THE ENFLO TUNNEL AND ITS CHALLENGES

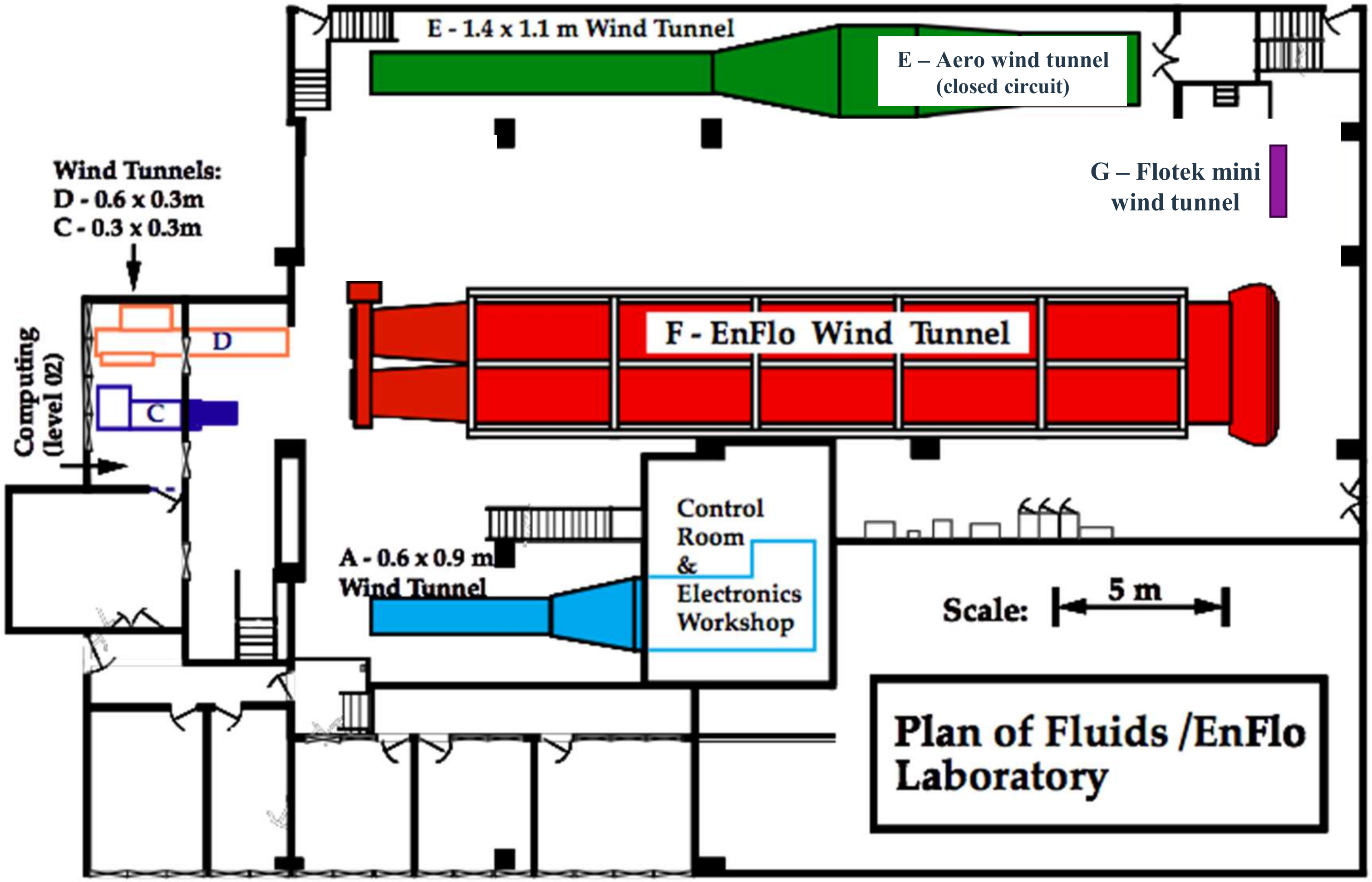
MATTEO CARPENTIERI

UNIVERSITY OF SURREY

THE ENFLO LABORATORY

- Introduction
- Wind tunnels & instrumentation
- The EnFlo meteorological wind tunnel
- Simulating non-neutral flows
  - Stable boundary layers
  - Convective boundary layers
- Overview of research
  - StratEnFlo: pollution dispersion in urban
  - Fundamental research
  - Heavy/buoyant gas dispersion: MODISAFE
  - Urban heterogeneity (ASSURE & FUTURE)
  - Natural ventilation
  - Wind power aerodynamics

THE ENFLO LABORATORY



Three major research facilities:

- **EnFlo meteorological wind tunnel**

National Facility, part of AMOF (NCAS/NERC) and NWTF (EPSRC)

- **Aero tunnel**

Closed circuit, wind speed up to 40 m/s, rolling road, working section 1.1m x 1.4m x 9m

- **'A' tunnel**

Open circuit, working section 0.9m x 0.6 m x 5 m, low-cost facility, wind speed up to 30 m/s

THE ENFLO METEOROLOGICAL WIND TUNNEL

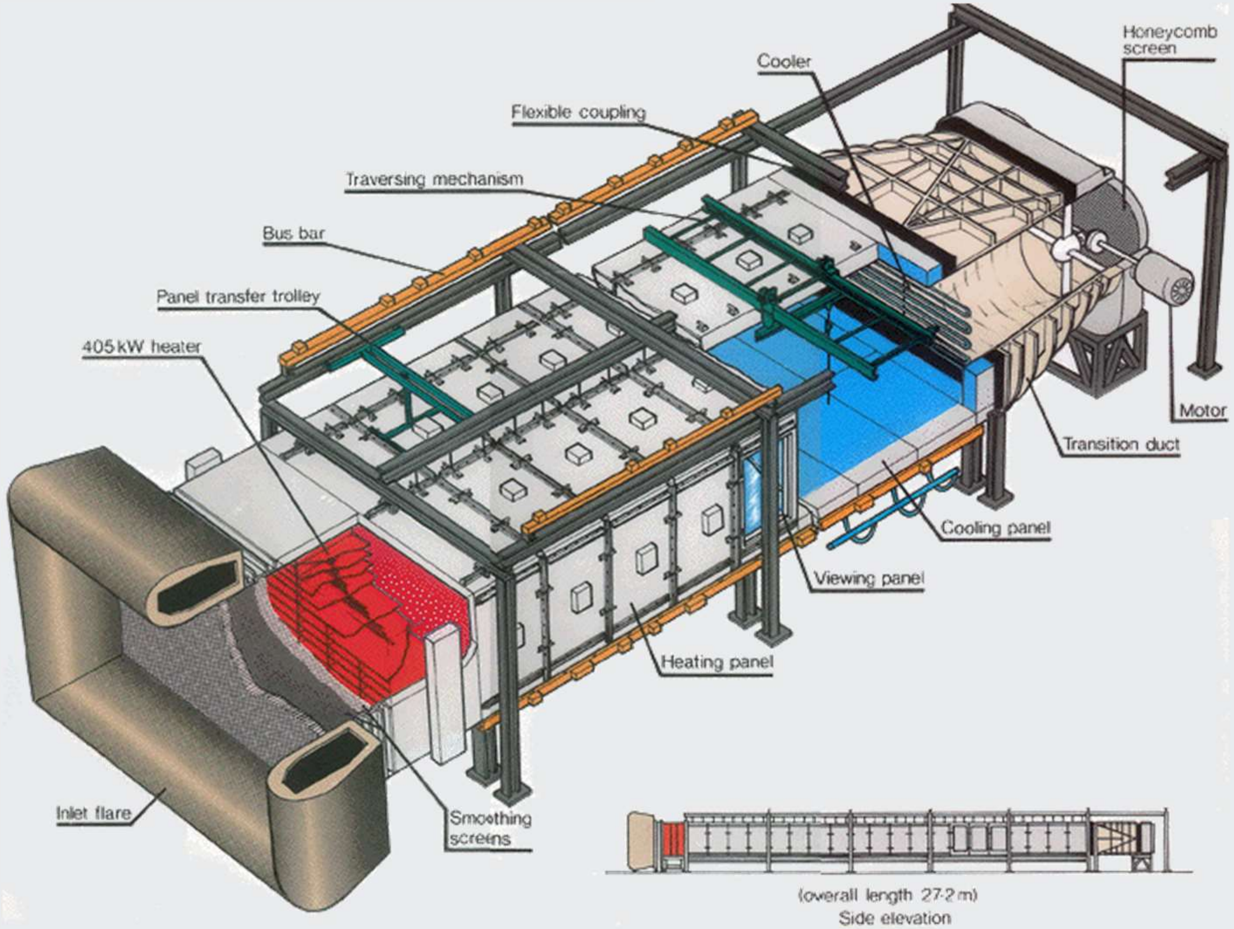
Open-return meteorological wind tunnel

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

Air speed range: 0.5 - 5 m/s

Temperature range: 10 – 110 °C

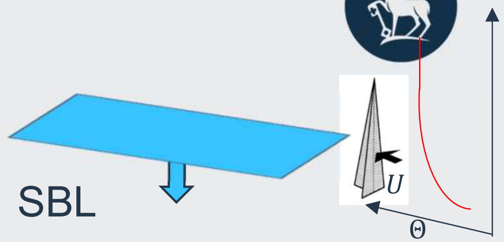
Max heating power: 800 kW



INSTRUMENTATION

- LDA (1D, 2D, 3D)
- PIV
- HWA / CWA
- FFID
- Pressure (with its challenges in EnFlo tunnel)
- Force balances, ad-hoc sensor development, …

