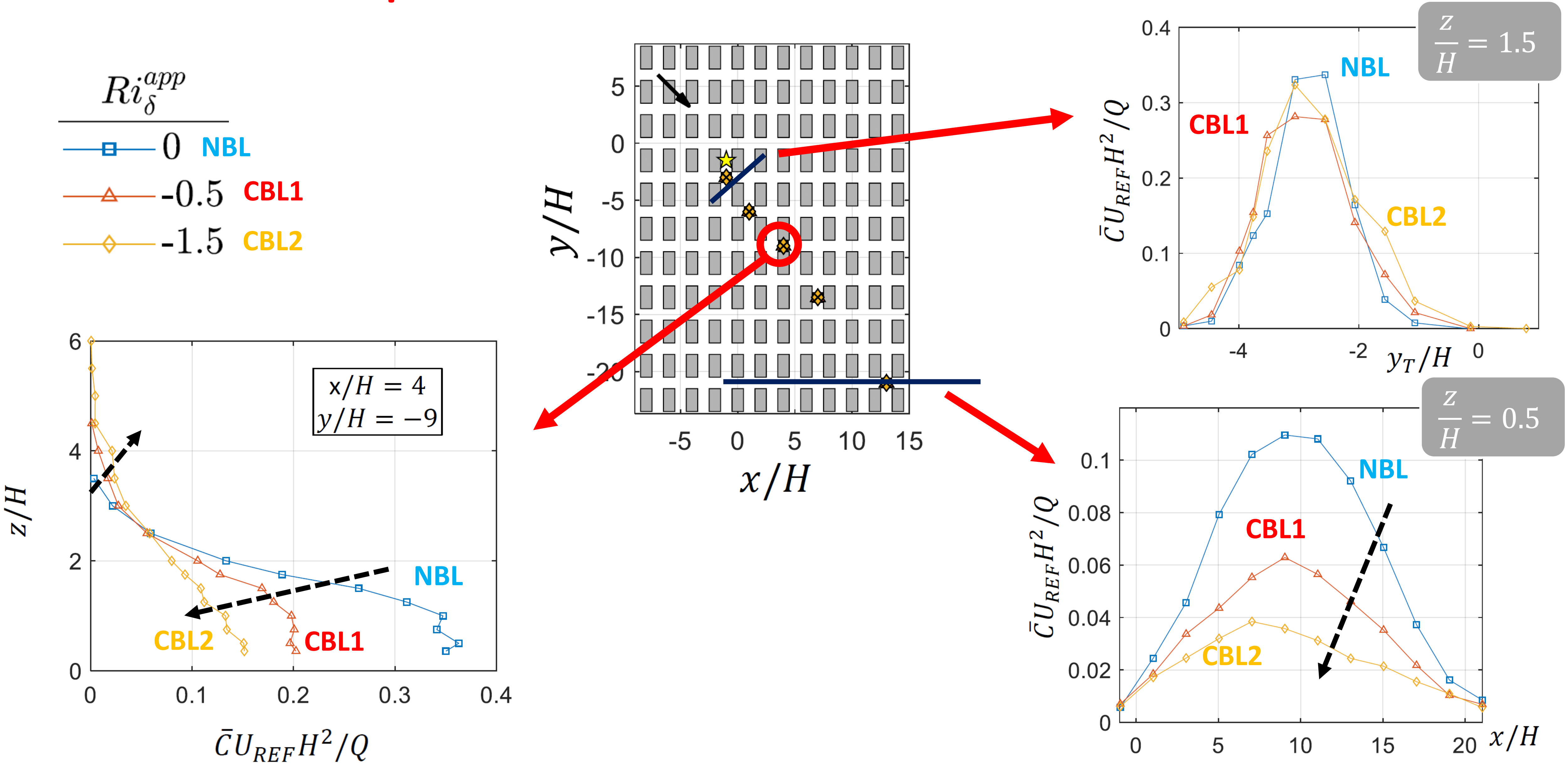


Bulk Richardson number:

$$Ri_b = \frac{g(\Theta_\delta - \Theta_0)\delta}{\Theta_0 U_\delta^2}$$

	NBL (ref)	CBL 1	CBL 2
U_{ref} (m/s)	1.25	1.25	1.00
$\Delta\Theta_{\mathrm{max}}$ (°C)	0	-24.2	-39.2
δ (mm)	1000	1200	1350
u_*/U_{ref}	0.081	0.105	0.118
z_0 (mm)	4.0	6.3	6.2
d (mm)	50.8	23.5	21.5
Ri_b^{app}	0	-0.5	-1.5
Ri_b	0	-0.35	-0.91
L (mm)	∞	-2355	-1240

