Non-neutral flows: simulating the full range of atmospheric conditions in the EnFlo Environmental Wind Tunnel

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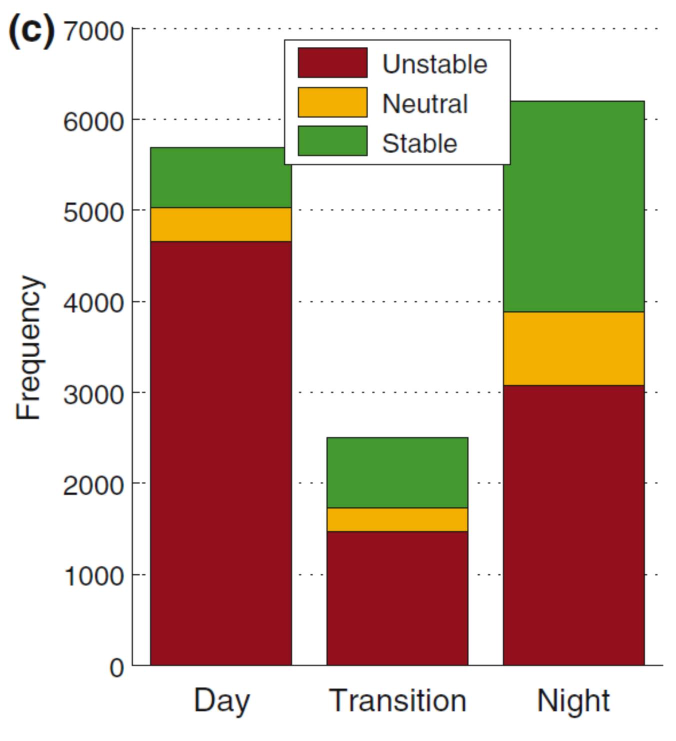
Outline

Non-neutral flows: simulating the full range of atmospheric conditions in the EnFlo Environmental Wind Tunnel

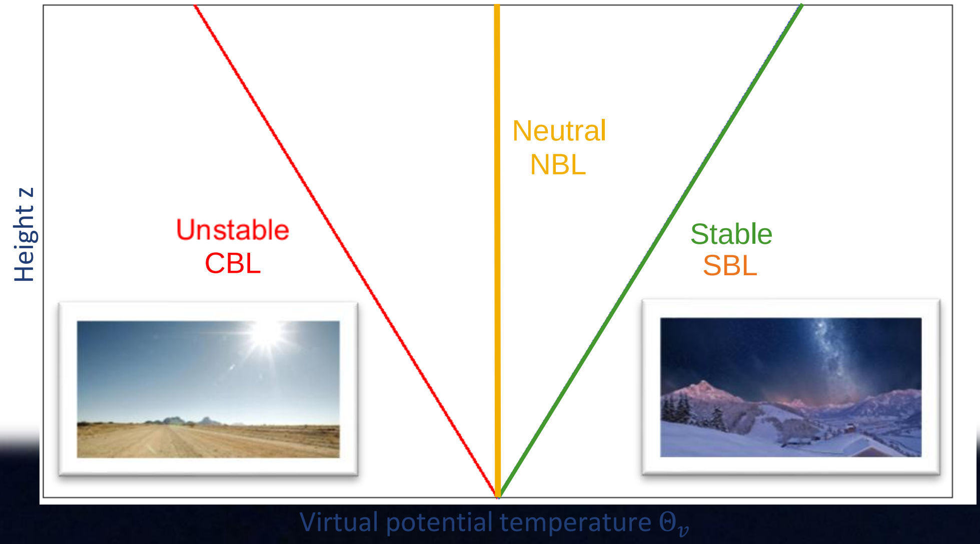
- Background & Methodology
    - Non-neutral flows
    - The EnFlo environmental wind tunnel
    - Instrumentation
    - Generating a SBL
    - Generating a CBL
- Project results
    - StratEnFlo: Pollution dispersion in urban areas
    - Fundamental research
    - Urban heterogeneity (ASSURE)
    - Wind power aerodynamics

