Complexity: Friend not a Foe

Street Network Entropy & Wind Flow in Heterogeneous Urban Environments

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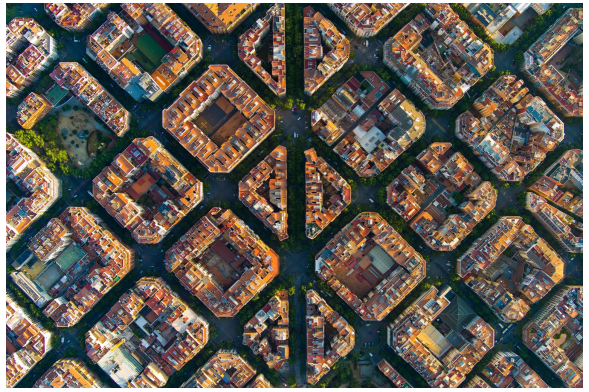
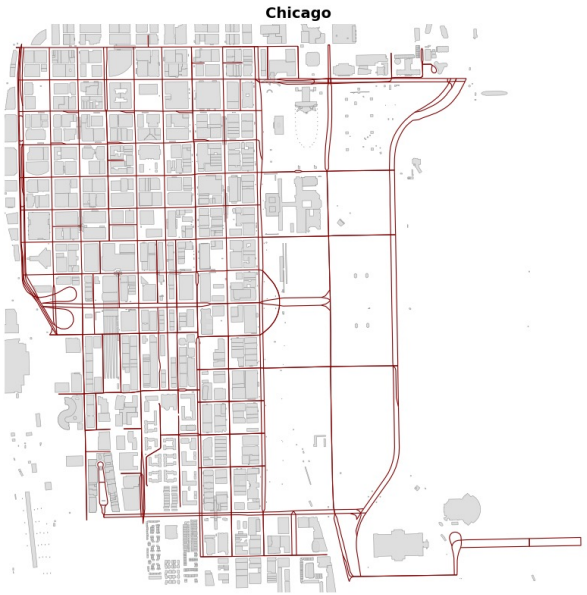
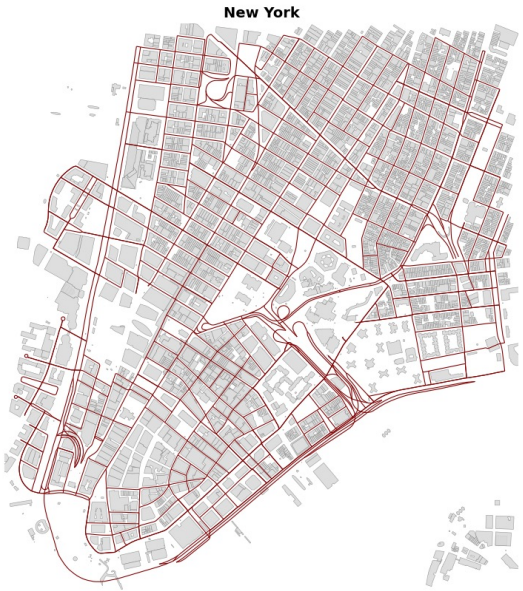
Urban Built Environment

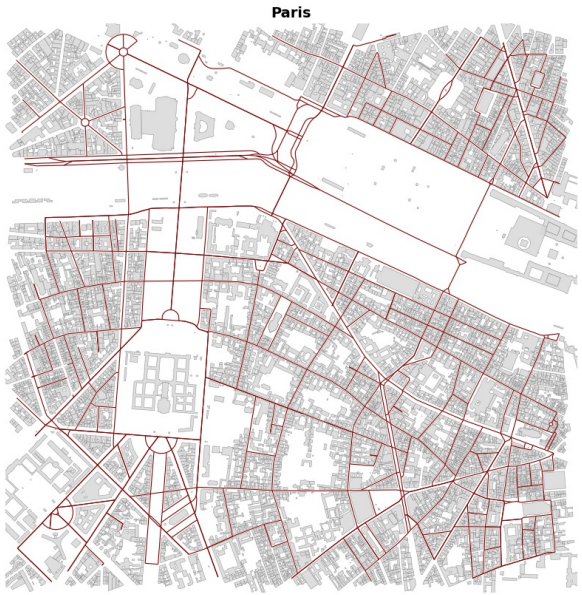


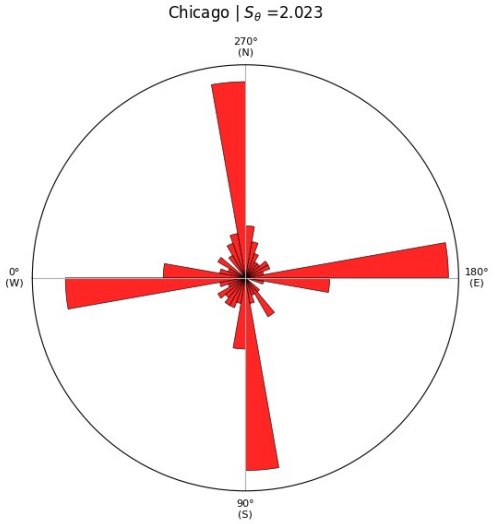
Street Network

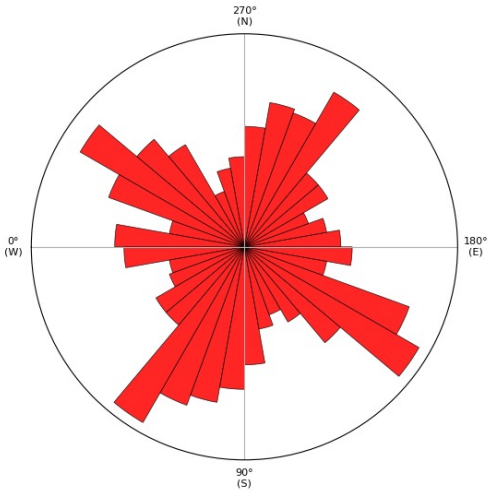
Increasing Entropy

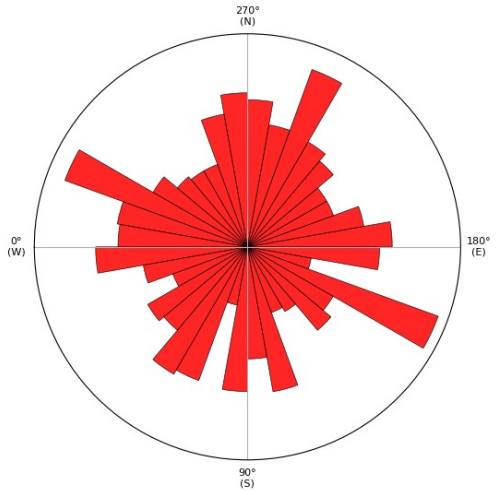












Null Hypotheses

- Street-network orientation entropy has no relationship with mean wind speed and turbulence levels
- Classical bulk morphological parameters* are sufficient predictors of urban wind speed and turbulence levels.

*Plan area density (λ_p), Frontal area density (λ_f), Mean Building Height ($\overline{H}_b$)