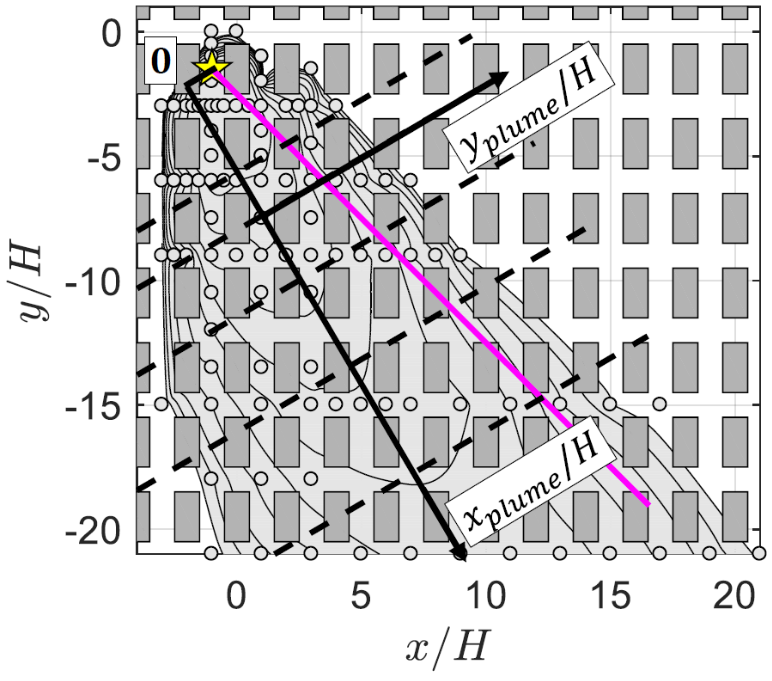
Plume development and concentrations in a CBL