Effects of non-neutral stratification

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



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 environmental wind tunnel

After the recent upgrade

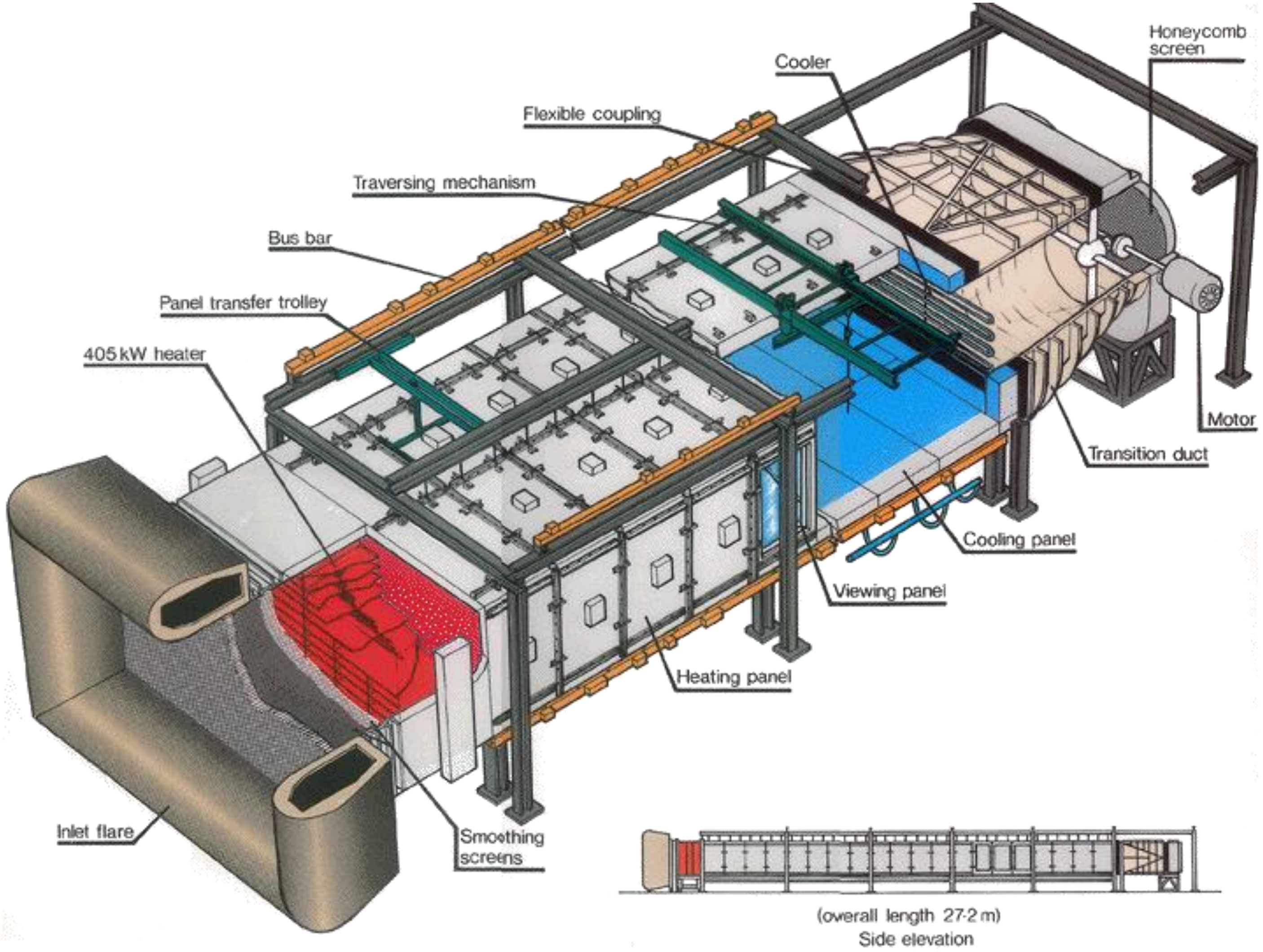
Open-return meteorological wind tunnel

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

Air speed range: 0.5 - 5 m/s

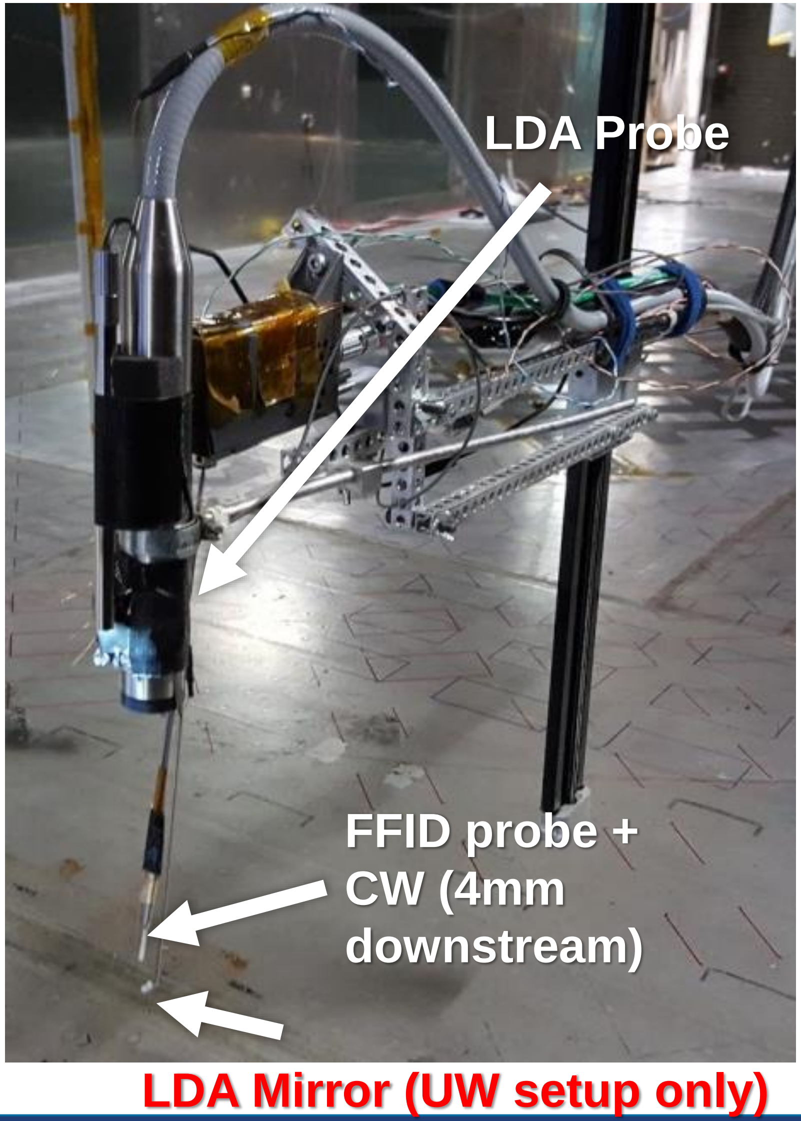
Temperature range: 10 – 110 °C

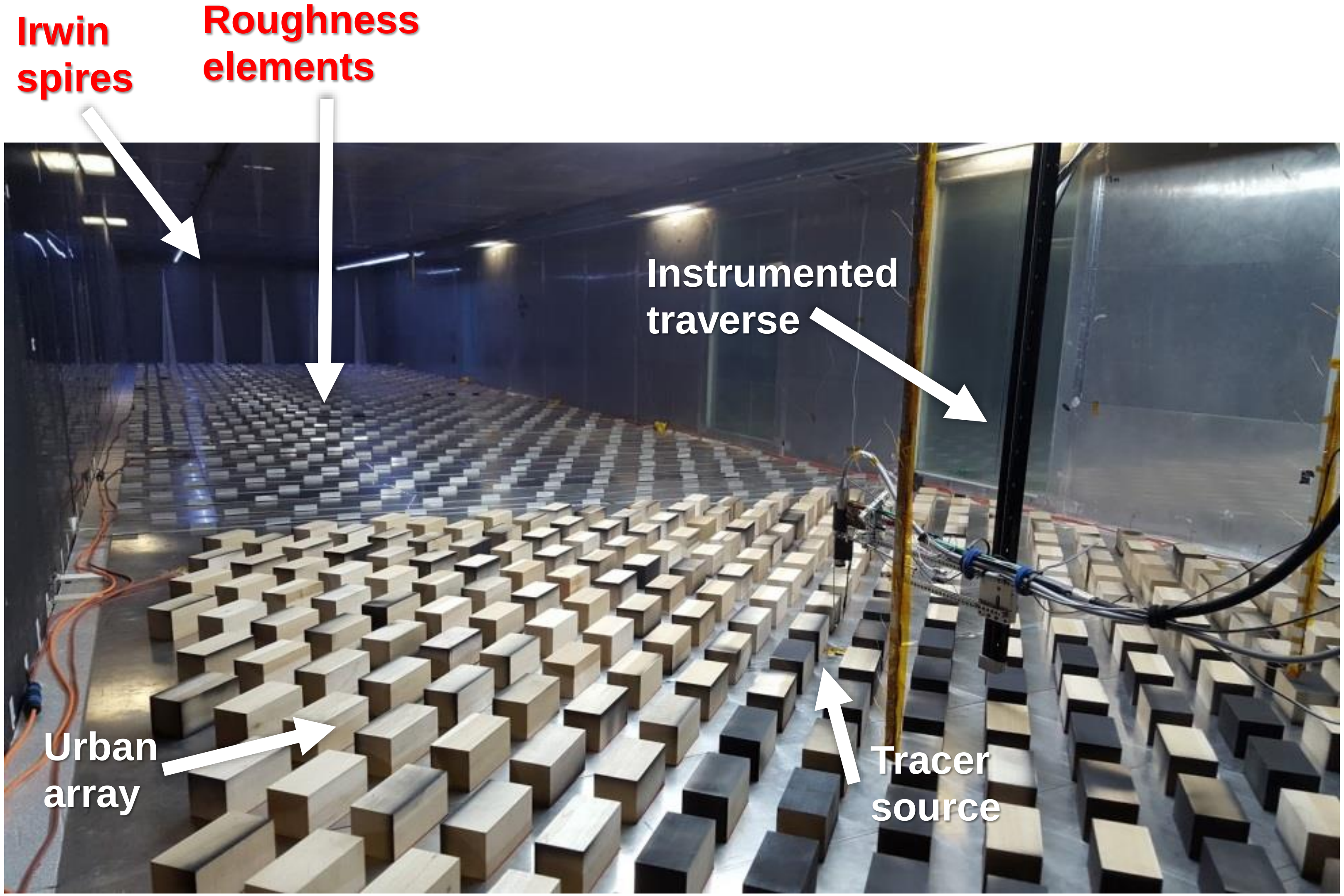
Max heating power: 800 kW



Effects of non-neutral stratification

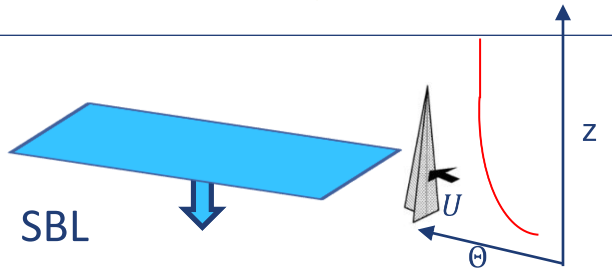
Wind tunnel setup





Generating non-neutral boundary layers

Stable boundary layer



Parameters investigated:

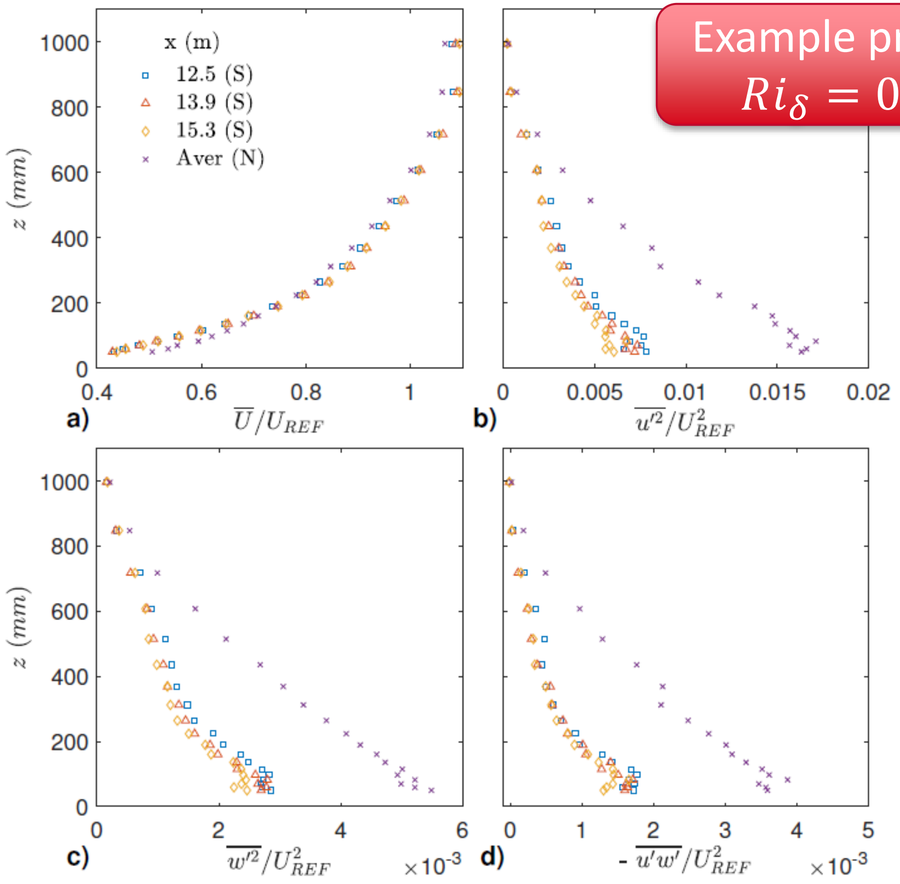
- Floor temperature vs inlet max temperature
- Length of uncooled floor
- Imposed temperature profile

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
$Ri_\delta = 0.21$



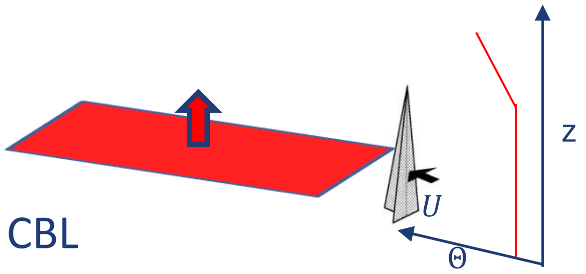
Generating non-neutral boundary layers

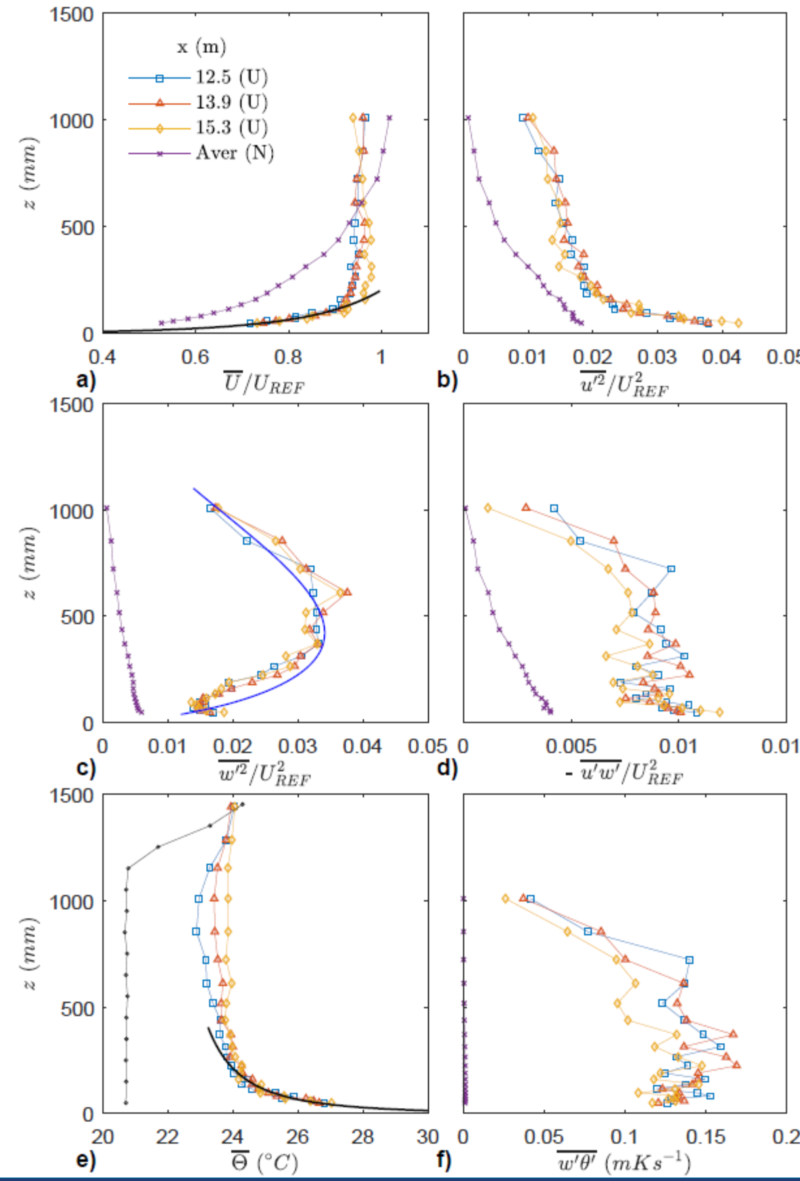
Convective boundary layer

Parameters investigated:

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

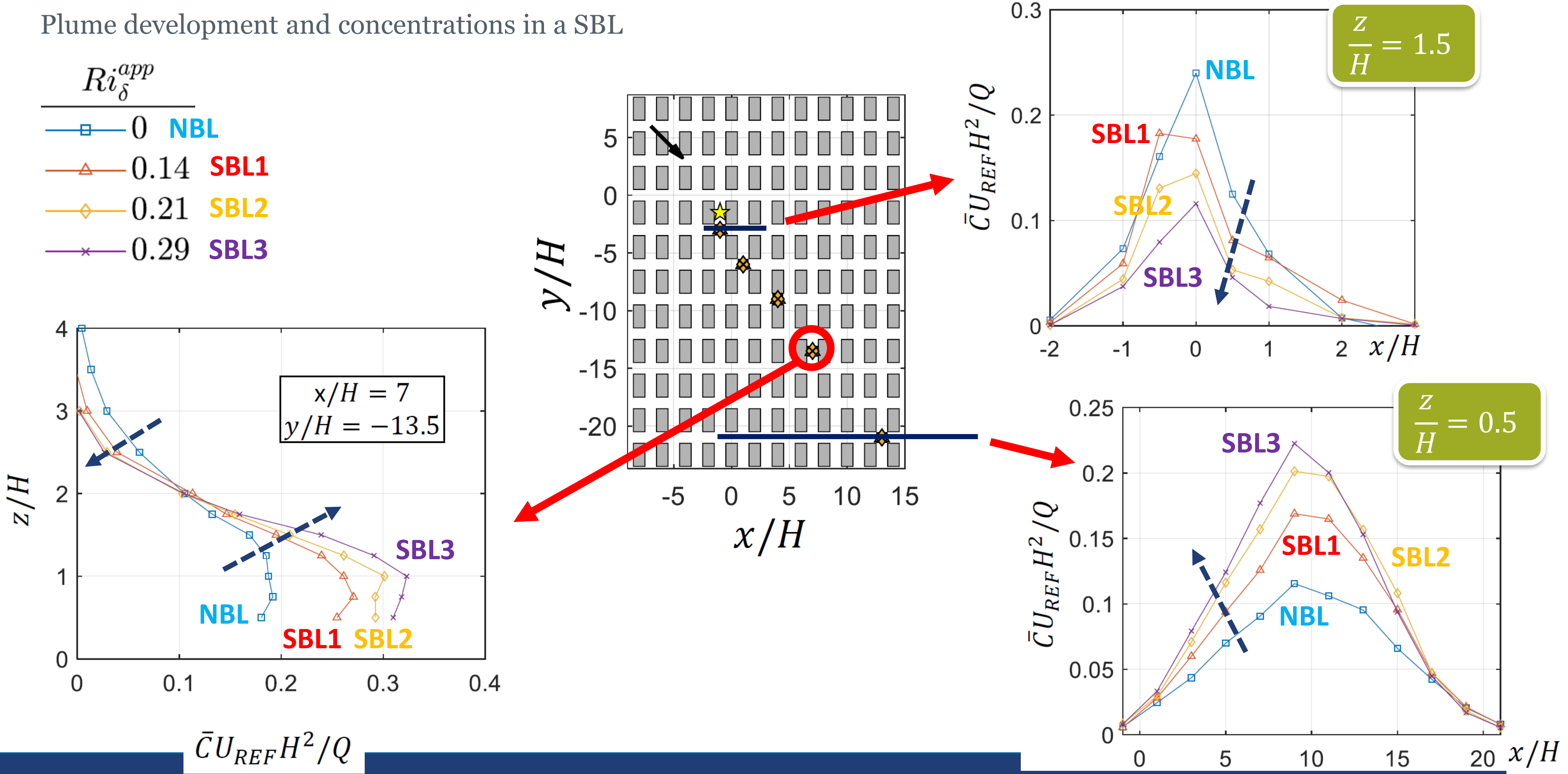
	N	HR2	HR1(U)
U_{REF} (m/s)	2.0	1.25	1.0
$\Delta\Theta_{MAX}$ (°C)	0	−23	−36
δ (m)	1.0	1.2	1.3
u_*/U_{REF}	0.065	0.084	0.100
z_0 (mm)	2.0	1.8	2.0
θ_* (K)	-	−0.78	−1.4
$\tilde{\theta}_*$ (K)	-	0.56	0.79
u_*/w_*	-	0.72	0.56
δ/L	0	−1.1	−2.2
Ri_δ	0	−0.5	−1.5
Re_δ (x10^4)	13.3	8.7	6.9