NON-NEUTRAL STRATIFICATION - SBL



Parameters investigated:

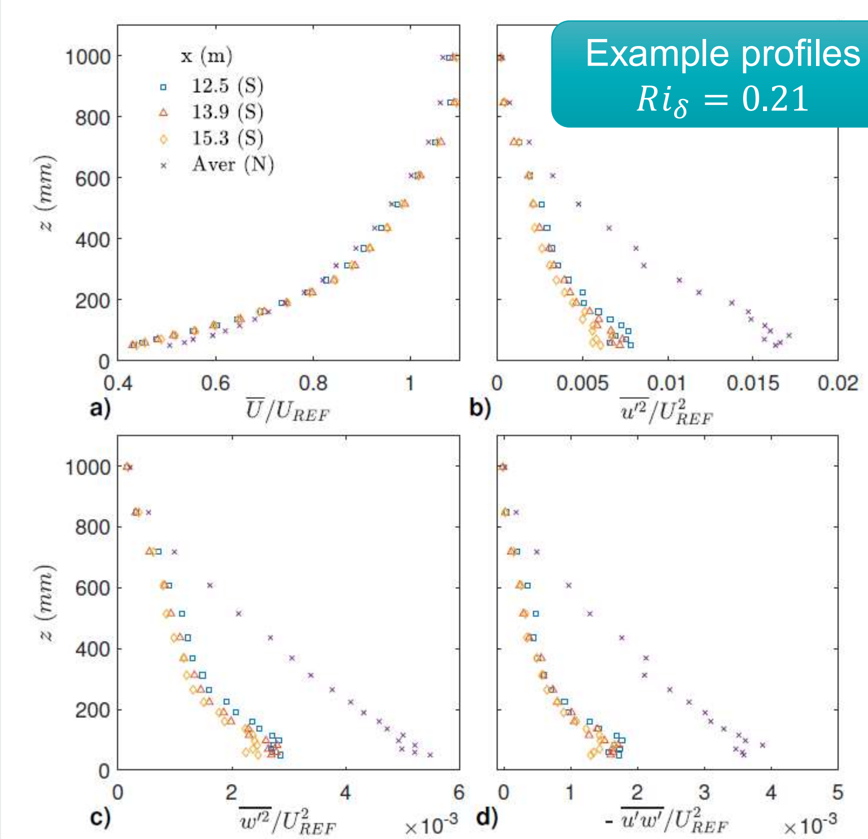
- Floor temperature vs inlet max temperature
- Length of uncooled floor
- Imposed temperature profile

Bulk Richardson number:

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

Ri_δ	0	0.14	0.21	0.33	0.21 (LR)
U_{REF} (m/s)	1.25	1.50	1.25	1.00	1.25
$\Delta\Theta_{MAX}$ (°C)	0	16	16	16	16
u_*/U_{REF}	0.065	0.053	0.047	0.040	0.042
z_0 (mm)	2.2	2.4	2.3	2.4	0.6
θ_* (K)	-	0.35	0.34	0.30	0.30
δ/L	0	0.64	1.13	2.18	1.27

Example profiles $Ri_\delta = 0.21$

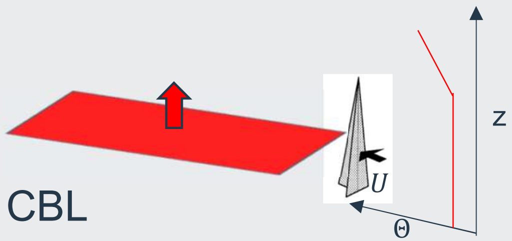


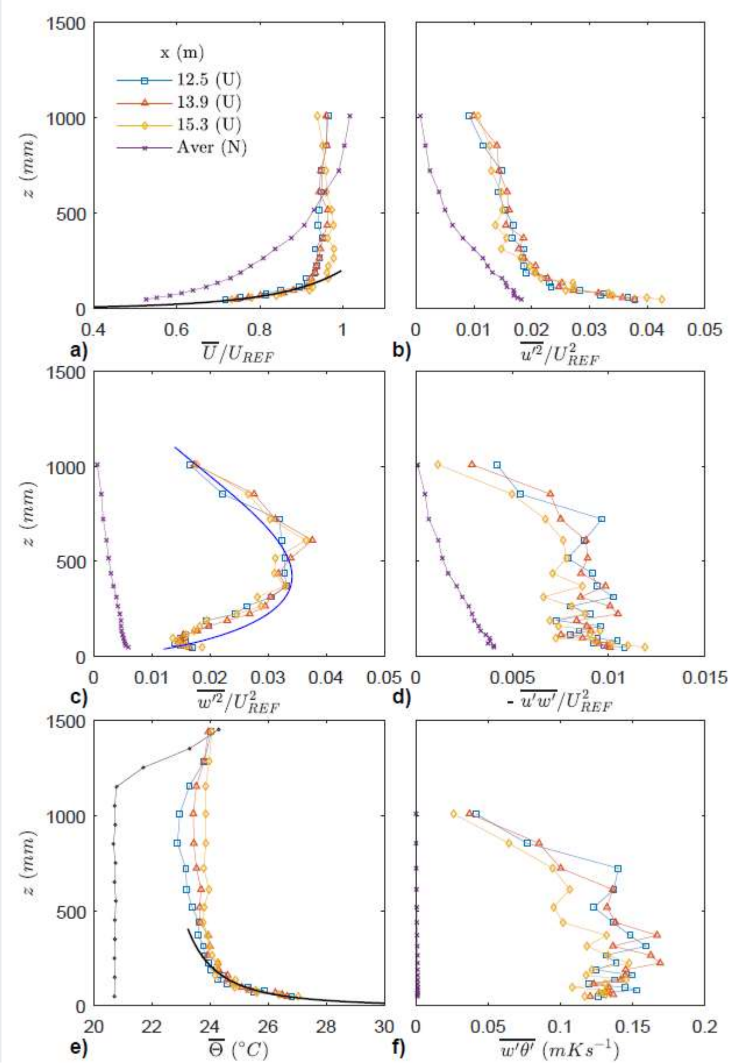
NON-NEUTRAL STRATIFICATION - CBL

Parameters investigated:

- Floor temperature vs inlet max temperature
- Layout of heating panels
- Imposed temperature profile
- Capping temperature inversion layer

	N	HR2	HR1(U)
U_{REF} (m/s)	2.0	1.25	1.0
$\Delta\Theta_{MAX}$ (°C)	0	−23	−36
δ (m)	1.0	1.2	1.3
u_*/U_{REF}	0.065	0.084	0.100
z_0 (mm)	2.0	1.8	2.0
θ_* (K)	-	−0.78	−1.4
$\tilde{\theta}_*$ (K)	-	0.56	0.79
u_*/w_*	-	0.72	0.56
δ/L	0	−1.1	−2.2
Ri_δ	0	−0.5	−1.5
Re_δ (x10^4)	13.3	8.7	6.9





ENFLO
OVERVIEW OF RESEARCH

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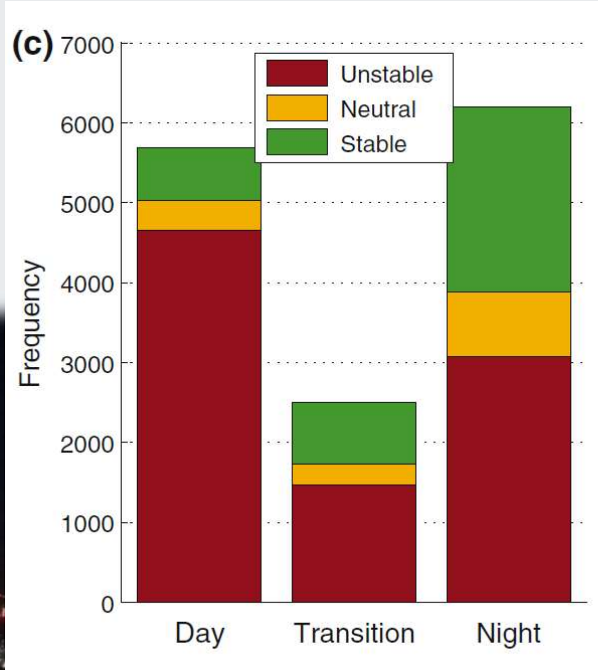
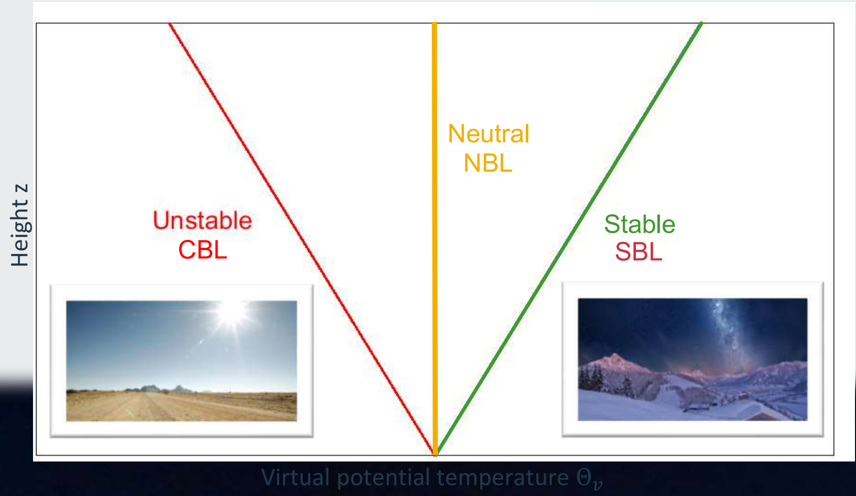
NON-NEUTRAL FLOWS IN URBAN AREAS