In this talk, all results pertain to 10m above ground

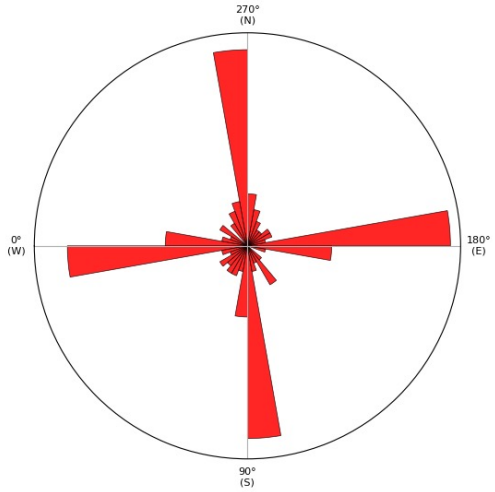
Methodology

$$S_\theta = -\sum_{i=1}^{N} p_i \ln p_i$$

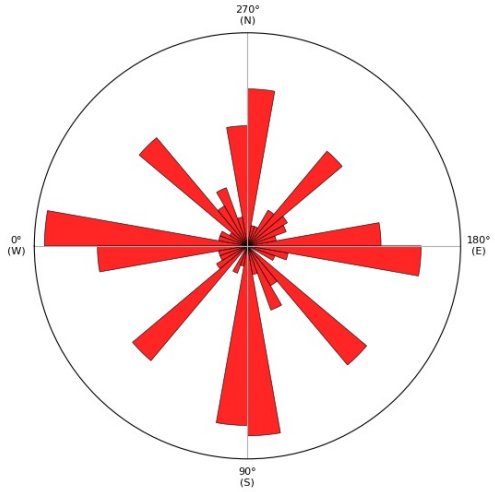
$$S_\theta^{min} = 0.693$$

$$S_\theta^{max} = 3.580$$

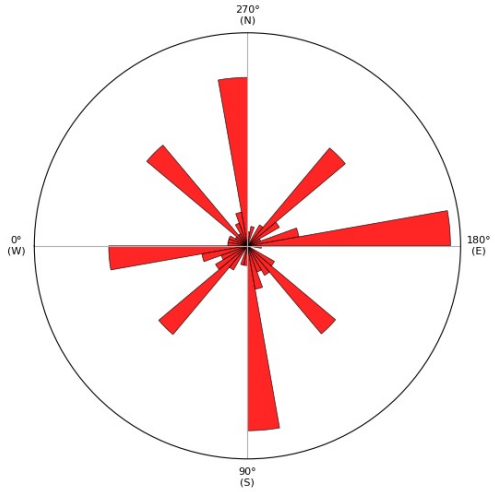
Chicago | S_θ =2.023



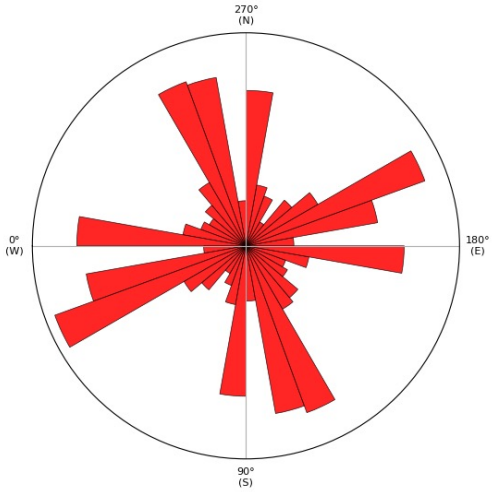
Denver | S_θ =2.545



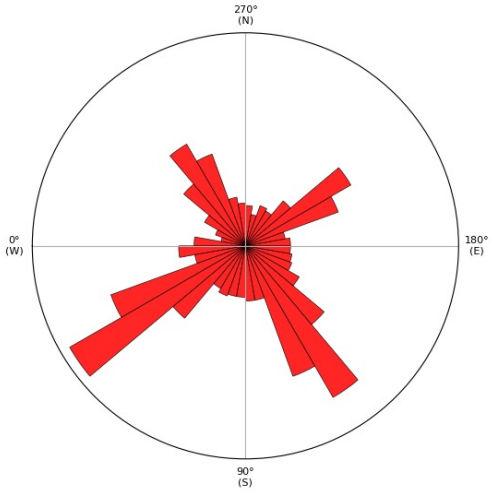
San Francisco | S_θ =2.461



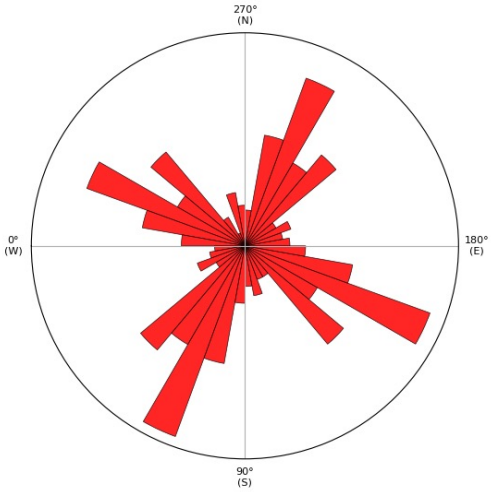
Melbourne | S_θ =2.795



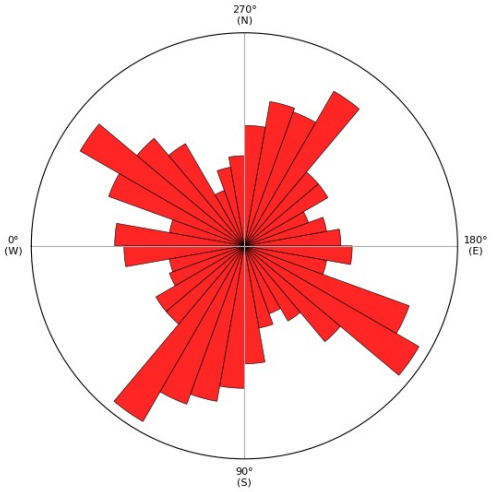
Den Haag | S_θ =3.063



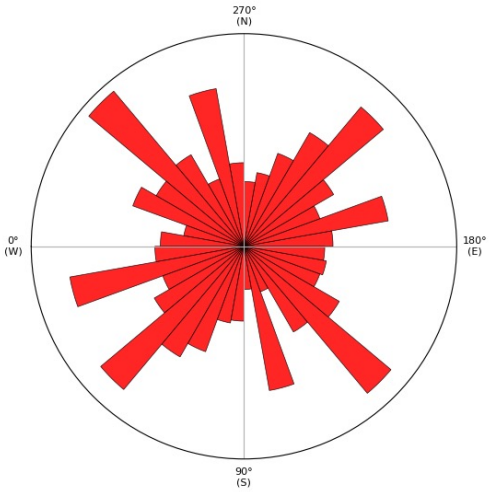
Tokyo | S_θ =3.117



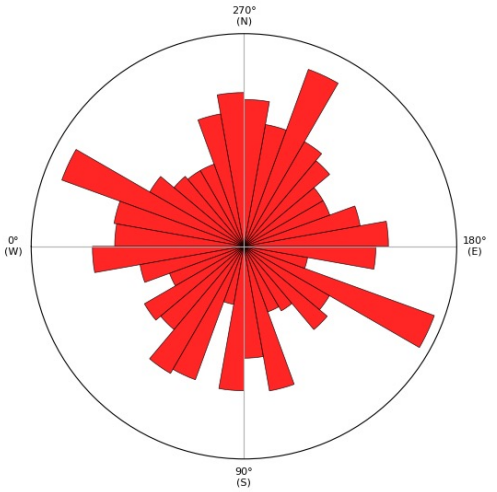
New York | S_θ =3.345



Barcelona | S_θ =3.372



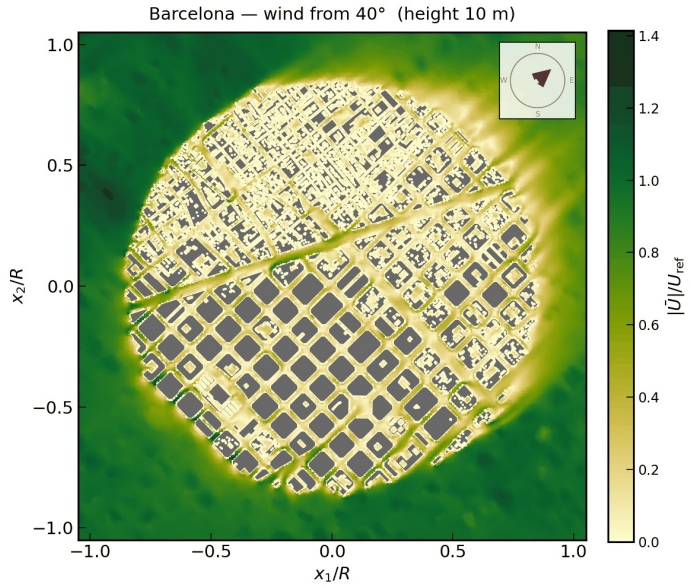
Paris | S_θ =3.448

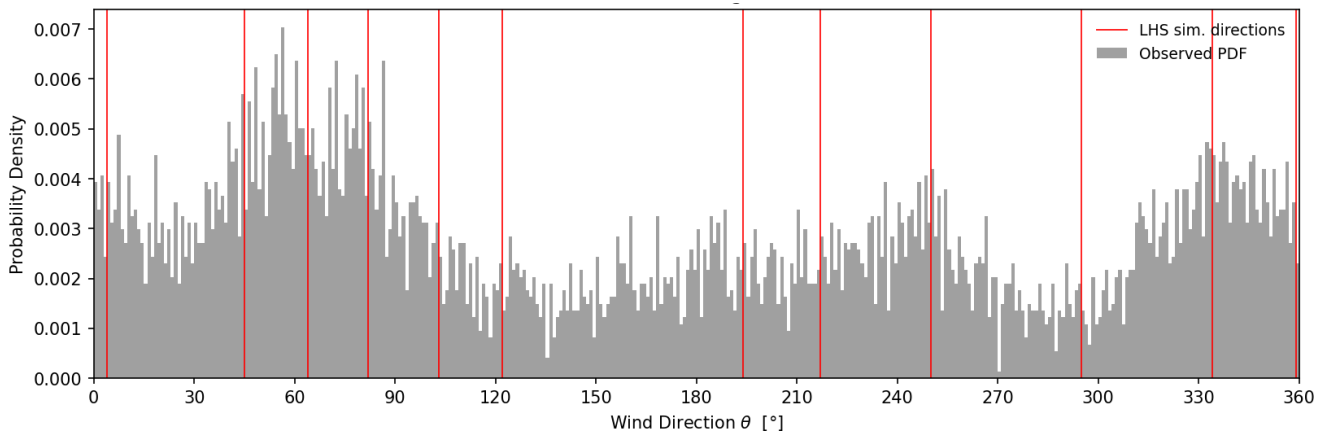


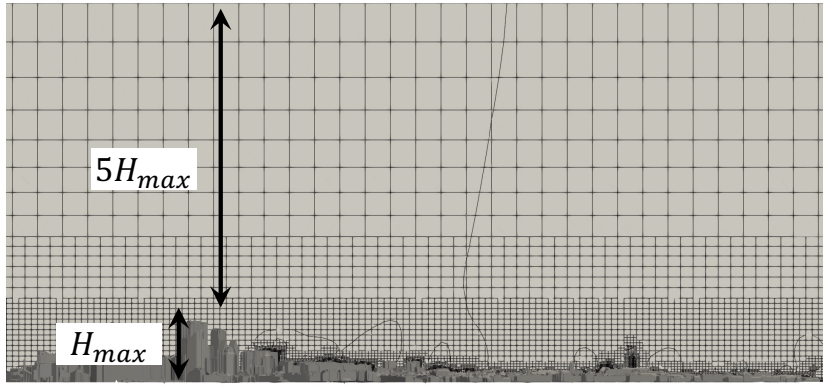
Methodology

Steady-State RANS equations – Finite Volume + SIMPLE

- Two-equation closure (K-Epsilon)
- Best Practice Guidelines (Franke et al., 2011; Blocken, 2015)
- Neutral Boundary Layer simulations
- Latin Hypercube Sampling - Wind Directions