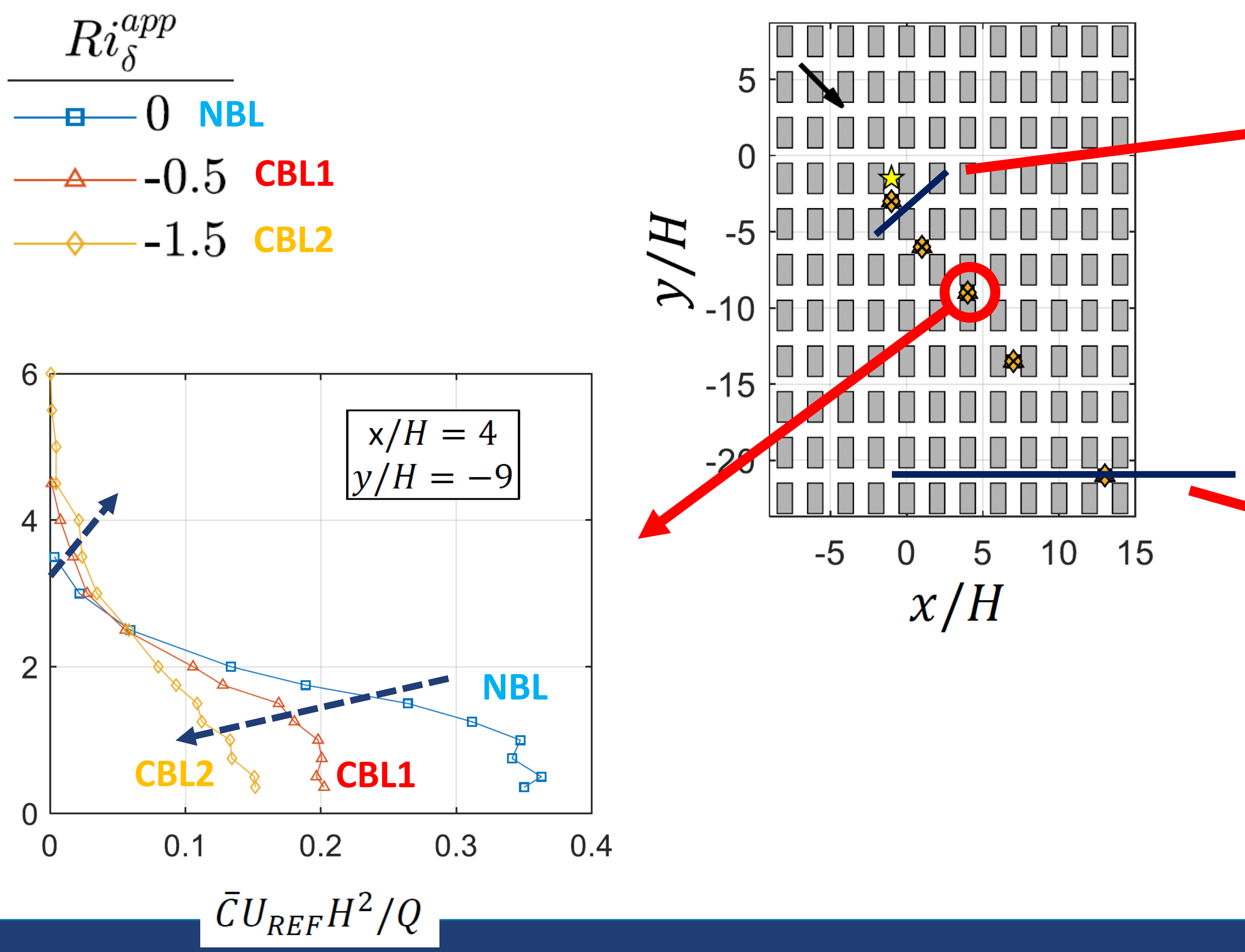
Effects of non-neutral stratification

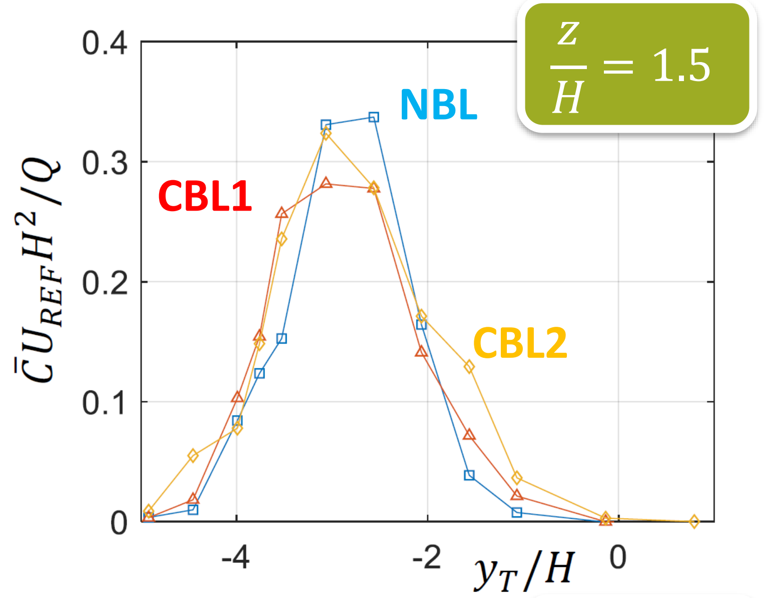
Plume development and concentrations in a SBL

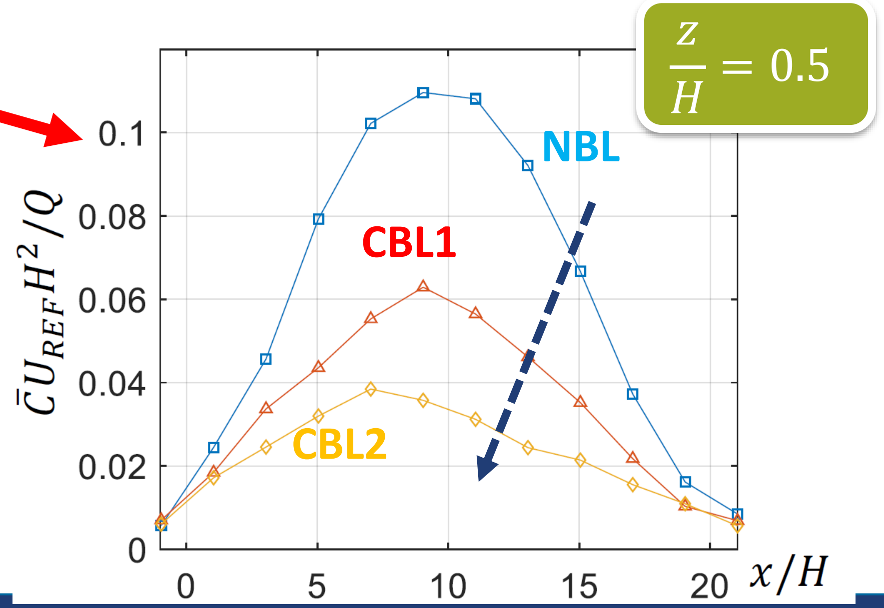


Effects of non-neutral stratification

Plume development and concentrations in a CBL

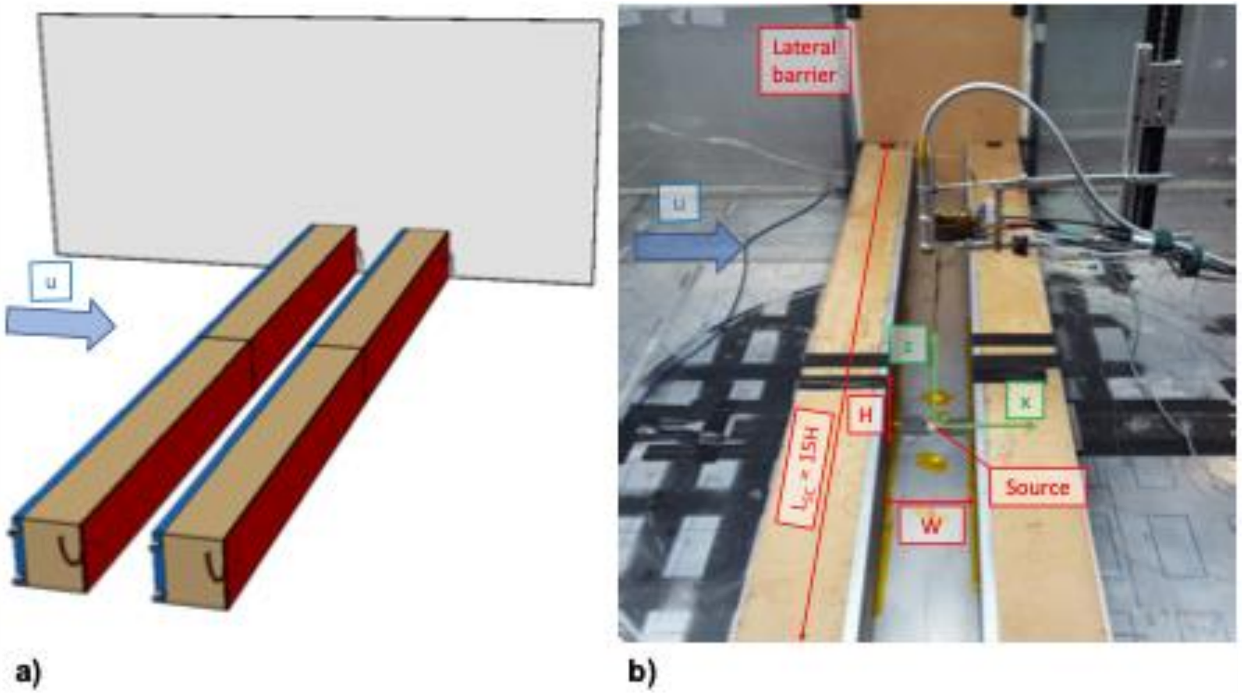






Effects of non-neutral stratification

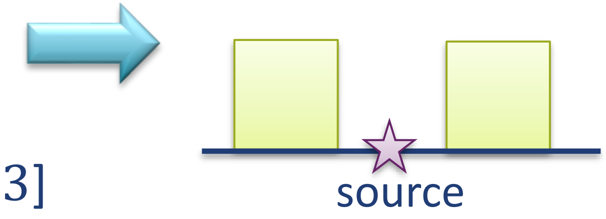
Local stratification: test cases



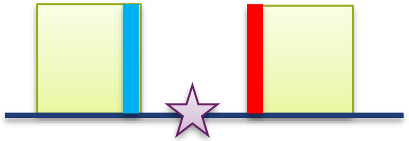
H = 165 mm
Canyon aspect ratio = 1 [H = W]

2x5 local heating/cooling configurations

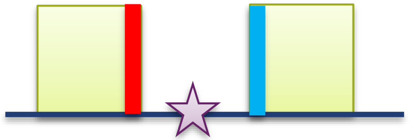
Approach flow:
(1) NBL [$Ri_\delta^{app} = 0$]
(2) SBL [$Ri_\delta^{app} = 0.33$]