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



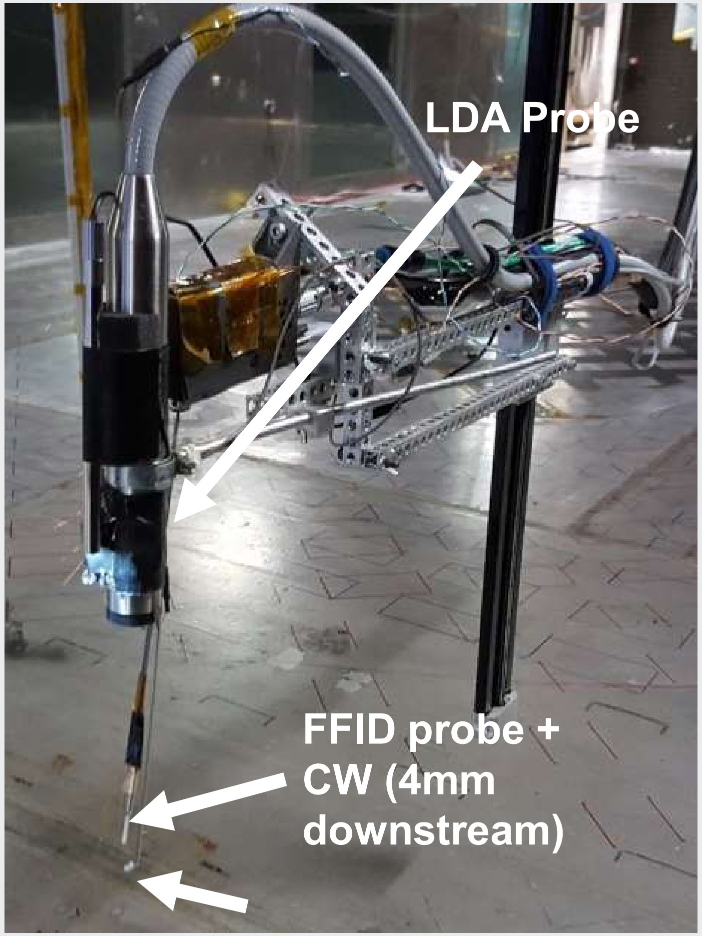
StratEnFlo

Lack of experimental data:

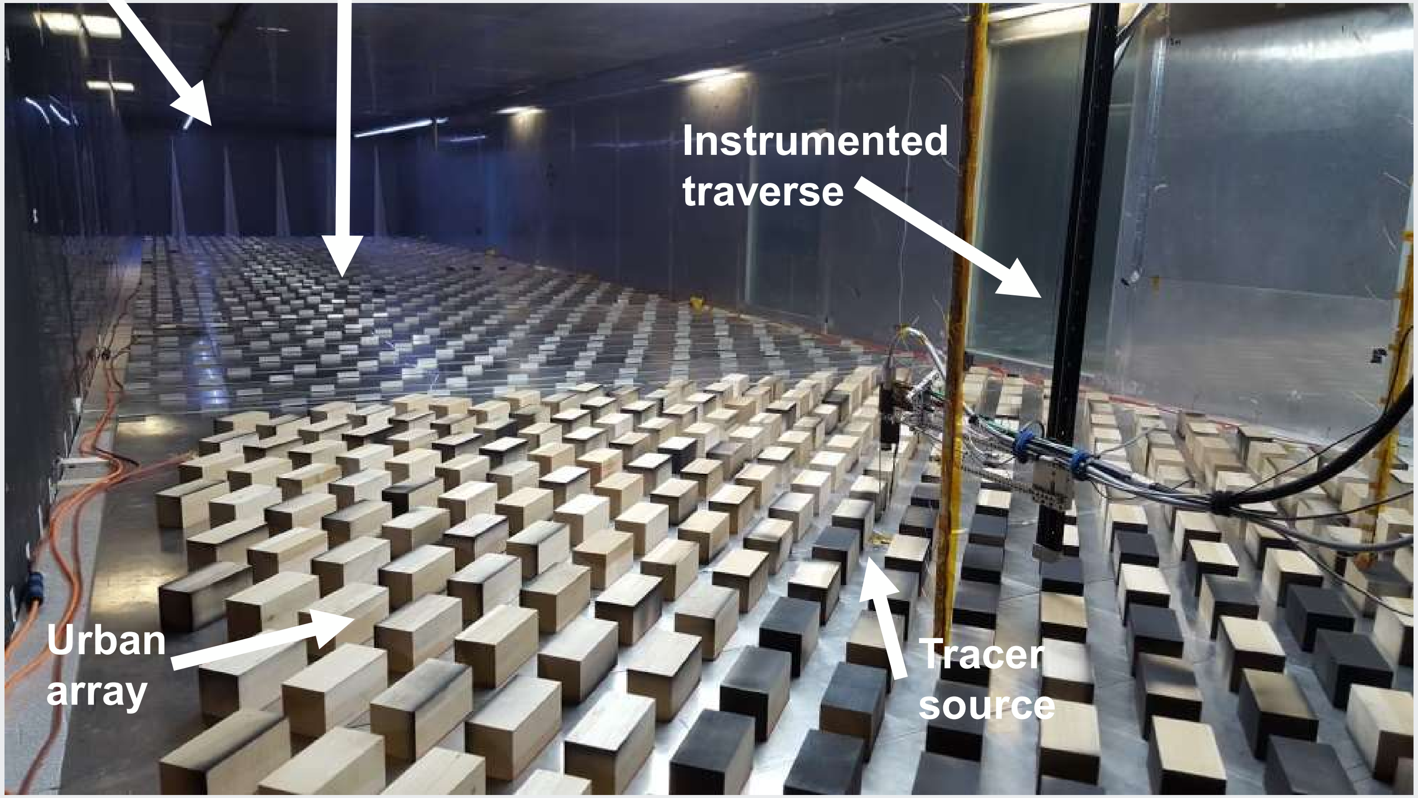
- Specifically-designed facilities?
- Time-consuming methodologies
- No established methods for SBL
- Artificial thickening not common