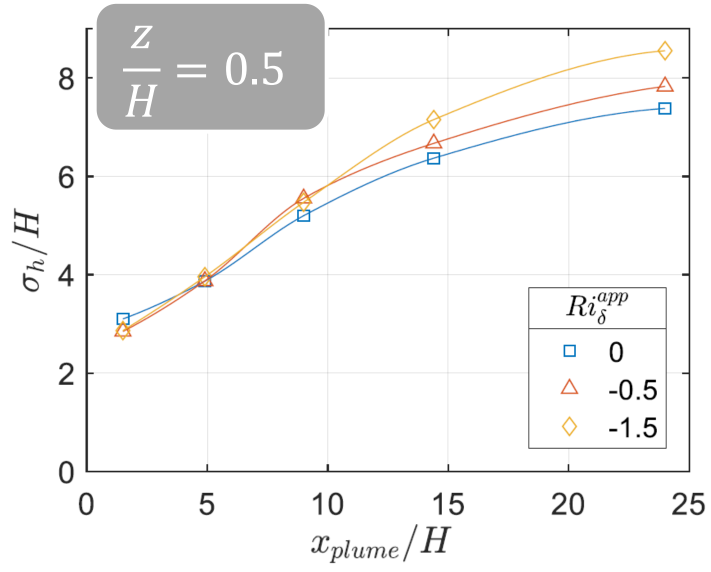


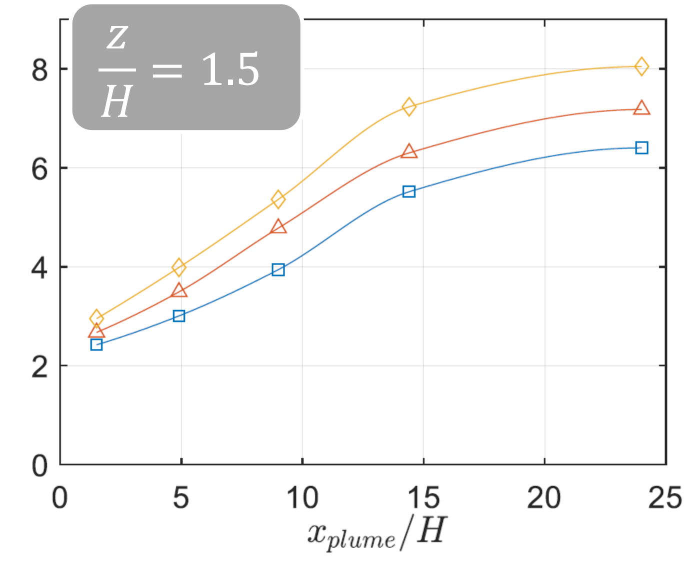
Plume development and concentrations in a CBL