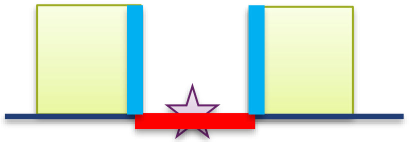
Windward



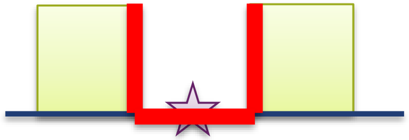
Leeward



Ground

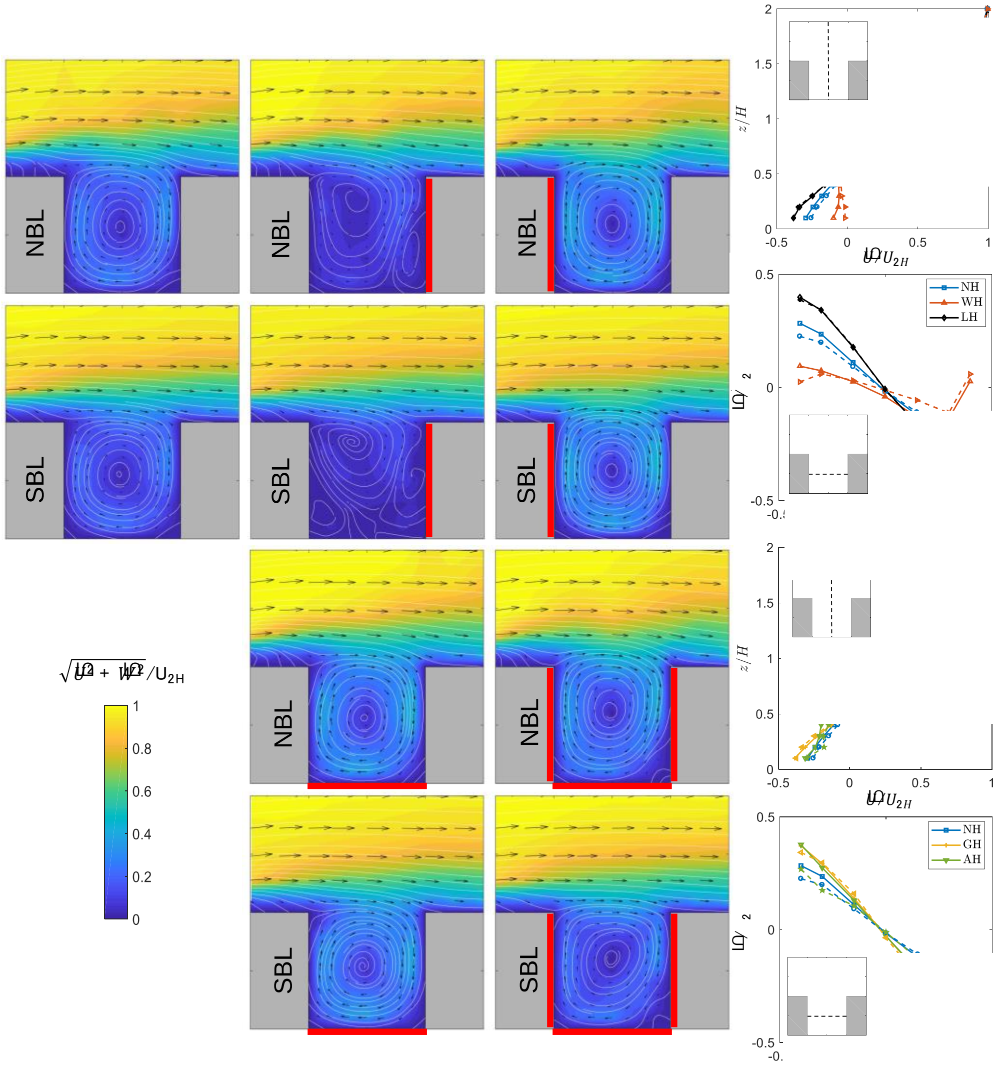


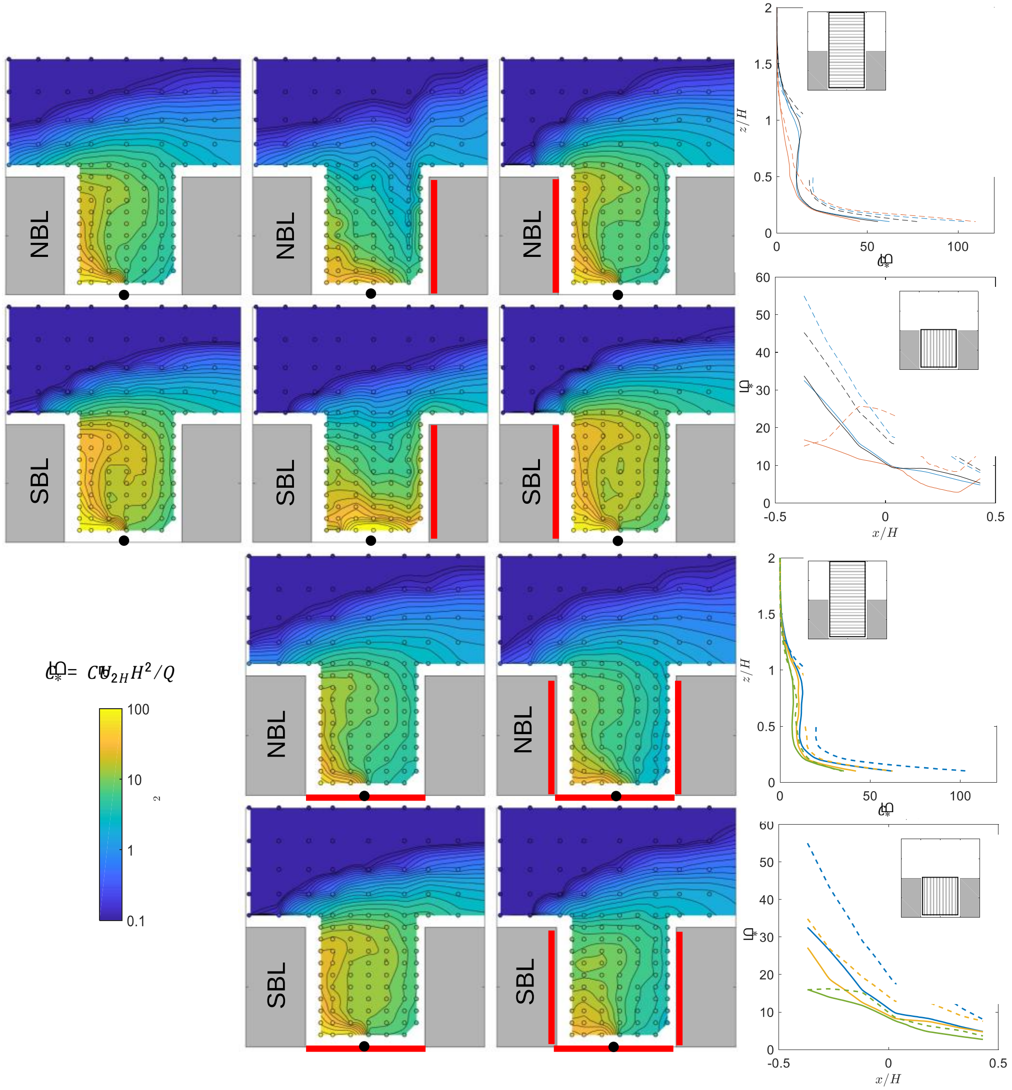
All



Effects of non-neutral stratification

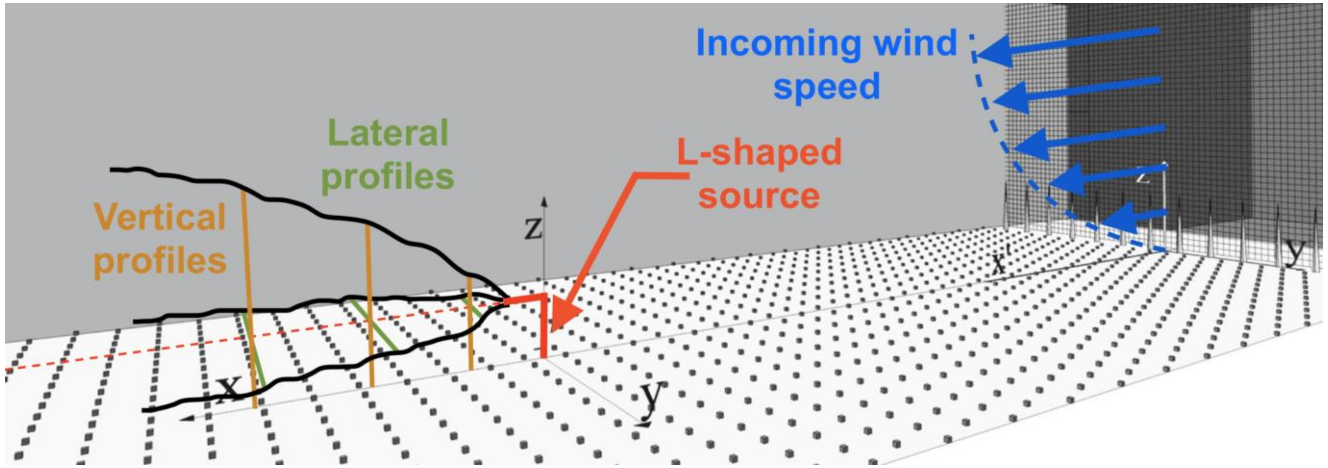
Local stratification: results

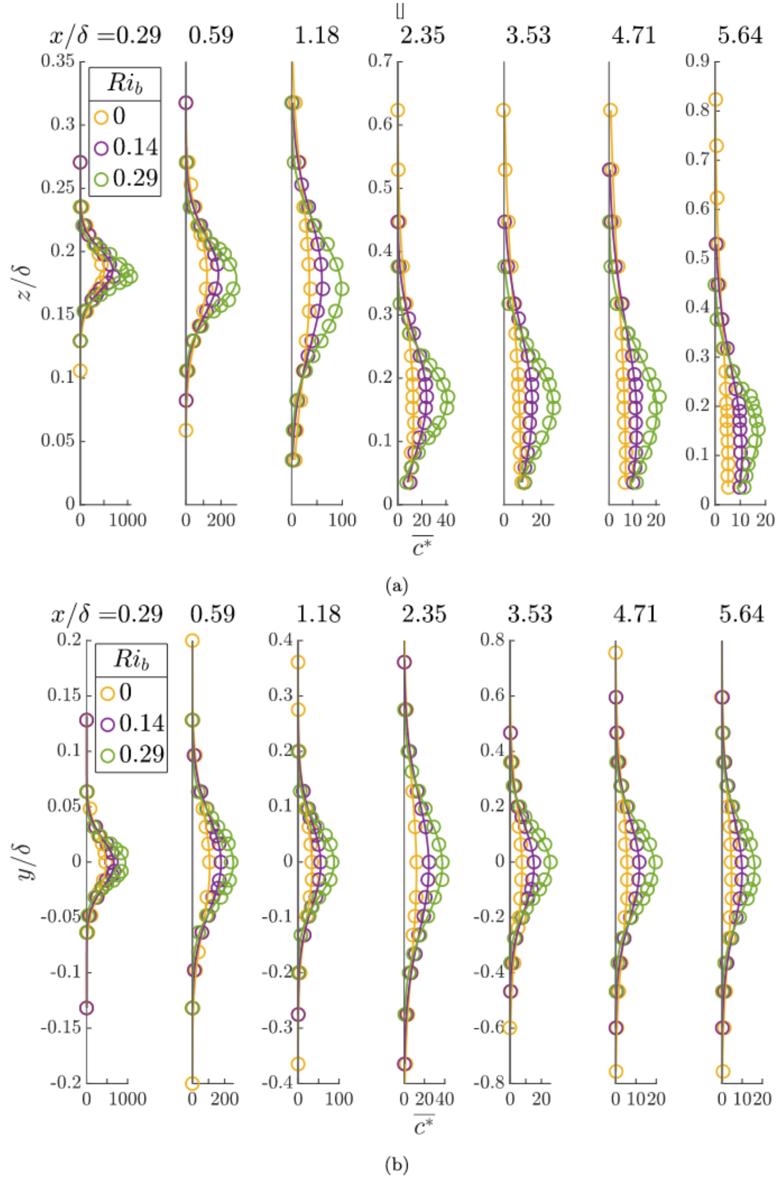




Turbulent dispersion in non-neutral BLs

Fundamental research





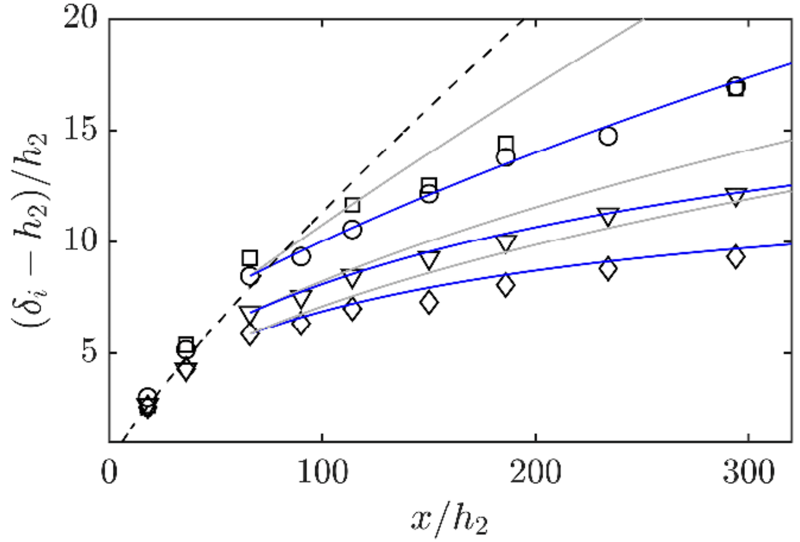