View of London from BT Tower

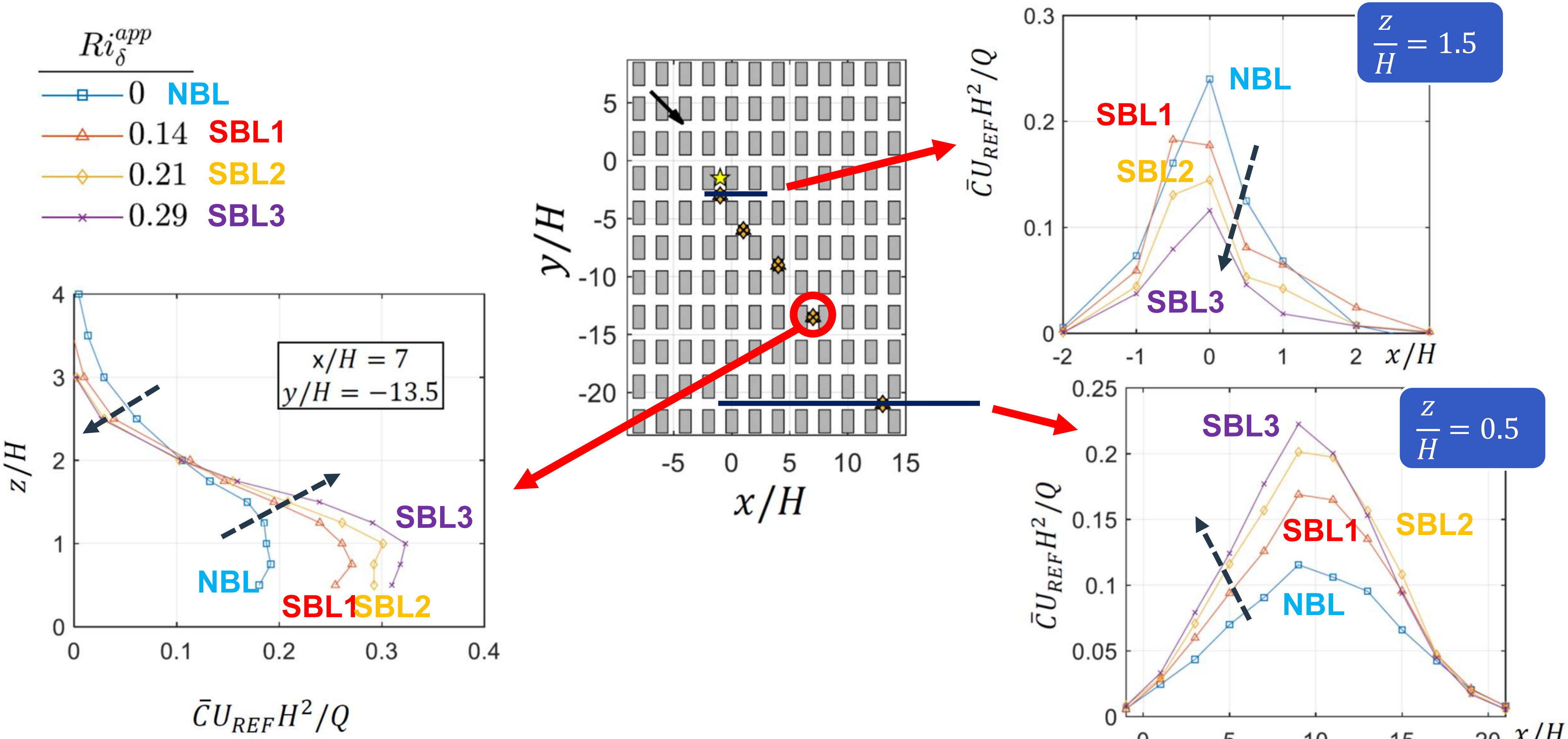
STRATENFLO - SETUP



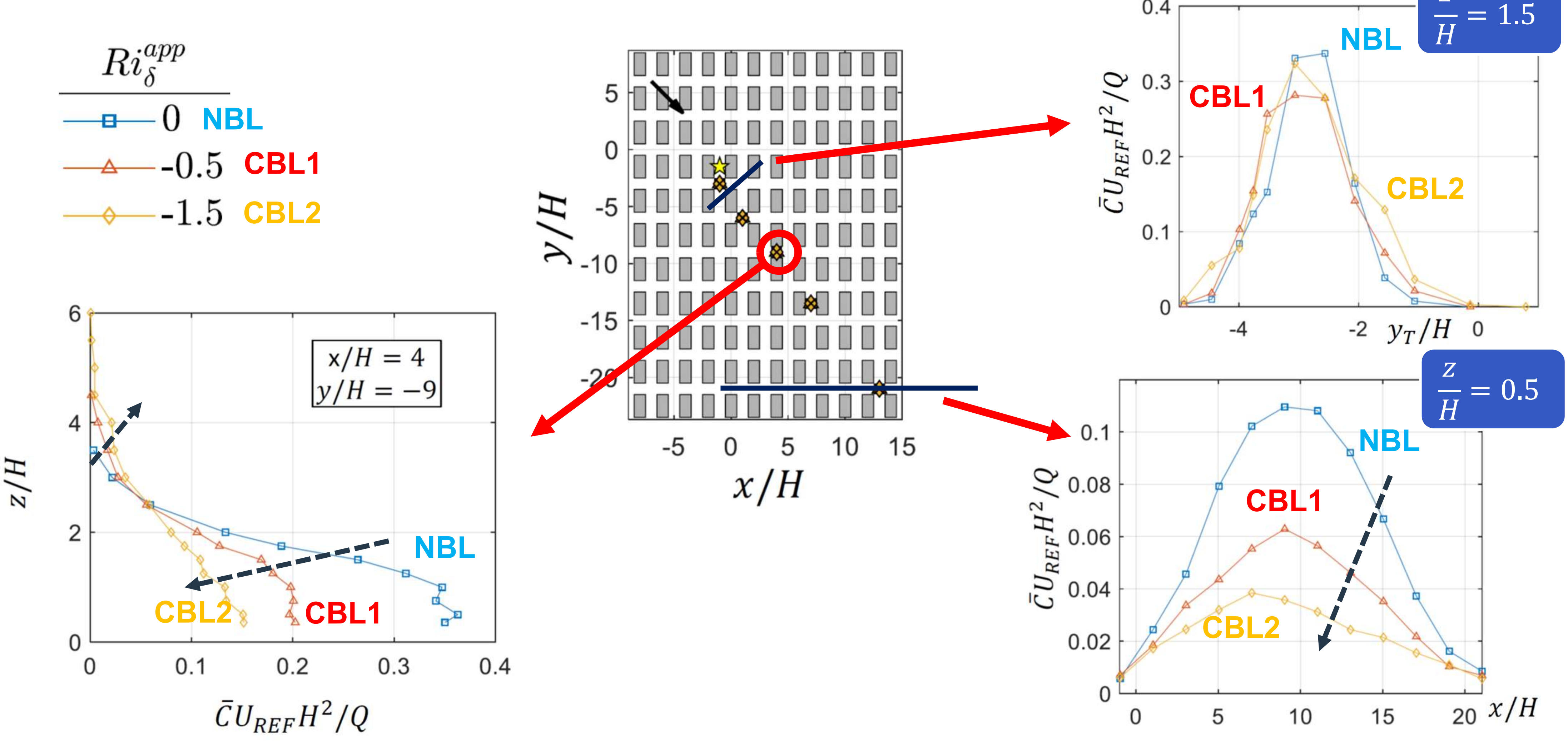
LDA Mirror (UW setup only)



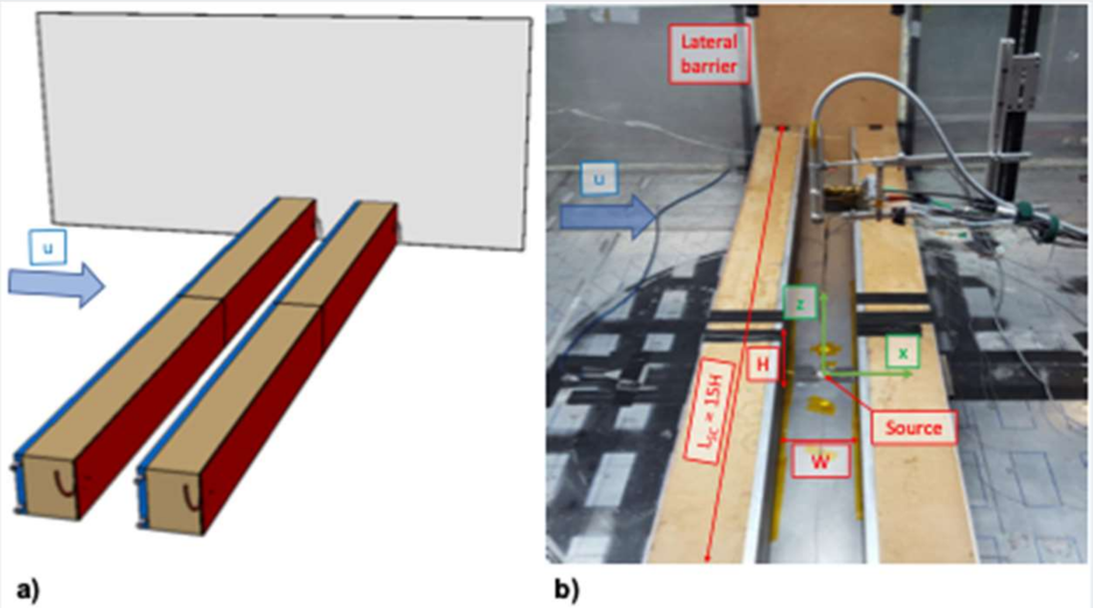
PLUME DEVELOPMENT AND CONCENTRATIONS IN A SBL



PLUME DEVELOPMENT AND CONCENTRATIONS IN A CBL



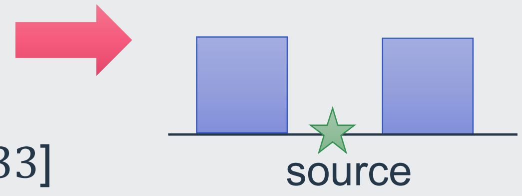
LOCAL STRATIFICATION



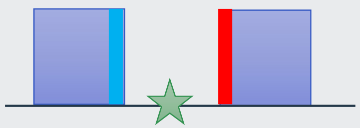
H = 165 mm
Canyon aspect ratio = 1 [H = W]

2x5 local heating/cooling configurations

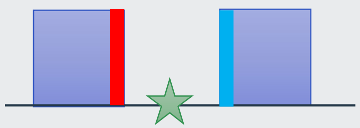
Approach flow:
(1) NBL $[Ri_{\delta}^{app} = 0]$
(2) SBL $[Ri_{\delta}^{app} = 0.33]$