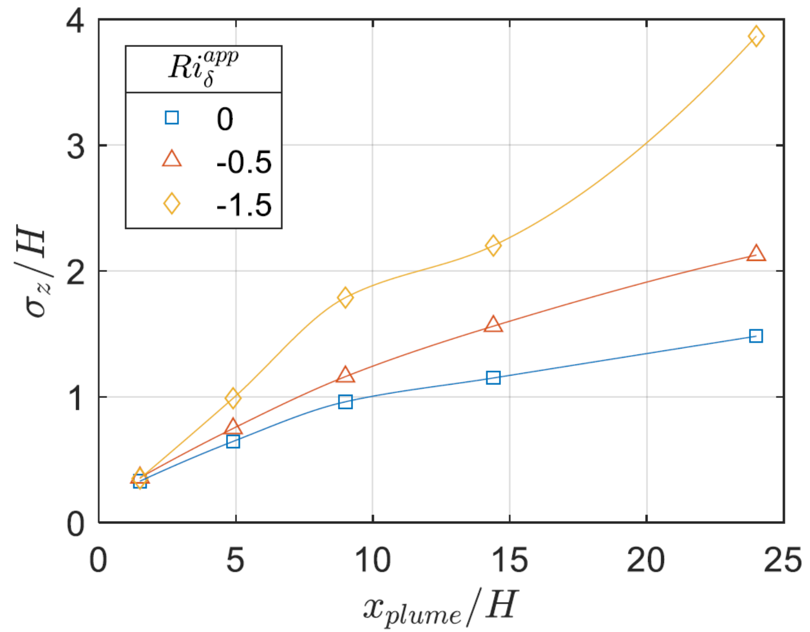
Gaussian fit

$$\overline{C} = Ae^{-\frac{(y_{plume}-\mu)^2}{2\sigma_h^2}}$$



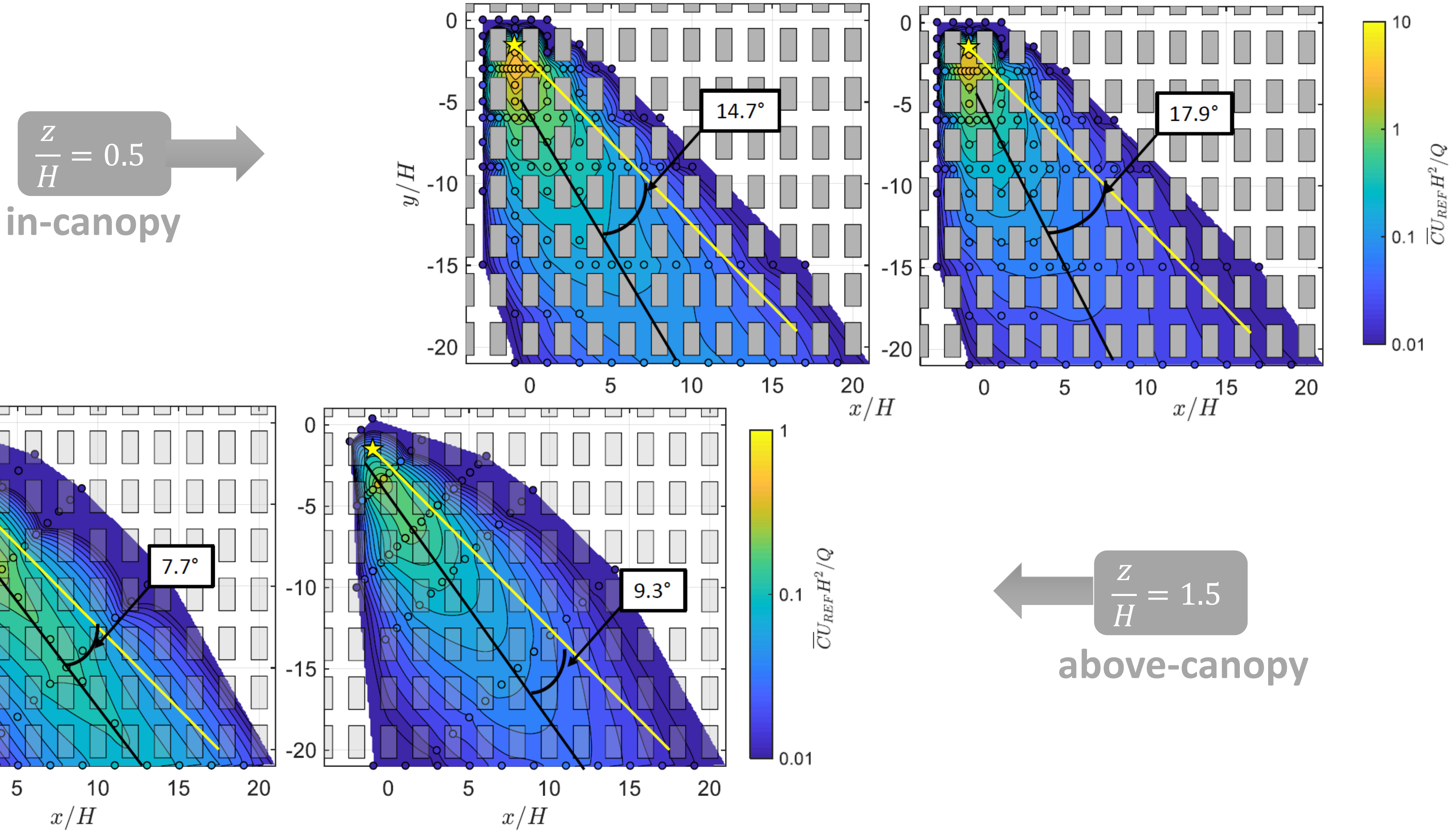






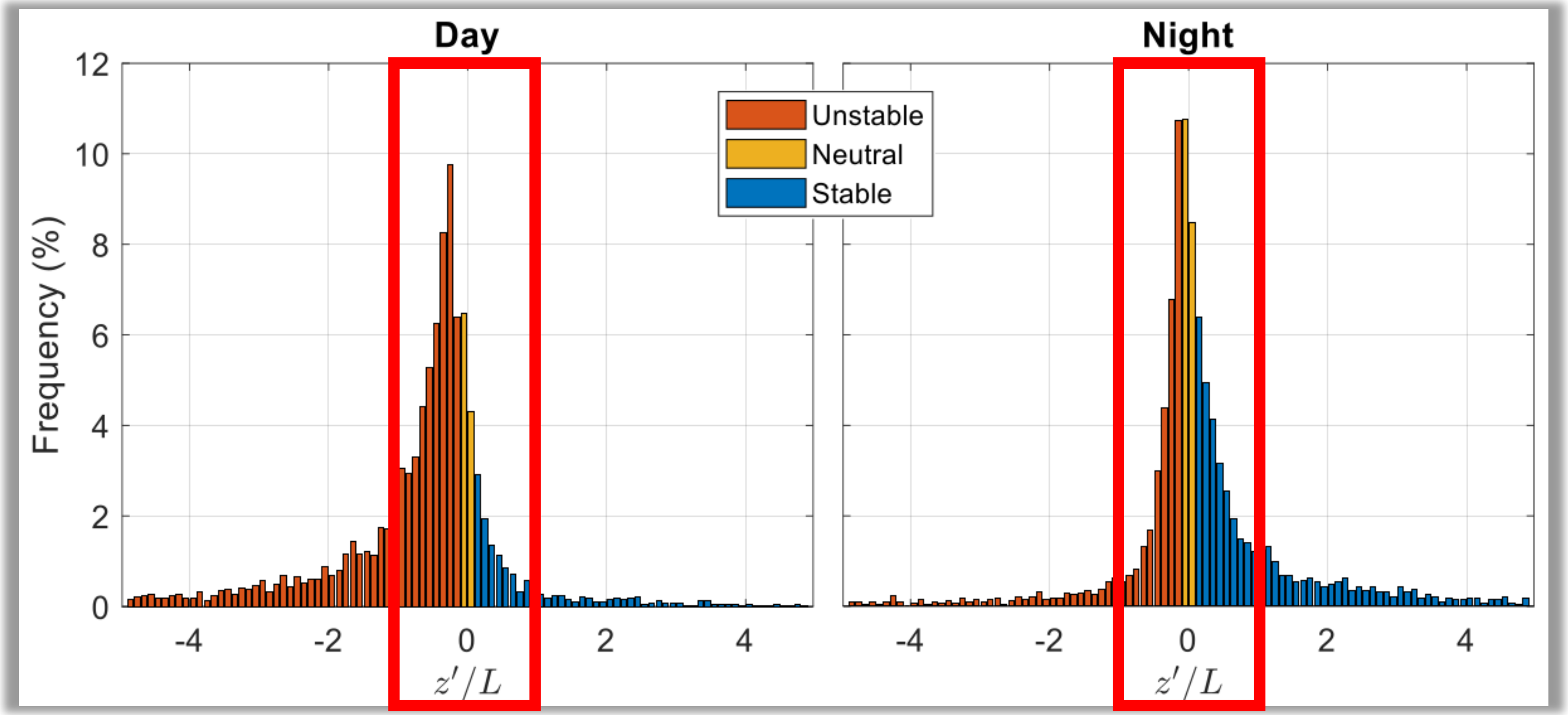
$$\overline{C} = Ae^{-\frac{(z-\mu)^2}{2\sigma_z^2}}$$

Plume channelling in a CBL



Stratified BLs in the wind tunnel

- High roughness and artificial thickening is preventing a very SBL
- No observed "very stable regime" for $Ri_\delta >$ 0.25 or 0.15
- Richardson number not a very good indicator
  - $Re_L = \frac{Lu_*}{\nu}$ might be a better one
  - Transition expected for $Re_L < 100 \div 130$
  - In all our cases $Re_L > 1000$
  - A very stable case cannot be expected



Adapted from Wood et al. (2010)

75% of cases covered

Summary and conclusions

- Generation of thick and very rough stable and unstable BLs in wind tunnel
- Well documented experimental methodology
- Effects of stratification on urban flow and dispersion
- Dispersion: minimal effect on plume width, significant on height and concentration levels
- Local stratification might have significant impact depending on strength vs. approaching flow

m.carpentieri@surrey.ac.uk

Marucci D, Carpentieri M, Hayden P (2018)
On the simulation of thick non-neutral boundary layers for urban studies in a wind tunnel
Int J Heat Fluid Fl, 72: 37-51

Marucci D, Carpentieri M (2020)
Stable and convective boundary-layer flows in an urban array
arXiv preprint (submitted to J Wind Eng Ind Aerodyn)

Marucci D, Carpentieri M (2020)
Dispersion in an array of buildings in stable and convective atmospheric conditions
Atmos Environ (in press), 117100

Marucci D, Carpentieri M (2019)
Effect of local and upwind stratification on flow and dispersion inside and above a bi-dimensional street canyon
Build Environ, 156: 74-88