Extensive work in neutral conditions:

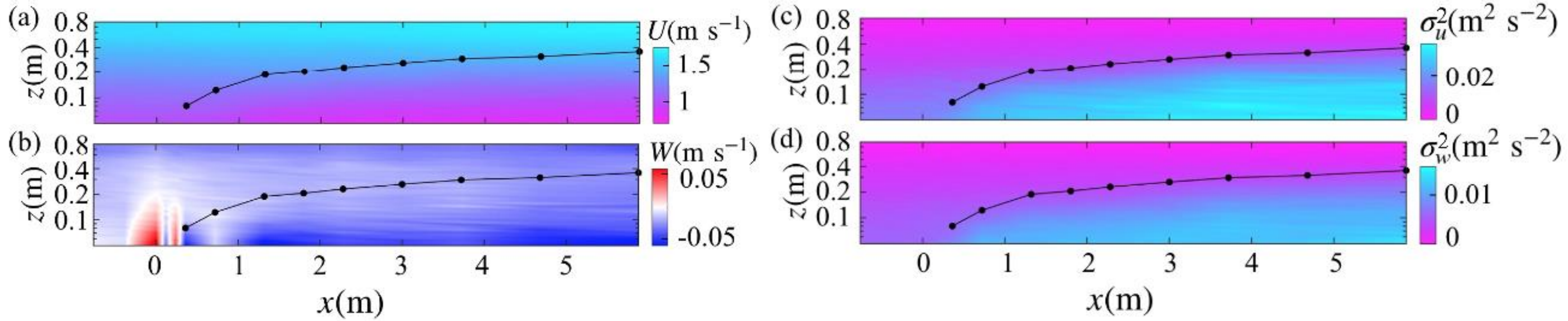
- Fackrell & Robins (1982), "Concentration fluctuations and fluxes in plumes from point sources in a turbulent boundary layer", JFM 117:1-26
- Nironi et al. (2015), "Dispersion of a passive scalar fluctuating plume in a turbulent boundary layer. Part I: Velocity and concentration measurements", BLM 156(3):415-446
- 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