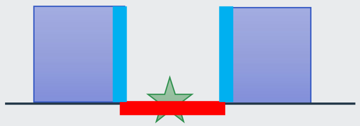
Windward



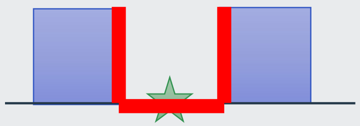
Leeward



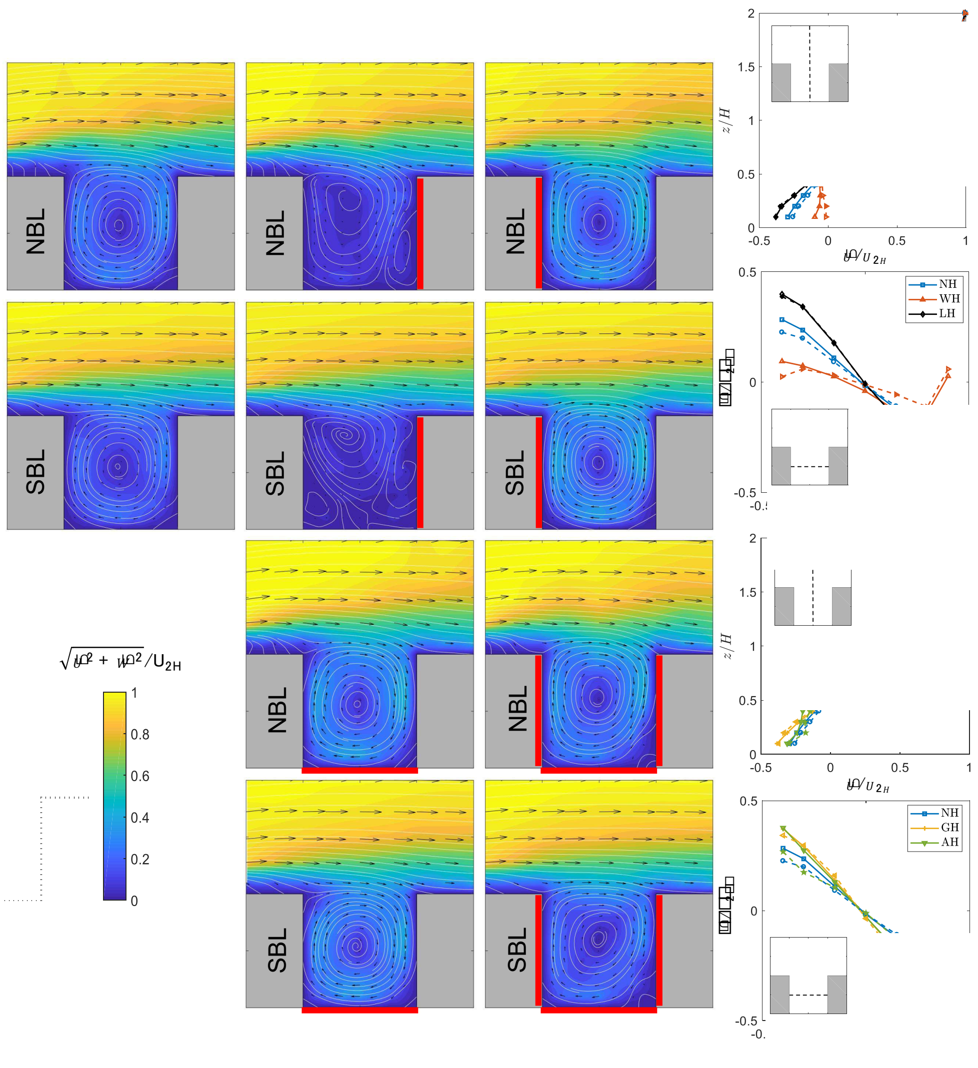
Ground

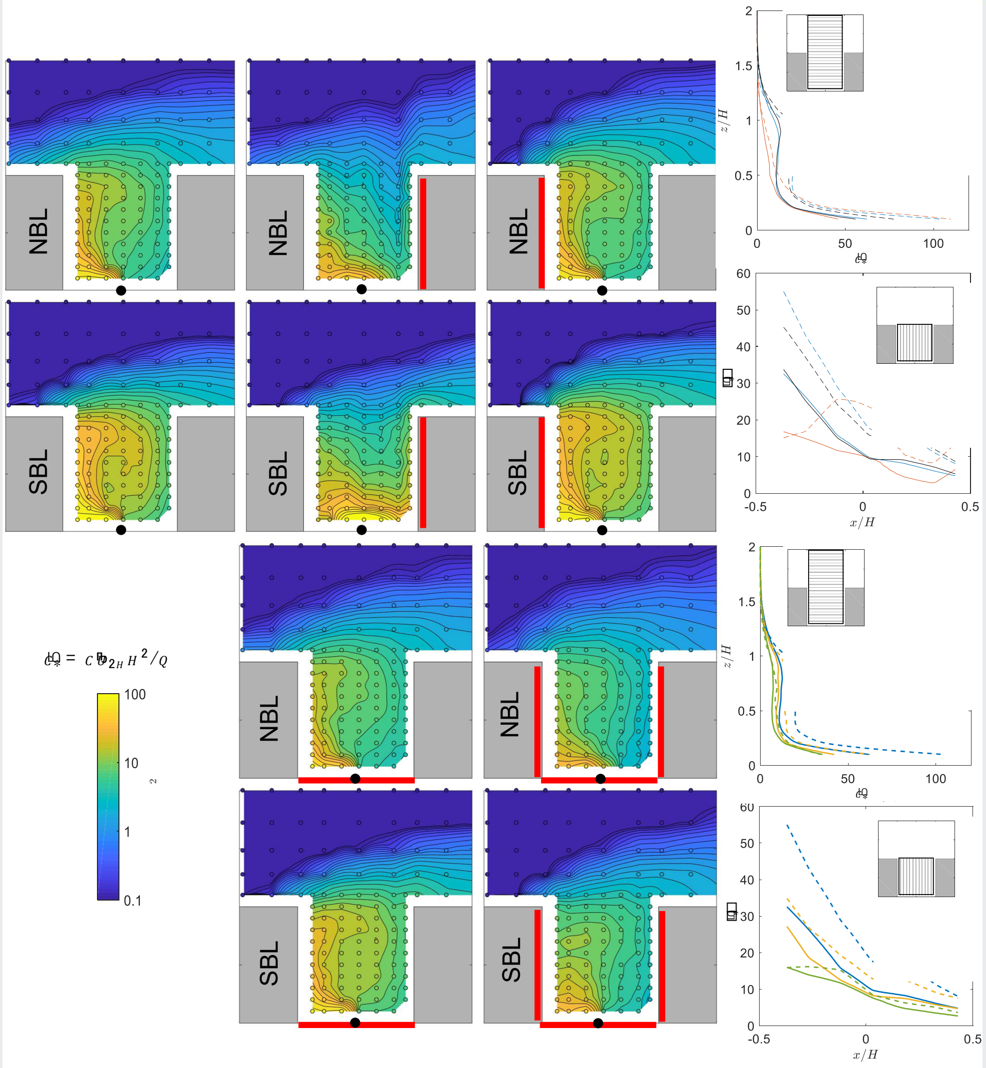


All



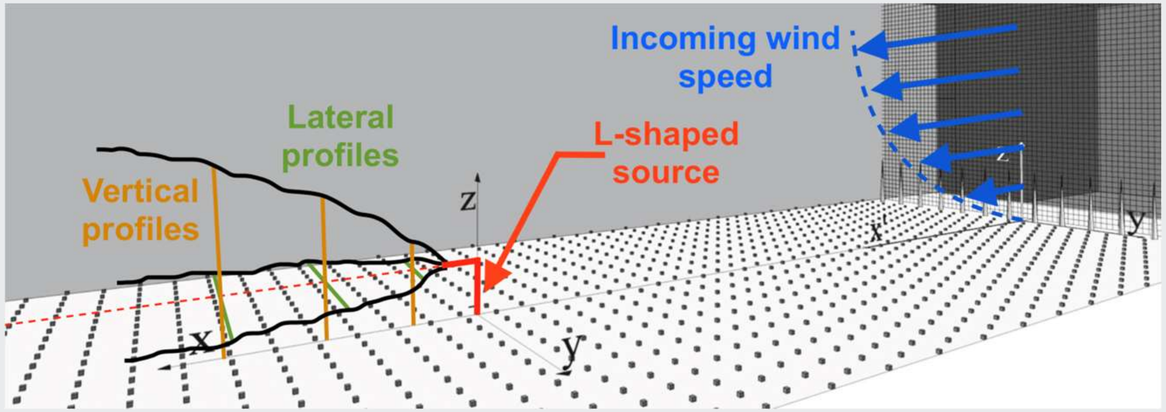
LOCAL STRATIFICATION



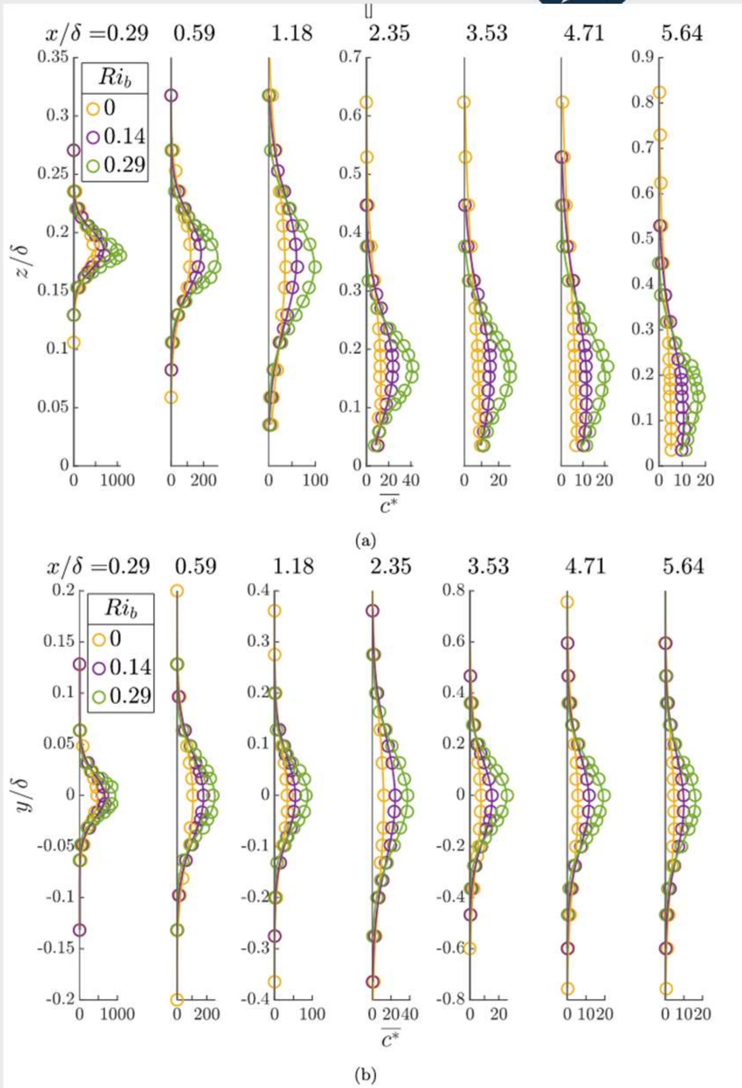


FUNDAMENTAL RESEARCH

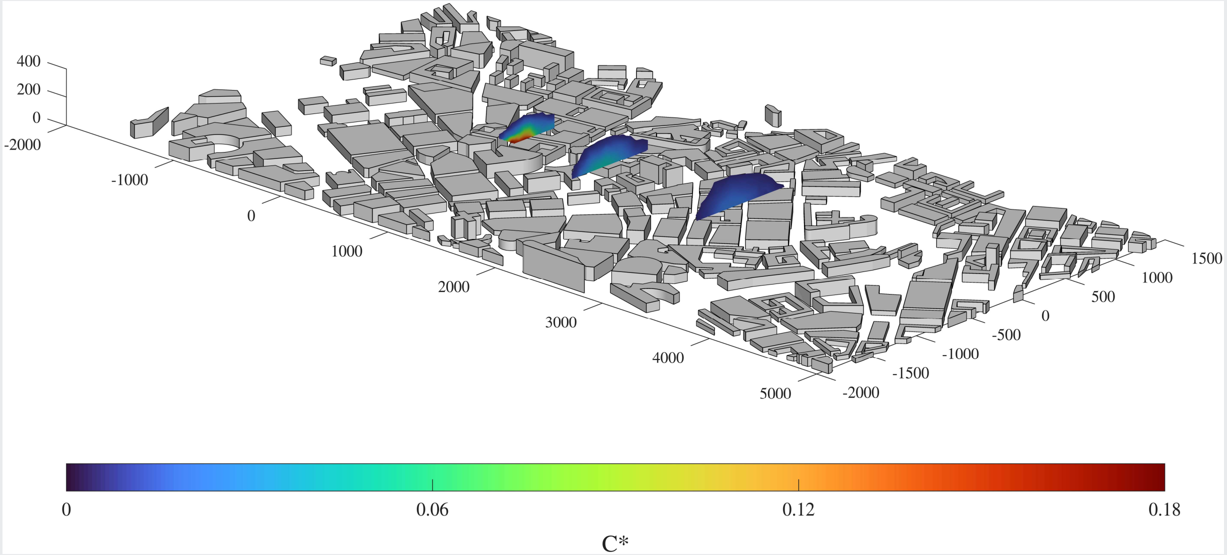
Turbulent dispersion in non-neutral BLs



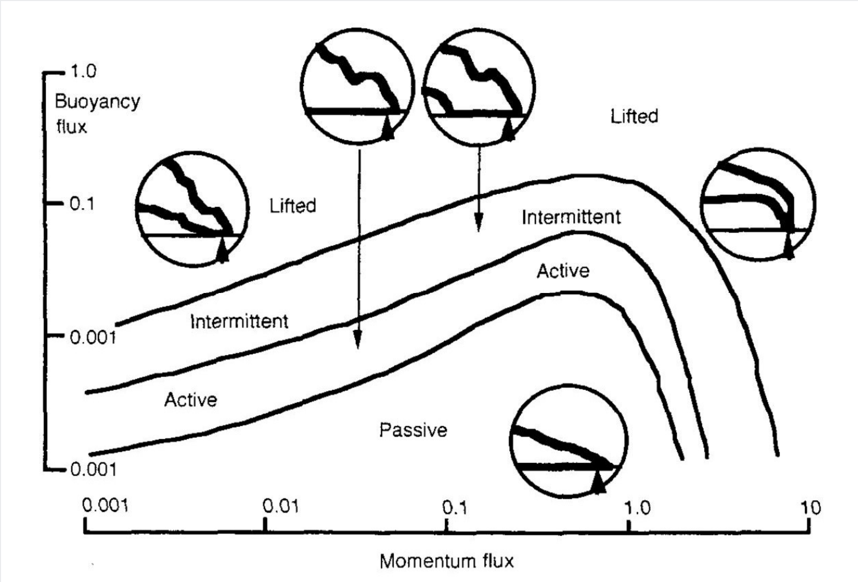
- Extensive work in neutral conditions:
- Fackrell & Robins (1982), “Concentration fluctuations and fluxes in plumes from point sources in a turbulent boundary layer”, JFM 117:1-26
- Nironi et al. (2015), “Dispersion of a passive scalar fluctuating plume in a turbulent boundary layer. Part I: Velocity and concentration measurements”, BLM 156(3):415-446