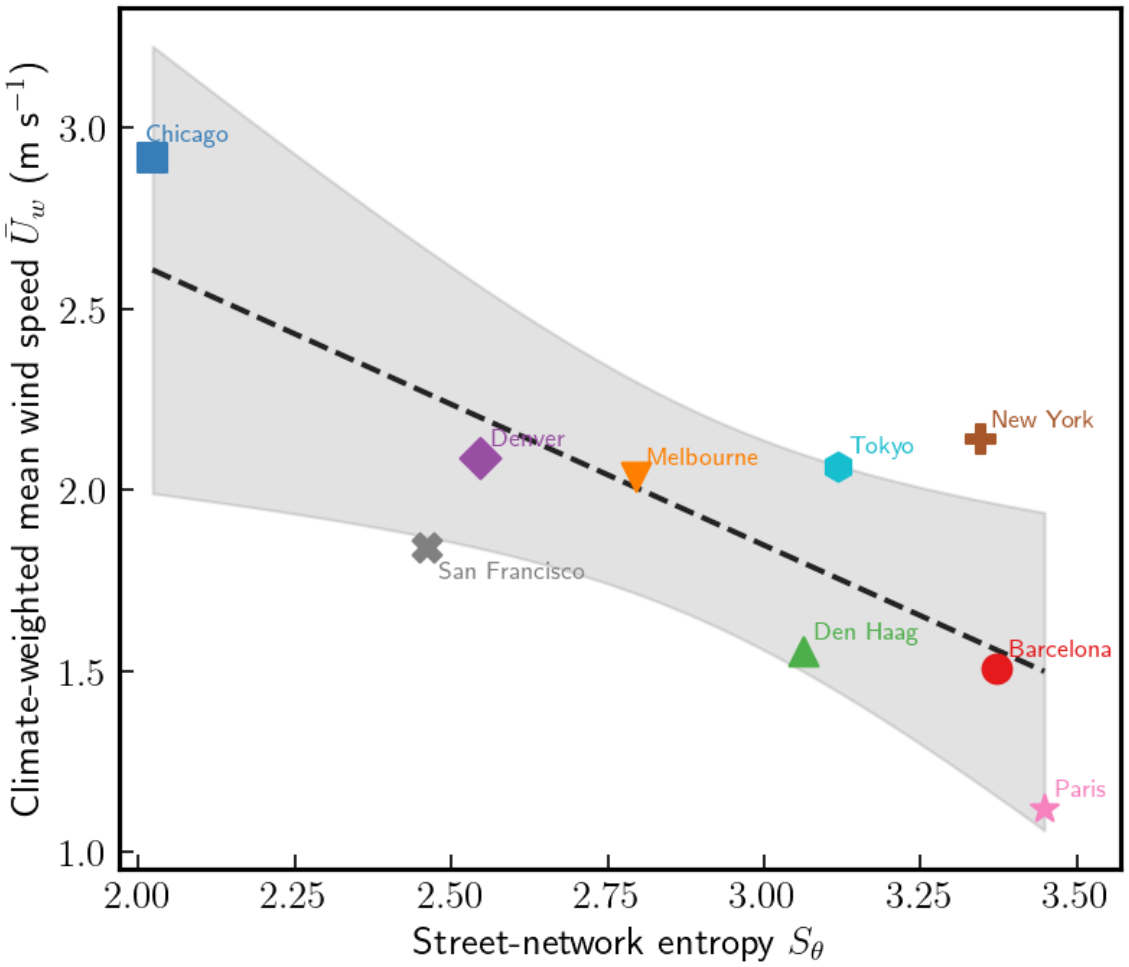


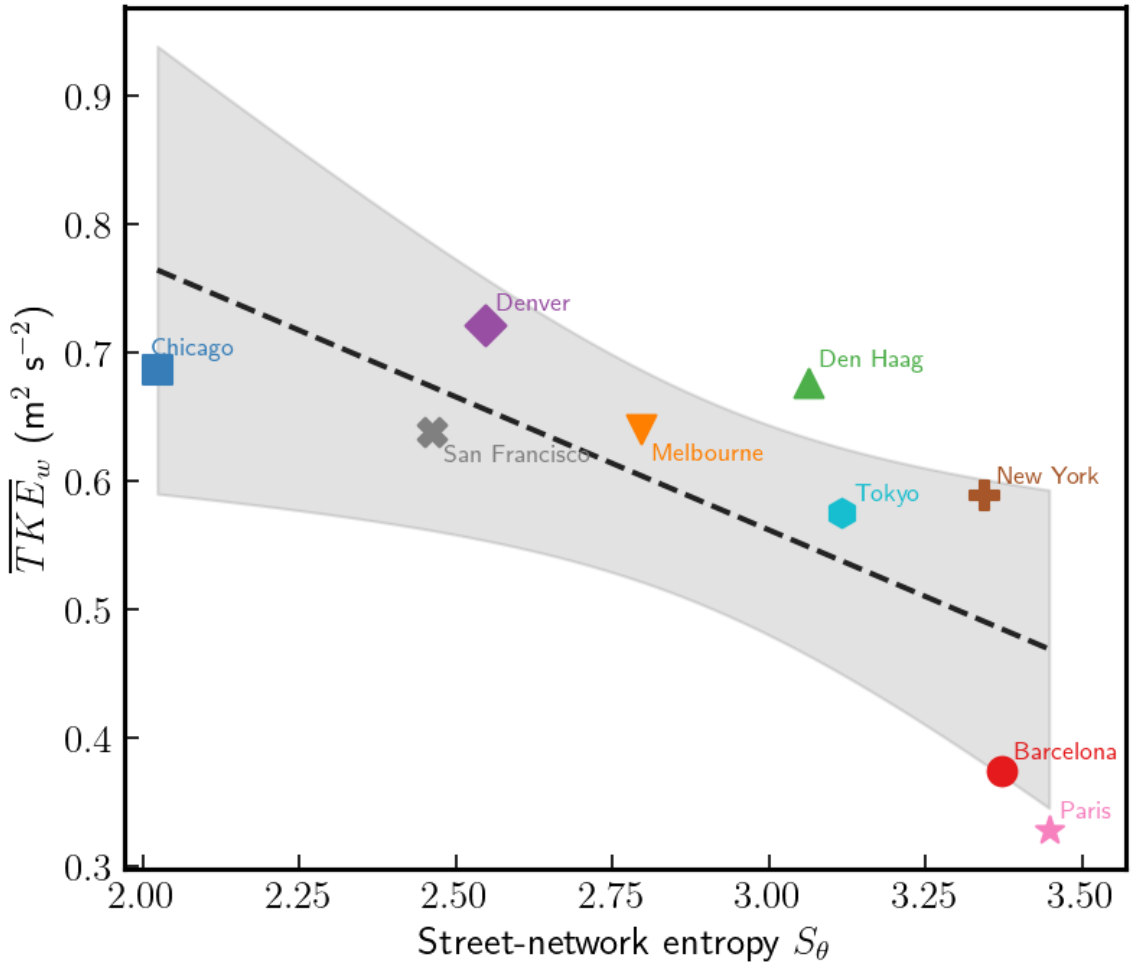




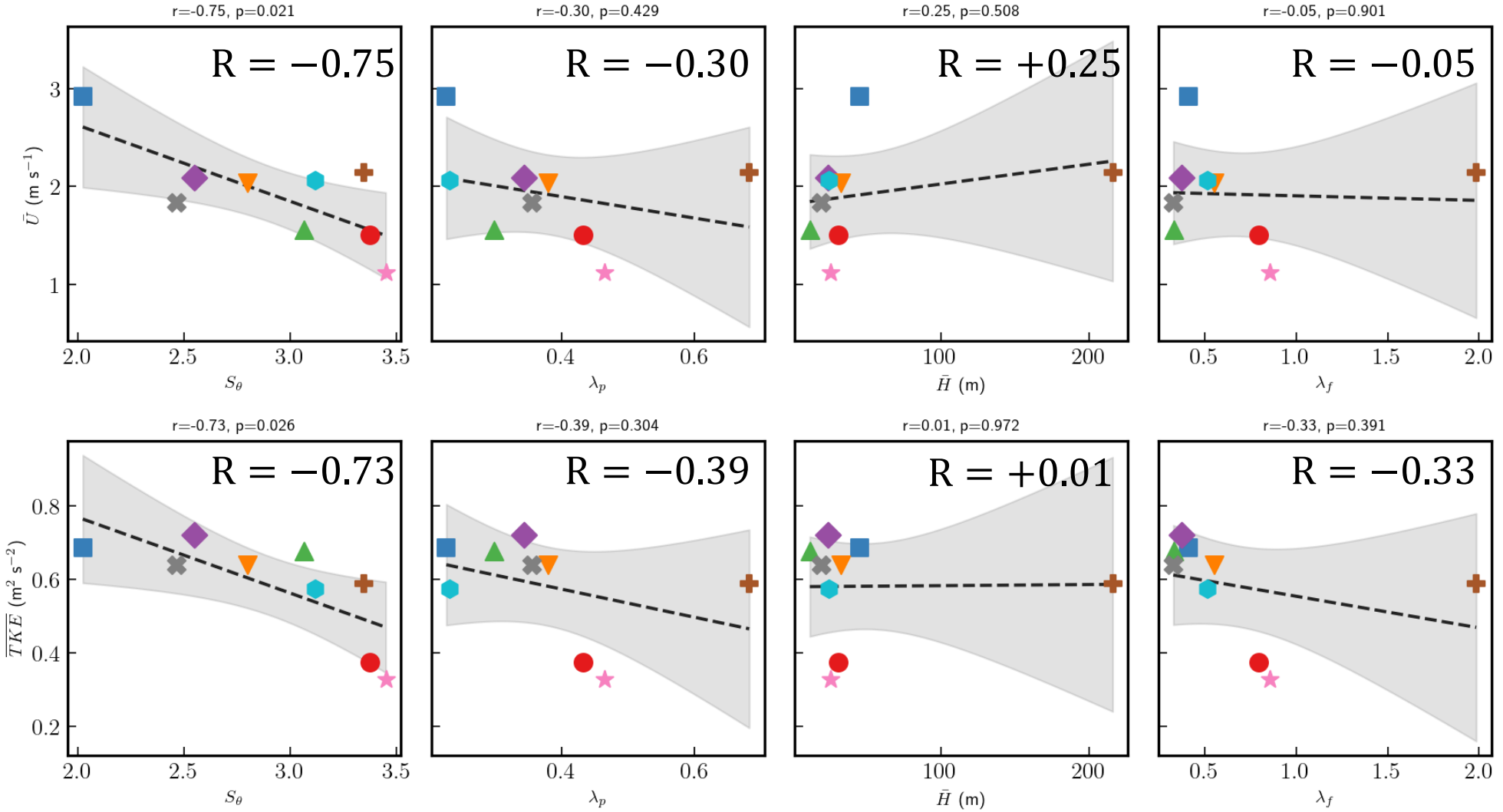
Geometry Generation – City4CFD (Pađen et al. 2022)

Street-network orientation entropy has no relationship with