Roughness step-change in NBL&SBL

Fundamental research (ASSURE project)

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





Offshore and onshore wind farms

Wind turbine

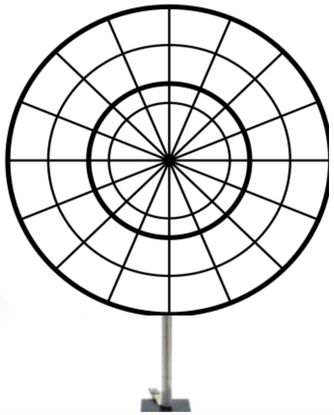
D = 416 mm

z_{hub}= 300 mm

TSR = 6

C_T = 0.48

Porous disk

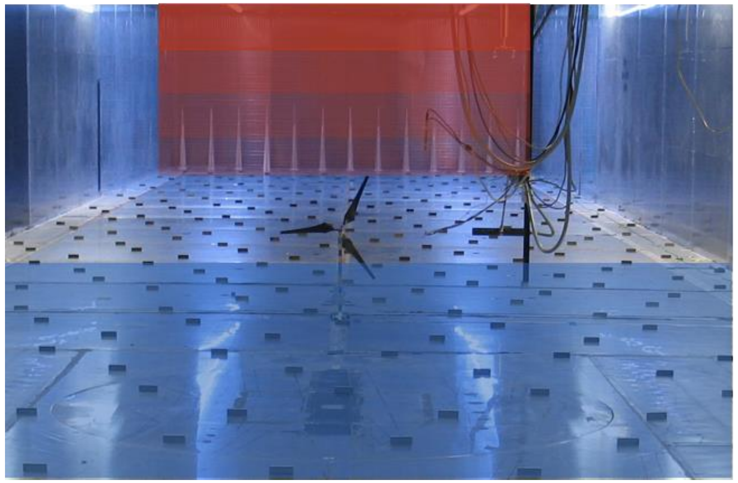


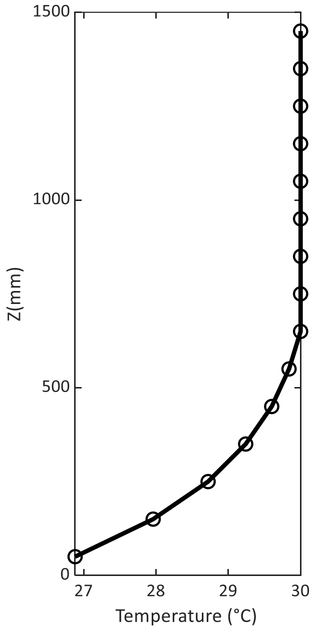
D = 416 mm

zhub = 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

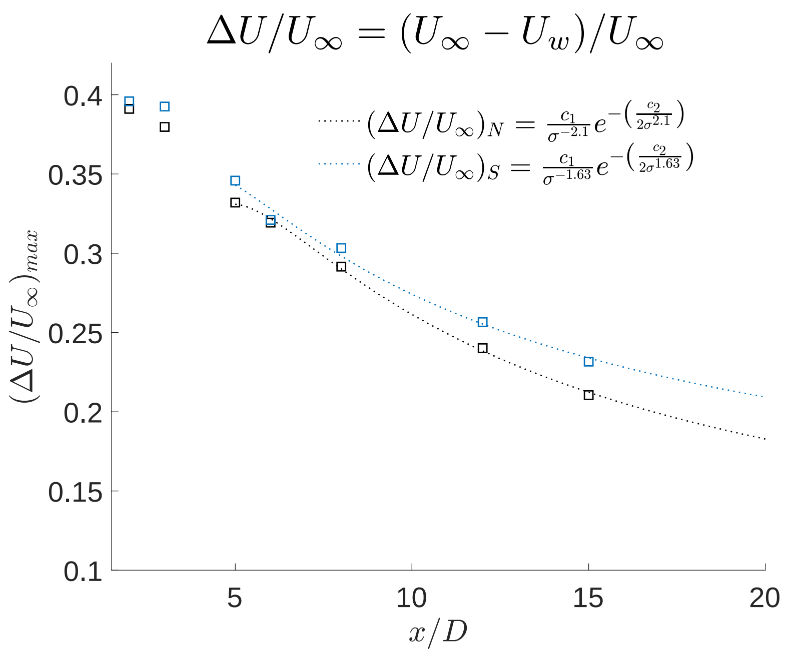


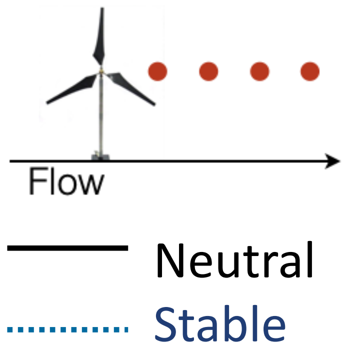


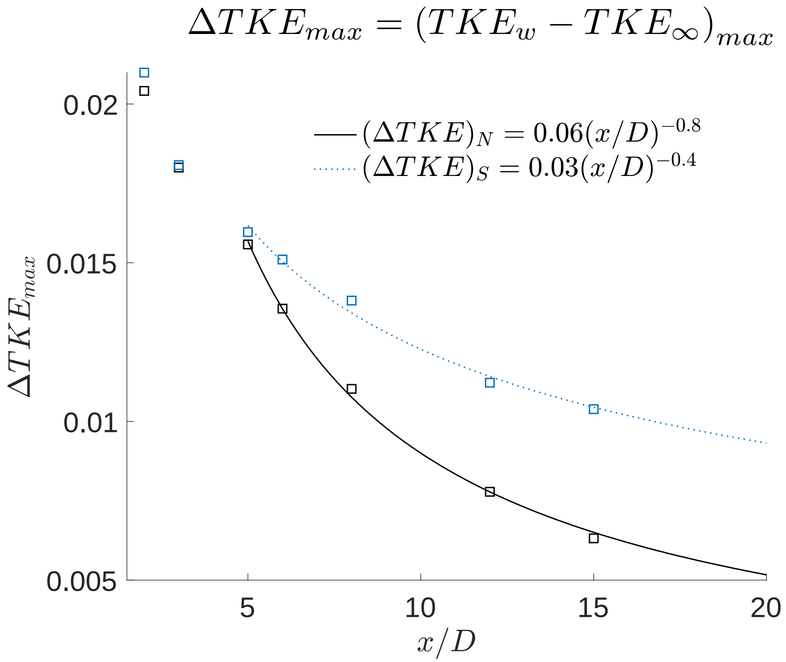
***Hancock & Hayden BLM (2018, 2020, 2021)**
Marucci & Carpentieri for convective ABLs

Wind power aerodynamics

Offshore and onshore wind farms







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

THANK YOU!

Contacts

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