- Marro et al. (2015), “Dispersion of a passive scalar fluctuating plume in a turbulent boundary layer. Part II: Analytical Modelling” BLM 156(3): 447-469



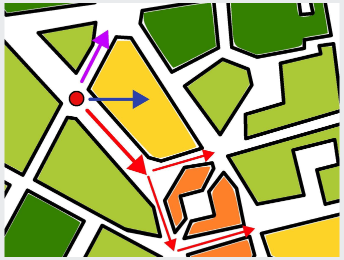
HEAVY/BUOYANT GAS DISPERSION



MODISAFE



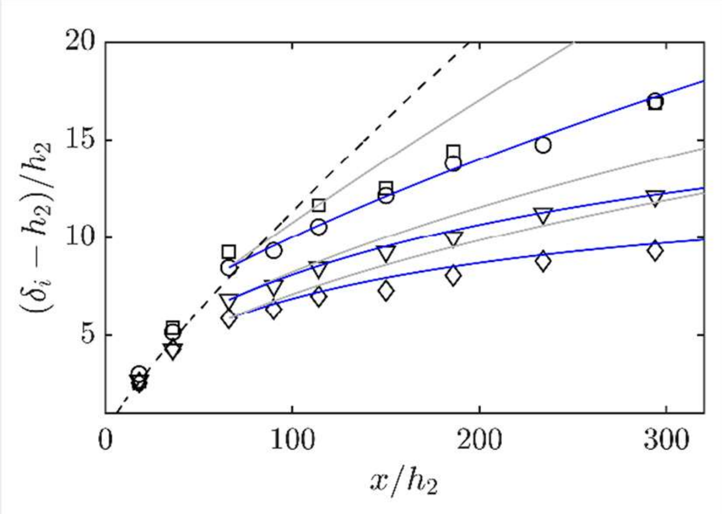
- Lighter-than-air emissions: helium / air as carrier gas
- Hevier-than-air emissions: carbon dioxide / air as carrier gas

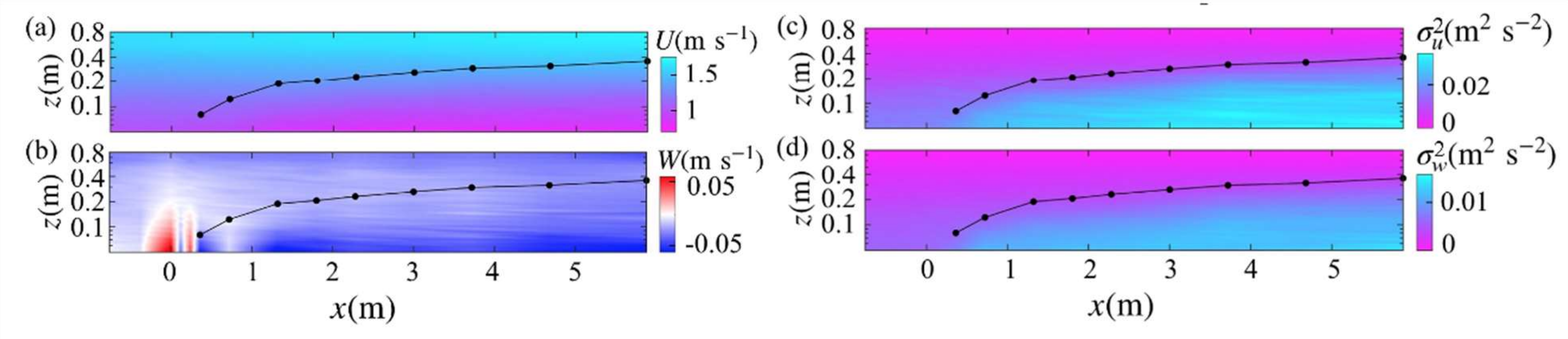


FUNDAMENTAL RESEARCH

Step-change in roughness (SBL)

Quantity	Case 1	Case 2	Case 3	Case 4
$Re_\delta(\times 10^4)$	4.5	4.5	3.0	2.9
Ri_b	0	0.13	0	0.27
Re_τ	2000	1600	1500	860
U_{ref}(m/s)	1.5	1.5	1.0	1.0
$\delta_0(m)$	0.52	0.52	0.53	0.50
$\Delta\Theta$(K)	0	16	0	16
u_{*1}/U_{ref}	0.045	0.036	0.049	0.030
u_{*2}/U_{ref}	0.064	0.049	0.067	0.047