mean wind speed and turbulence levels

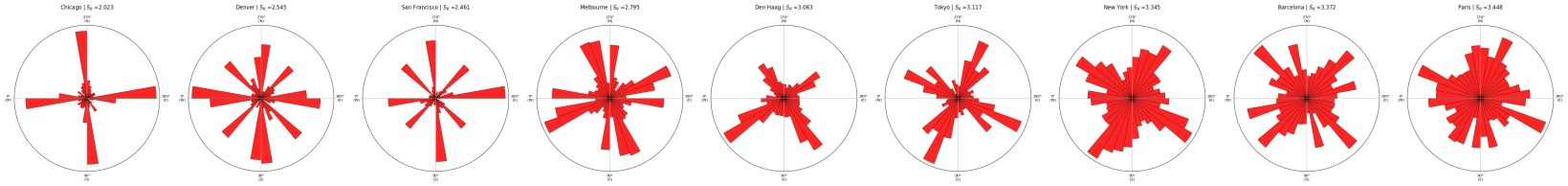




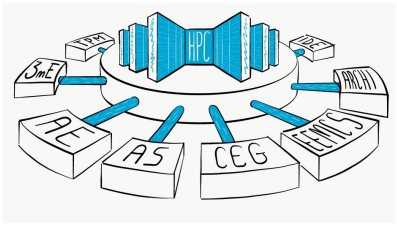
Classical bulk morphological parameters* are sufficient predictors of urban wind speed and turbulence levels.



Key Points

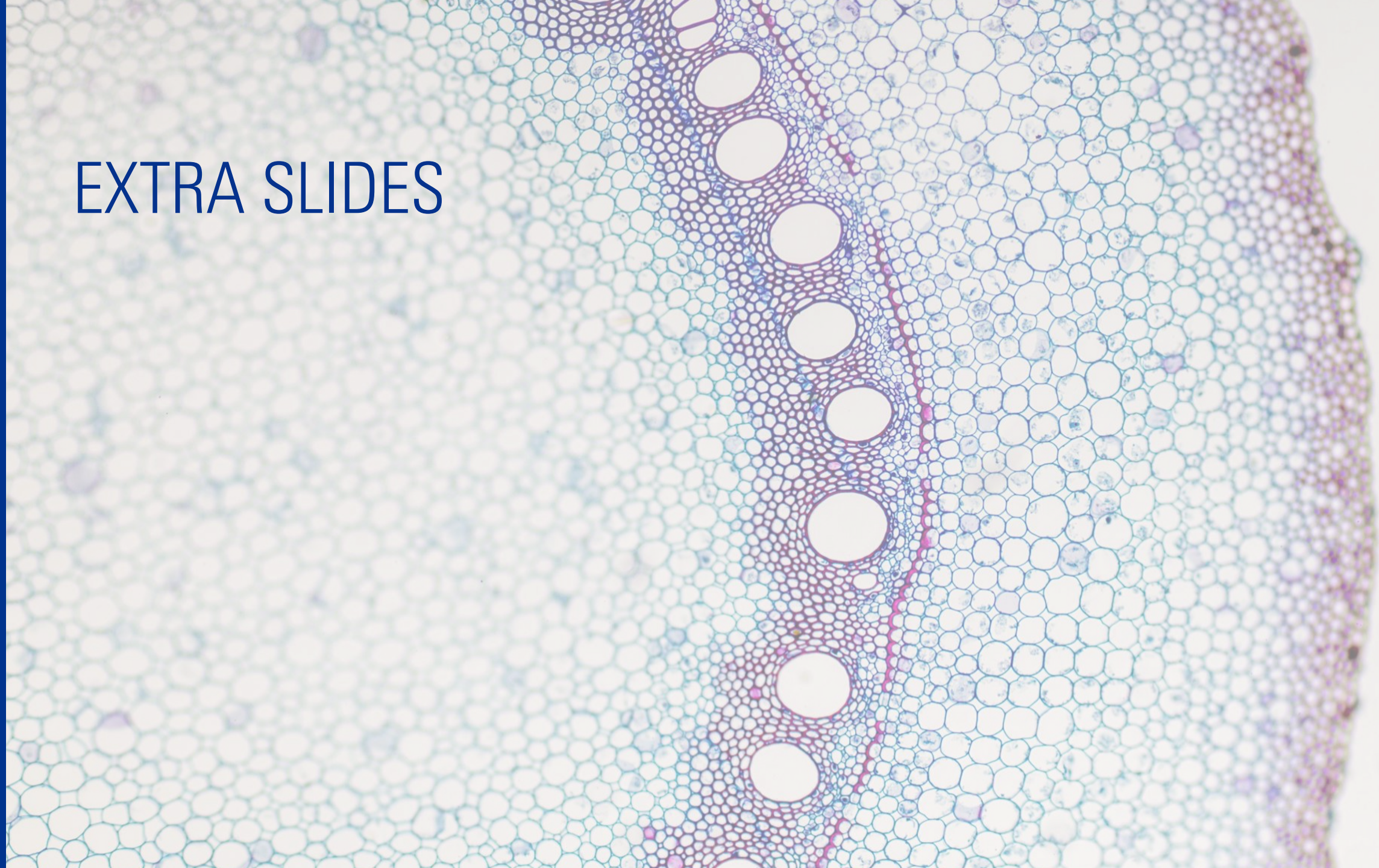


- Street Network Orientation Entropy explains 56% of the total variance in wind speed and turbulence levels (R = -0.75)
- Street Network Orientation Entropy outperforms parameters typically used in wind engineering studies by a factor ~ 5

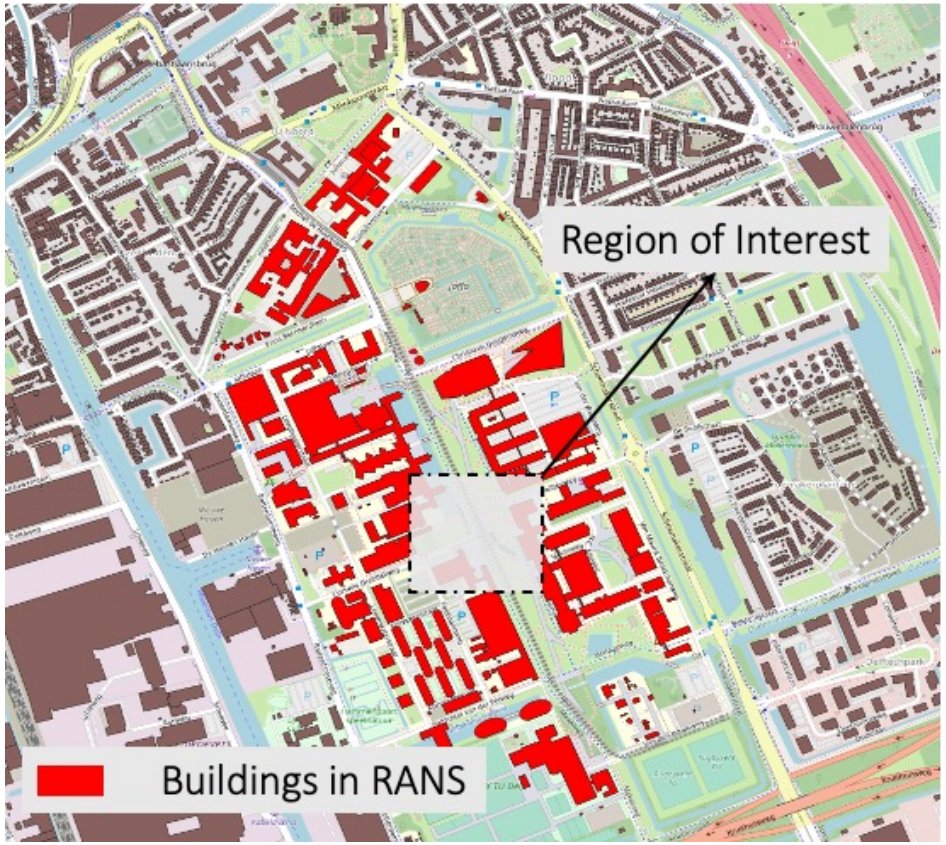


Funded by the European Union under Grant Agreement number 101188131 and made use of the Dutch national e-infrastructure with the support of the SURF Cooperative supplemented by the Dutch Research Council (NWO) "Multi-fidelity computational modelling of environmental fluid systems" with grant number 2024/ENW/01763969.