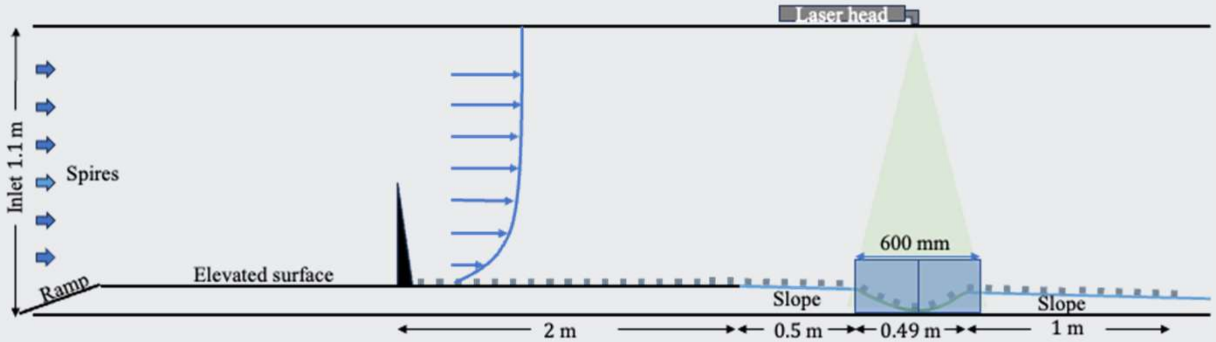


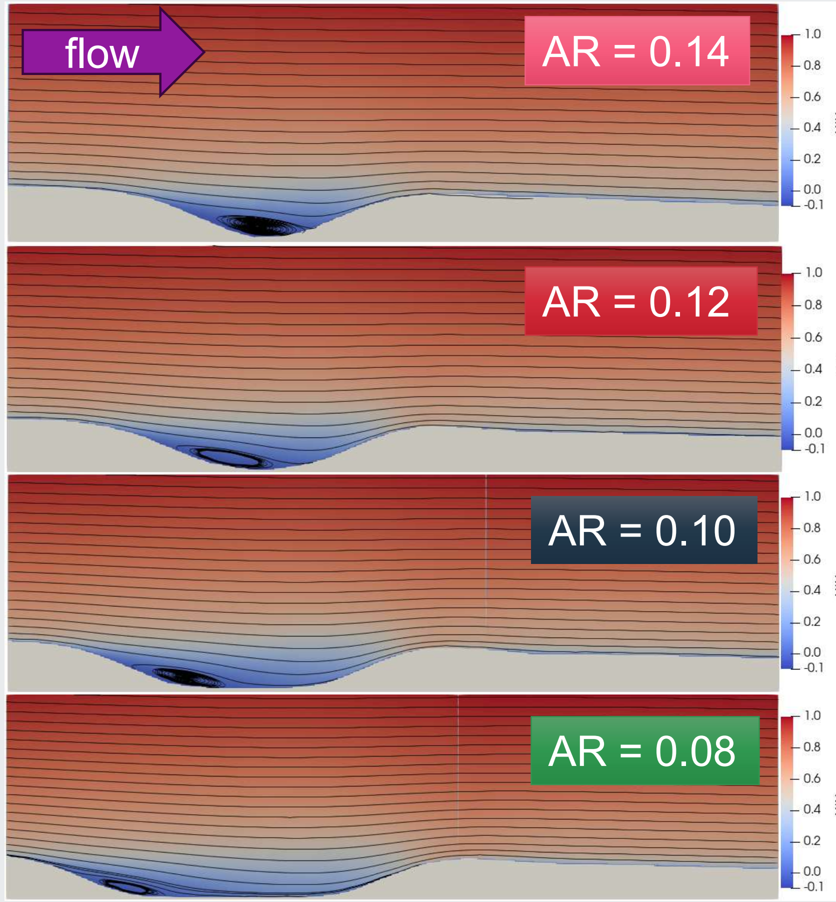


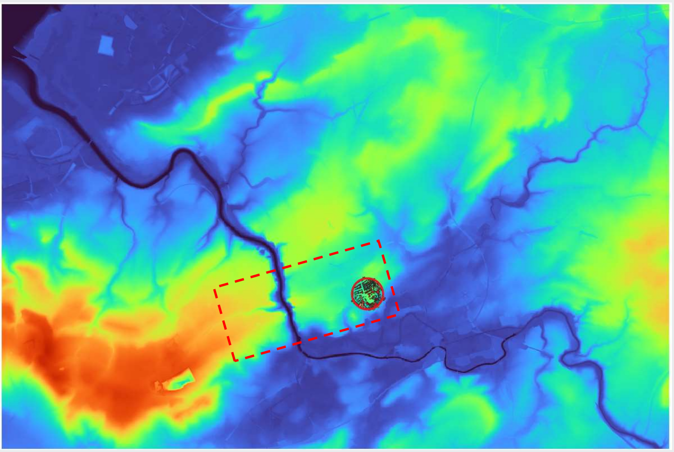
ASSURE

URBAN HETEROGENEITY

ASSURE

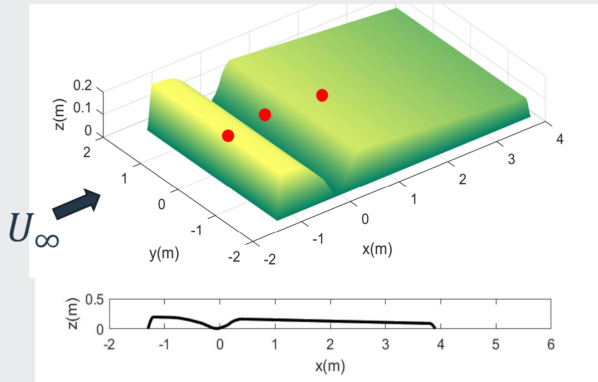






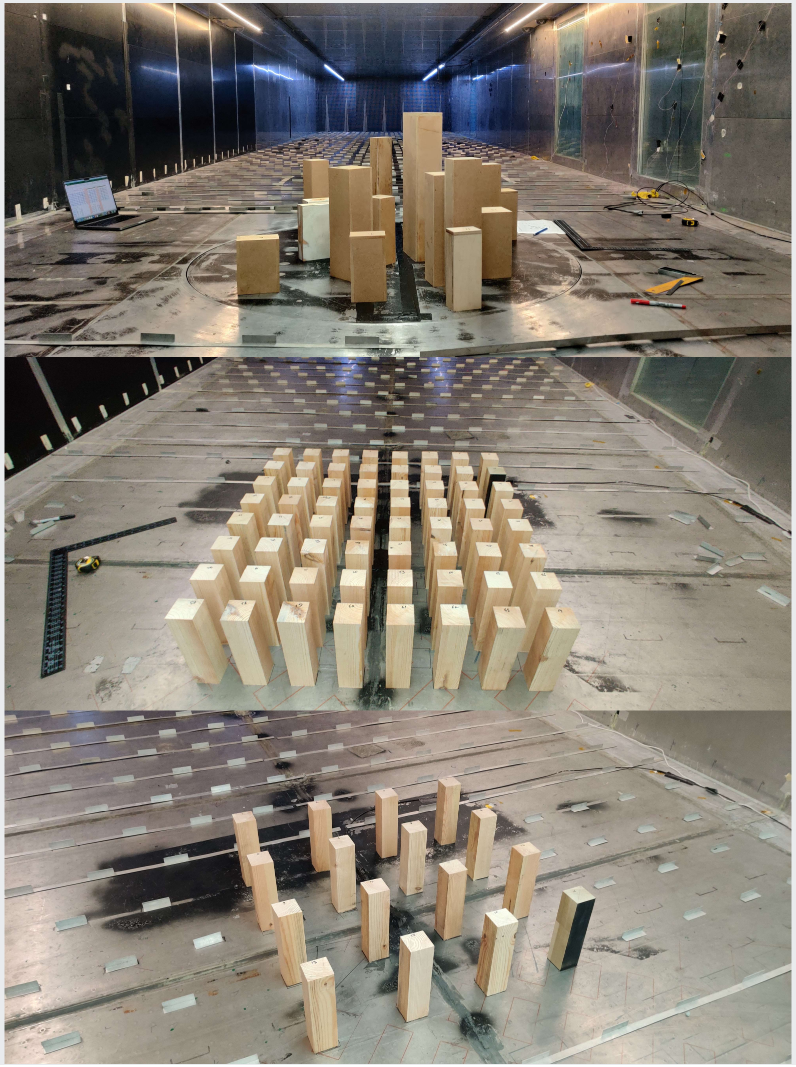
2D terrain model

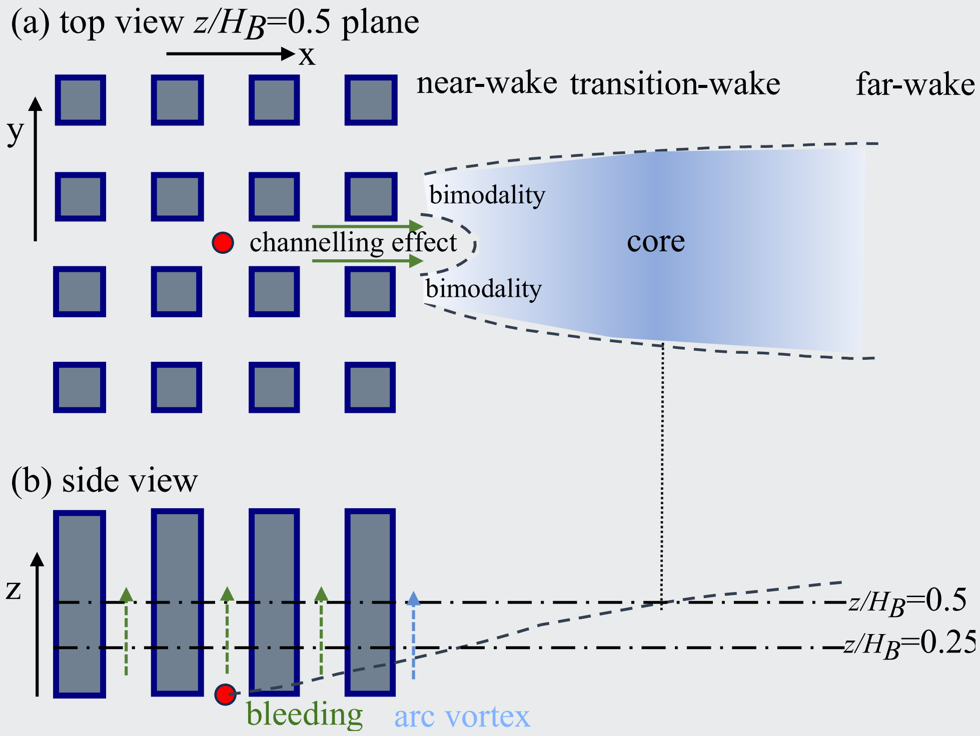
1:1000 scale



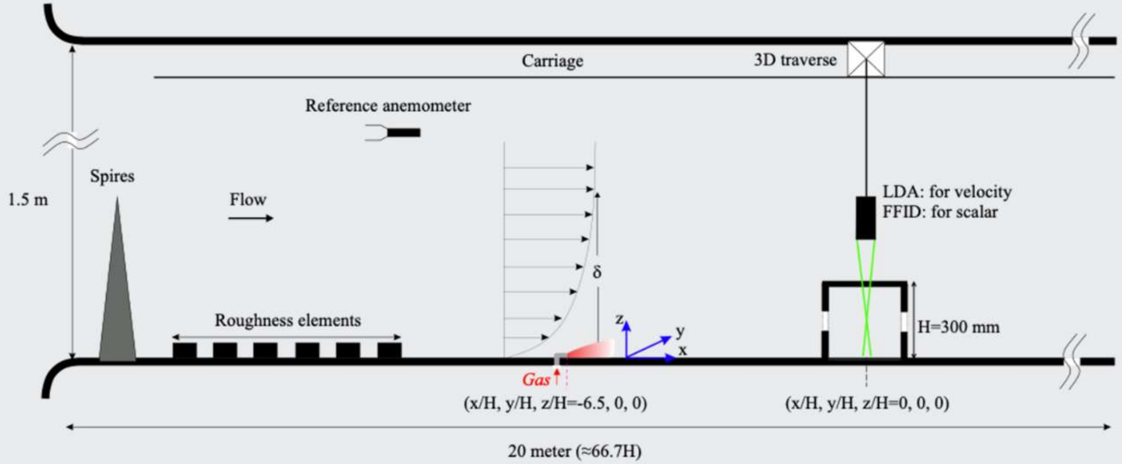
URBAN HETEROGENEITY

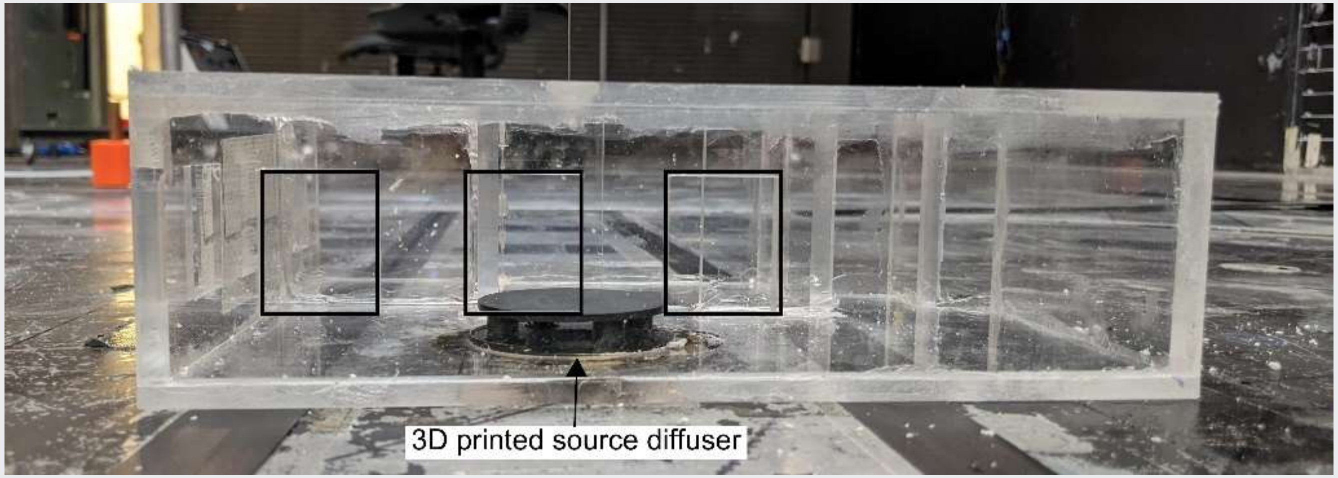
FUTURE





NATURAL VENTILATION





WIND POWER AERODYNAMICS

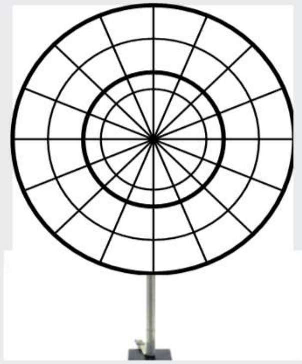
Offshore and onshore wind farms

Wind turbine

D = 416 mm
z_{hub}= 300 mm
TSR = 6
C_T = 0.48

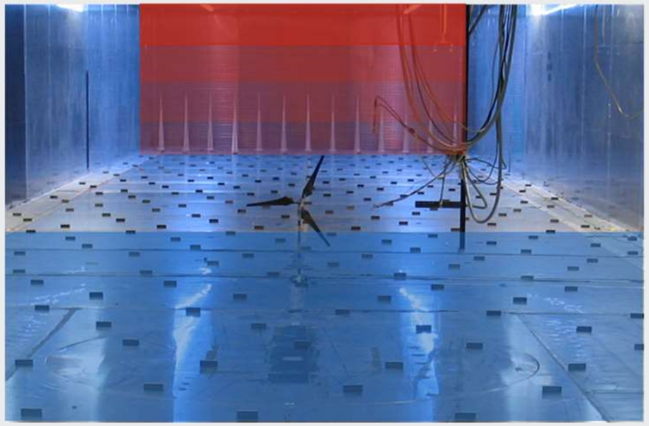
Porous disk