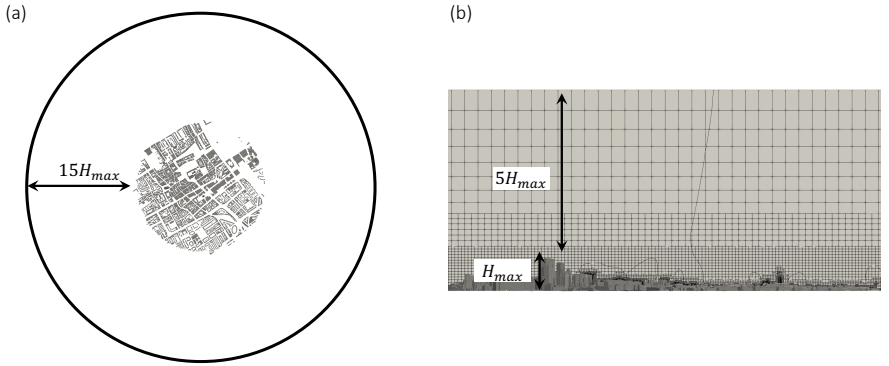
EXTRA SLIDES



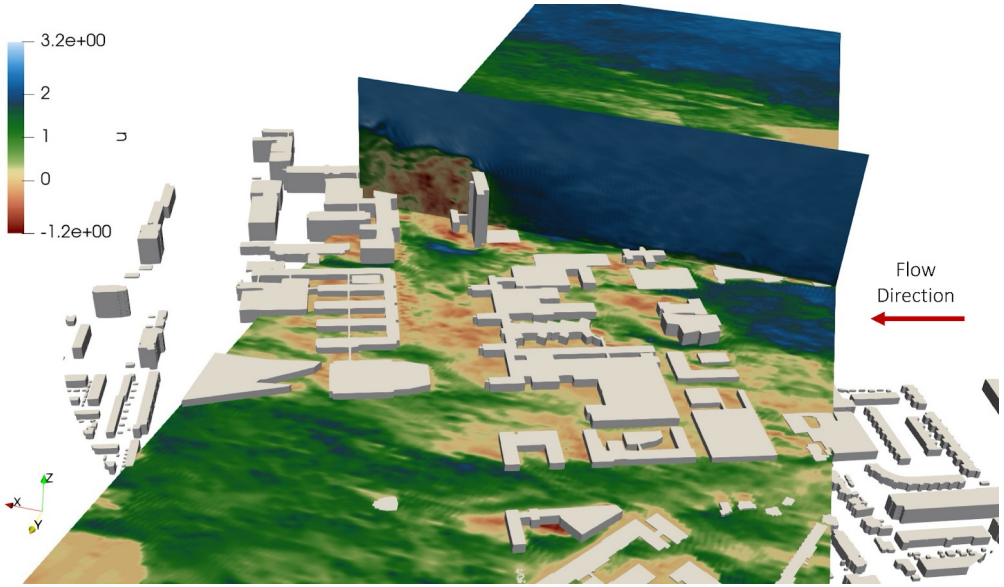
RANS – Error Quantification/Validation

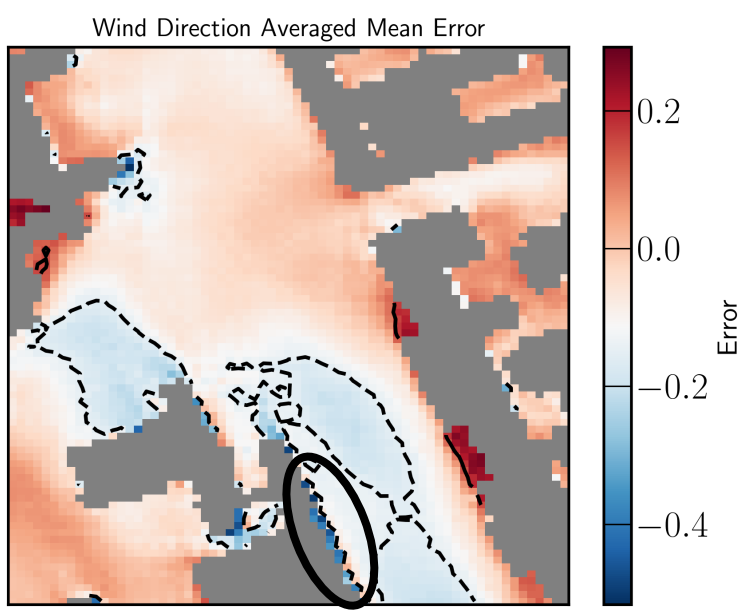


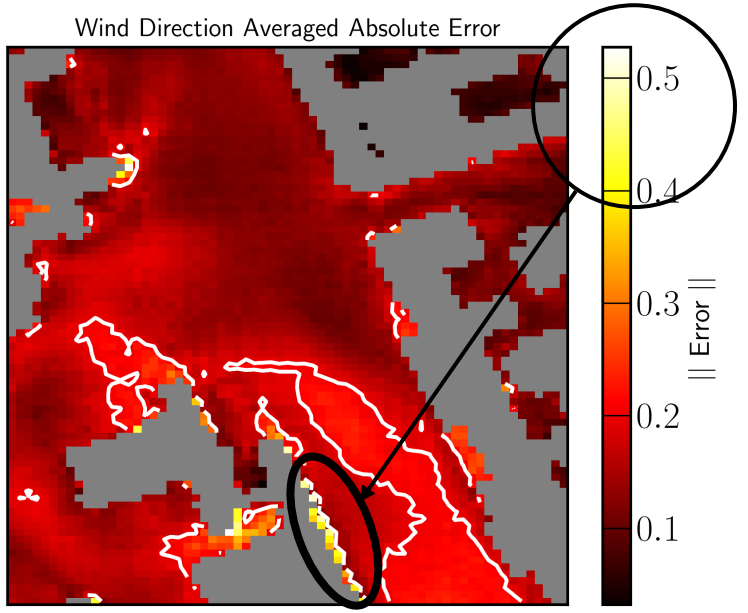
Low-Fidelity (RANS)

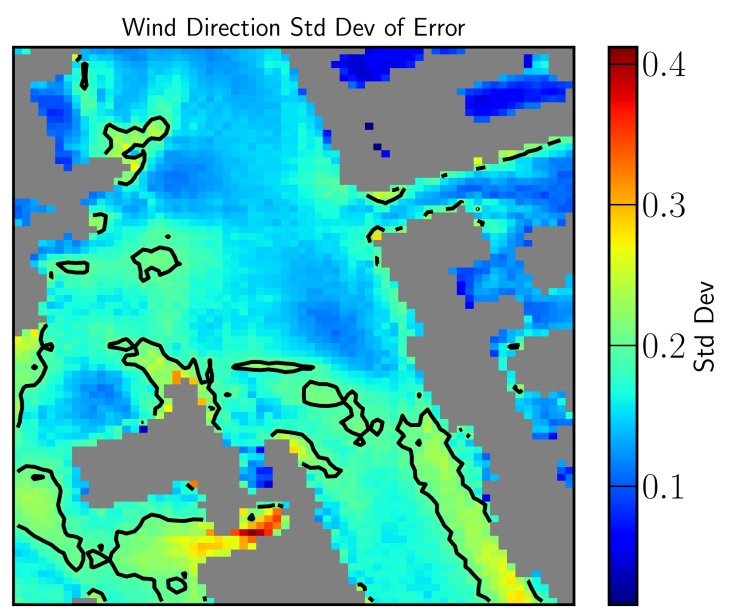


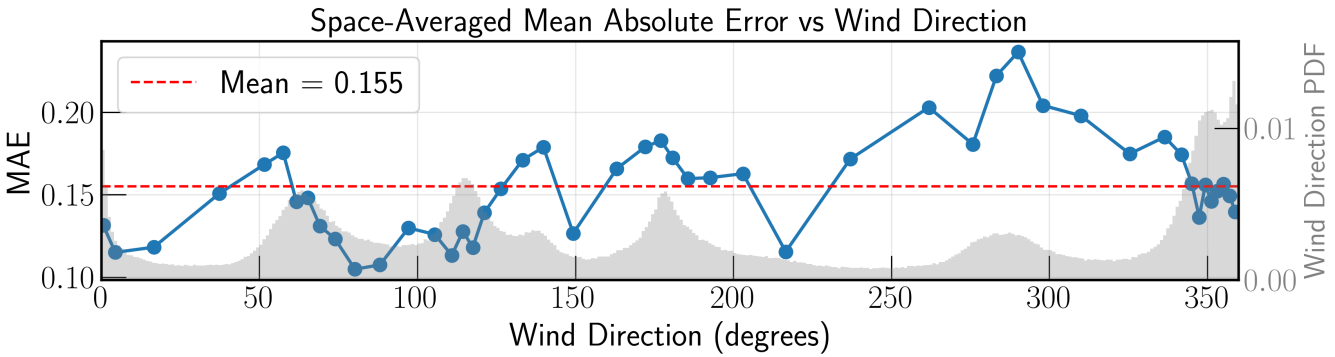
High-Fidelity (LES)