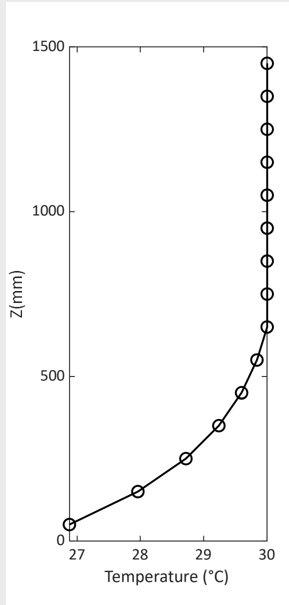
D = 416 mm
z_{hub} = 300 mm



Stable ABL setup

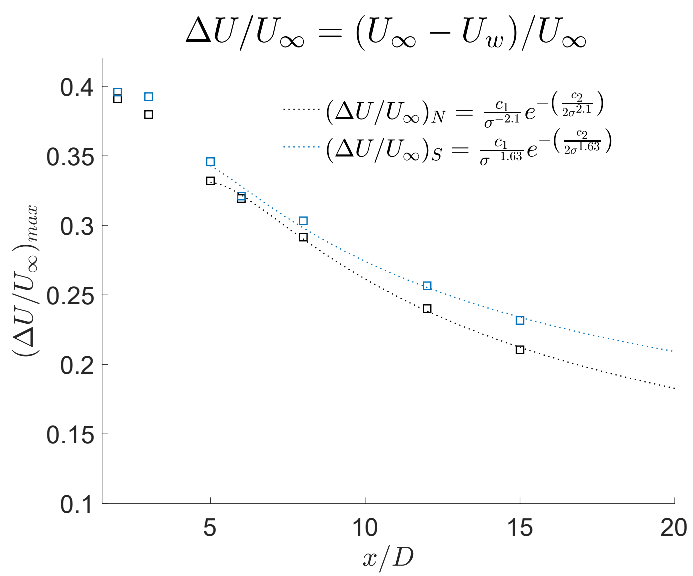
- Non-uniform inlet profile (needed but easy to get wrong)*
- First meters are uncooled (smooth varying quantities)*
- Neutral & Ri = 0.15

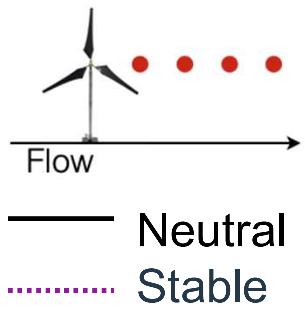


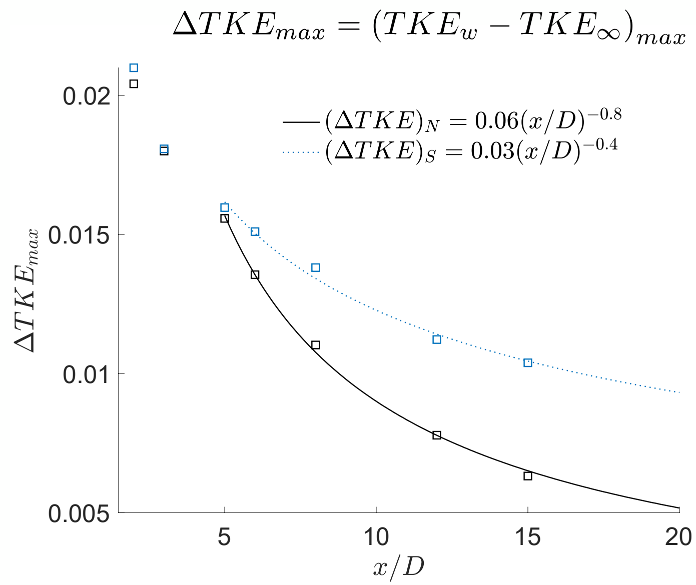


***Hancock & Hayden BLM (2018, 2020, 2021)**
Marucci & Carpentieri for convective ABLs

WIND POWER AERODYNAMICS







Stably stratified ABLs hinder the wake recovery in both near and far field

Stable wakes are more persistent

Stability effects are even larger in the turbulence, where the TKE decay is strongly hindered by the thermal stability

Questions?