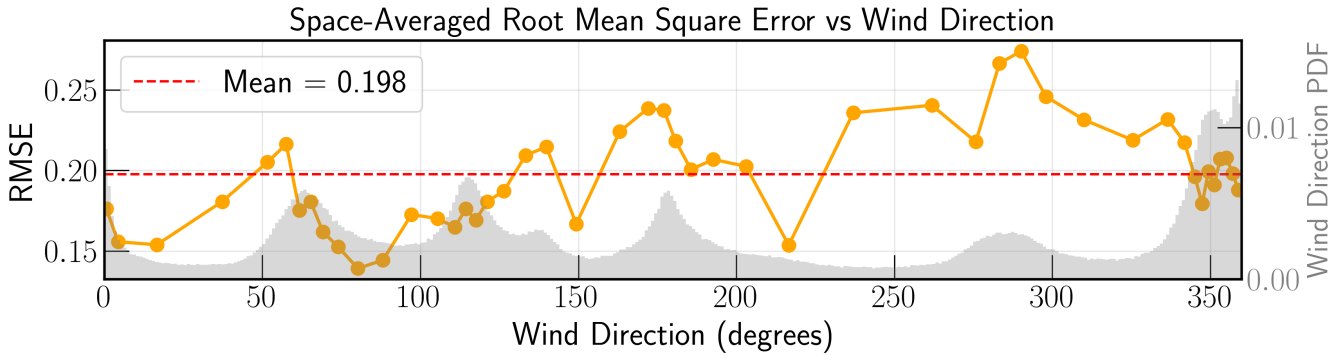


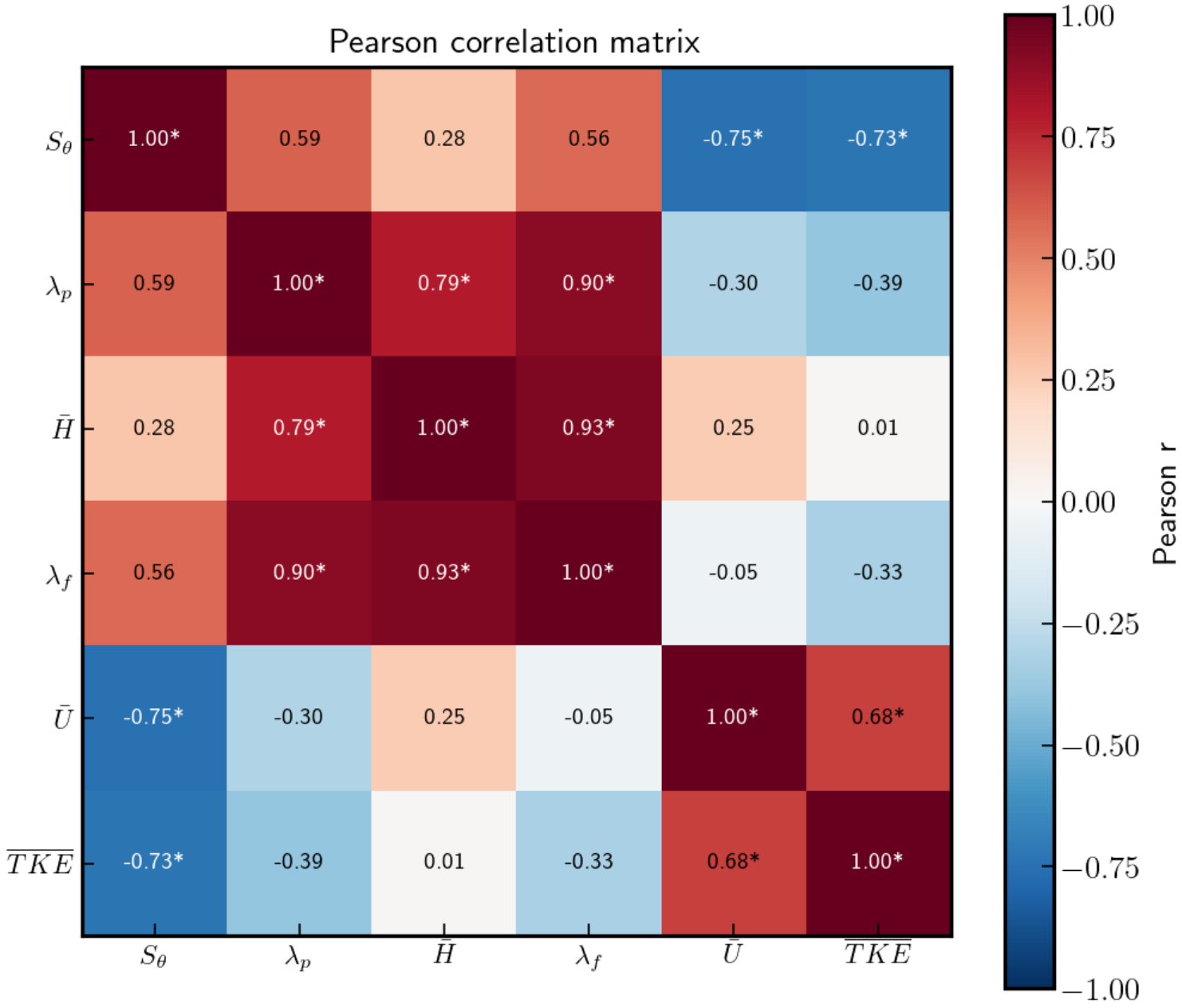

Wind Direction Averaged Mean Error
0.2
0.0
−0.2
−0.4
Error

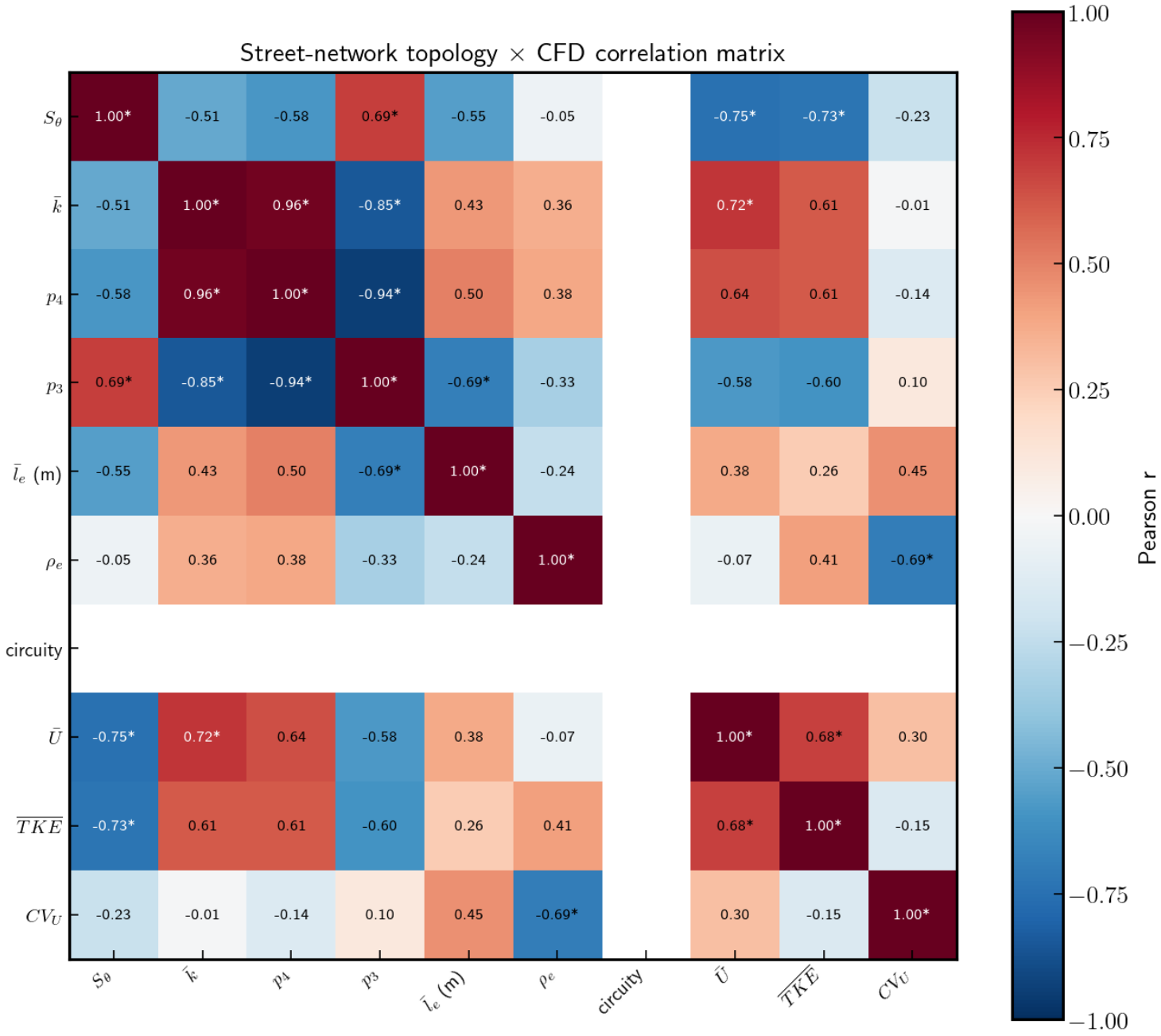

Wind Direction Averaged Absolute Error
0.5
0.4
0.3
0.2
0.1
|| Error ||

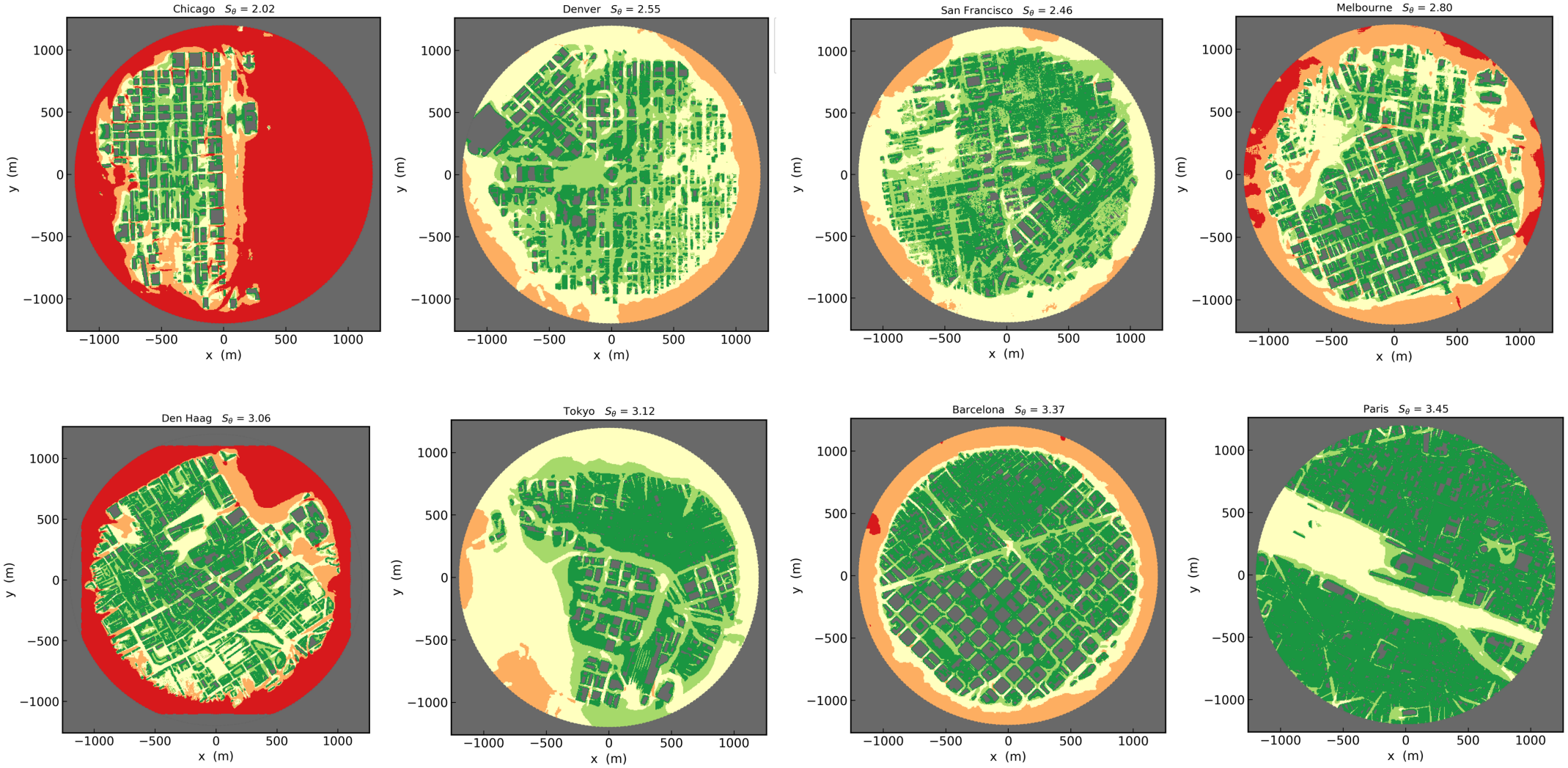

Wind Direction Std Dev of Error
0.4
0.3
0.2
0.1
Std Dev

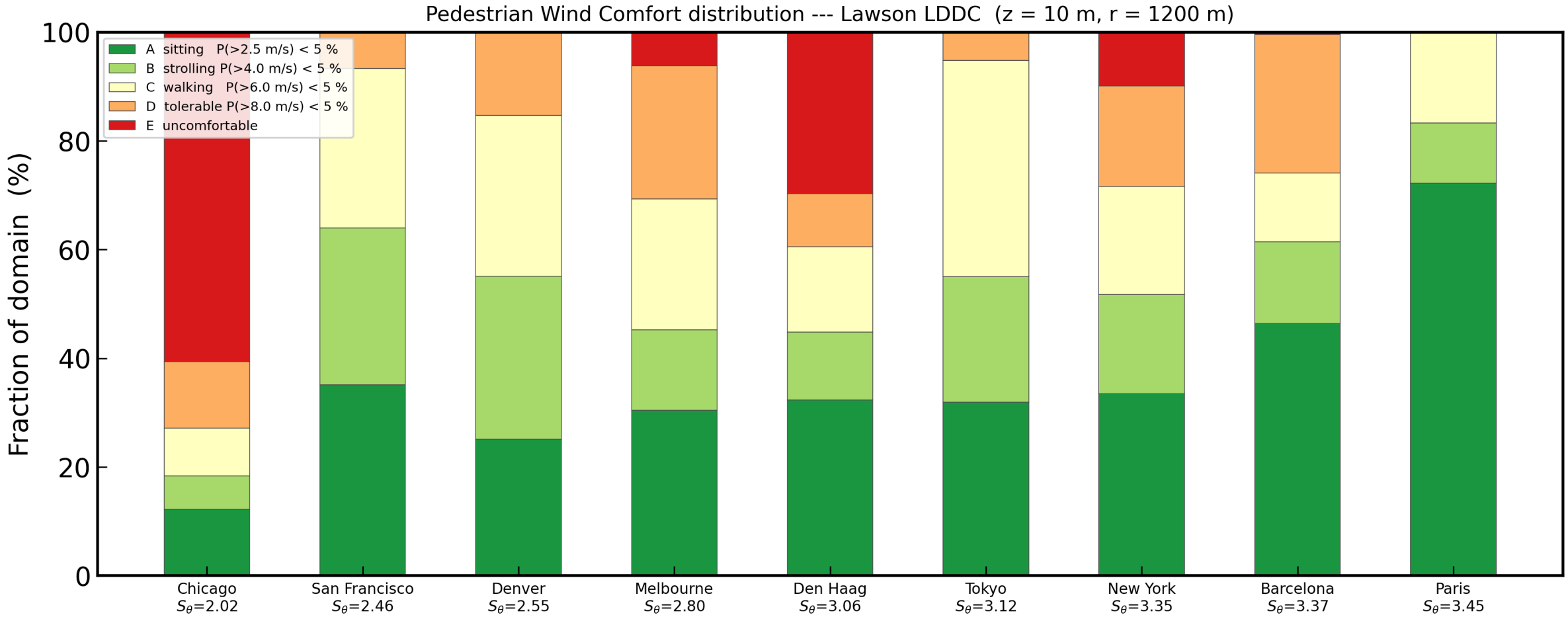

Space-Averaged Mean Absolute Error vs Wind Direction
Mean = 0.155
MAE
0.20
0.15
0.10
0
50
100
150
200
250
300
350
Wind Direction (degrees)
0.01
0.00
Wind Direction PDF


Space-Averaged Root Mean Square Error vs Wind Direction
Mean = 0.198
RMSE
0.25
0.20
0.15
0
50
100
150
200
250
300
350
Wind Direction (degrees)
0.01
0.00
Wind Direction PDF


Pearson correlation matrix
S_θ
λ_p
$\bar{H}$
λ_f
$\bar{U}$
$\overline{TKE}$
1.00* 0.59 0.28 0.56 -0.75* -0.73*
0.59 1.00* 0.79* 0.90* -0.30 -0.39
0.28 0.79* 1.00* 0.93* 0.25 0.01
0.56 0.90* 0.93* 1.00* -0.05 -0.33
-0.75* -0.30 0.25 -0.05 1.00* 0.68*
-0.73* -0.39 0.01 -0.33 0.68* 1.00*
S_θ λ_p $\bar{H}$ λ_f $\bar{U}$ $\overline{TKE}$
Pearson r
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00


Street-network topology × CFD correlation matrix
S_θ 1.00* -0.51 -0.58 0.69* -0.55 -0.05 -0.75* -0.73* -0.23
$\bar{k}$ -0.51 1.00* 0.96* -0.85* 0.43 0.36 0.72* 0.61 -0.01
p_4 -0.58 0.96* 1.00* -0.94* 0.50 0.38 0.64 0.61 -0.14
p_3 0.69* -0.85* -0.94* 1.00* -0.69* -0.33 -0.58 -0.60 0.10
$\bar{l}_e$ (m) -0.55 0.43 0.50 -0.69* 1.00* -0.24 0.38 0.26 0.45
ρ_e -0.05 0.36 0.38 -0.33 -0.24 1.00* -0.07 0.41 -0.69*
circuity
$\bar{U}$ -0.75* 0.72* 0.64 -0.58 0.38 -0.07 1.00* 0.68* 0.30
$\overline{TKE}$ -0.73* 0.61 0.61 -0.60 0.26 0.41 0.68* 1.00* -0.15
CV_U -0.23 -0.01 -0.14 0.10 0.45 -0.69* 0.30 -0.15 1.00*
S_θ $\bar{k}$ p_4 p_3 $\bar{l}_e$ (m) ρ_e circuity $\bar{U}$ $\overline{TKE}$ CV_U
Pearson r
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00


Chicago S_θ = 2.02
Denver S_θ = 2.55
San Francisco S_θ = 2.46
Melbourne S_θ = 2.80
Den Haag S_θ = 3.06
Tokyo S_θ = 3.12
Barcelona S_θ = 3.37
Paris S_θ = 3.45
x (m)
y (m)
−1000
−500
0
500
1000


Pedestrian Wind Comfort distribution --- Lawson LDDC (z = 10 m, r = 1200 m)
A sitting P(>2.5 m/s) < 5 %
B strolling P(>4.0 m/s) < 5 %
C walking P(>6.0 m/s) < 5 %
D tolerable P(>8.0 m/s) < 5 %
E uncomfortable
Fraction of domain (%)
0
20
40
60
80
100
Chicago
S_θ=2.02
San Francisco
S_θ=2.46
Denver
S_θ=2.55
Melbourne
S_θ=2.80
Den Haag
S_θ=3.06
Tokyo
S_θ=3.12
New York
S_θ=3.35
Barcelona
S_θ=3.37
Paris
S_θ=3.45