Energy & Resources Research Institute (ERRI)

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THE SENSITIVITY OF A 3D STREET CANYON CFD MODEL TO UNCERTAINTIES IN INPUT PARAMETERS

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Motivation

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- Predicting dispersion of a pollutant accurately requires information about flow and turbulence.
- CFD models increasingly used for this in urban studies.
  - Individual buildings resolved.
  - 3D flow structures are predicted.
  - Adaptable to any layout of buildings.
- Currently lack of information on computational fluid dynamic (CFD) model sensitivity/ uncertainty.
- Need to:
  - Determine the effect of uncertain input parameters.
  - Improve confidence in air pollution models.
  - Provide information to help develop pollution modelling system.
- Require suitable sensitivity and uncertainty analysis techniques.

Case Study

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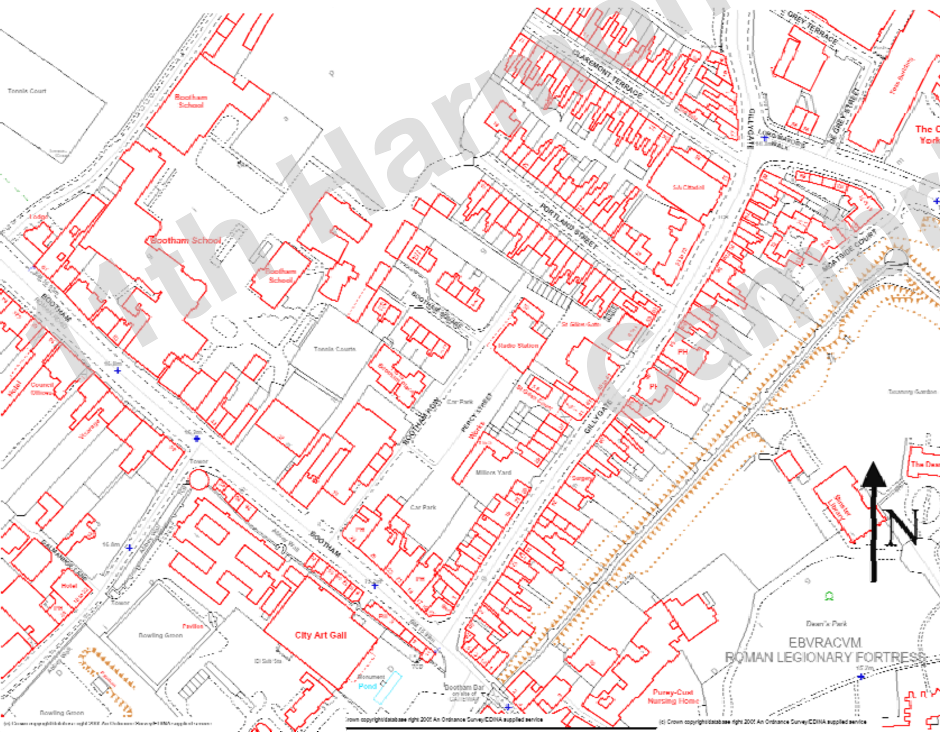
- Gillygate, York, UK.
- Typical street canyon. H/W ≈0.8.
- Site of extensive experimental campaign (Boddy et al. 2005).
- Experimental results allow comparison/ validation of CFD model.



Model

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- Model is CFD *k-ε* turbulent flow model MISKAM v4.21 (Eichorn, 1996).
- Used as an operation model (Lohmeyer et al., 2000).
- Interested in effects on predicted flow (*u, v, w* and mean wind speed, *U*) and turbulence (Turbulent Kinetic Energy - TKE) in street canyon.
- Uncertainties exist in input parameters including:
  - Background wind direction *θ.*
  - Surface and building roughness lengths.
  - Inflow surface roughness length (determines effect of upwind terrain on wind and turbulence profiles).

Model input parameters

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- Surface roughness length z_0, used in log-law of the wind.
  - Inflow, buildings and surface roughness lengths.

$$u = \frac{u_*}{\kappa} \ln\left(\frac{z + z_0}{z_0}\right)$$

u – horizontal wind velocity
u_*,- friction velocity
z – distance from surface
z_0 – surface roughness length
κ – Von Karman Constant

- Background wind direction θ:
  - To show the effect of misspecification when comparing to experimental results.

Input parameter ranges

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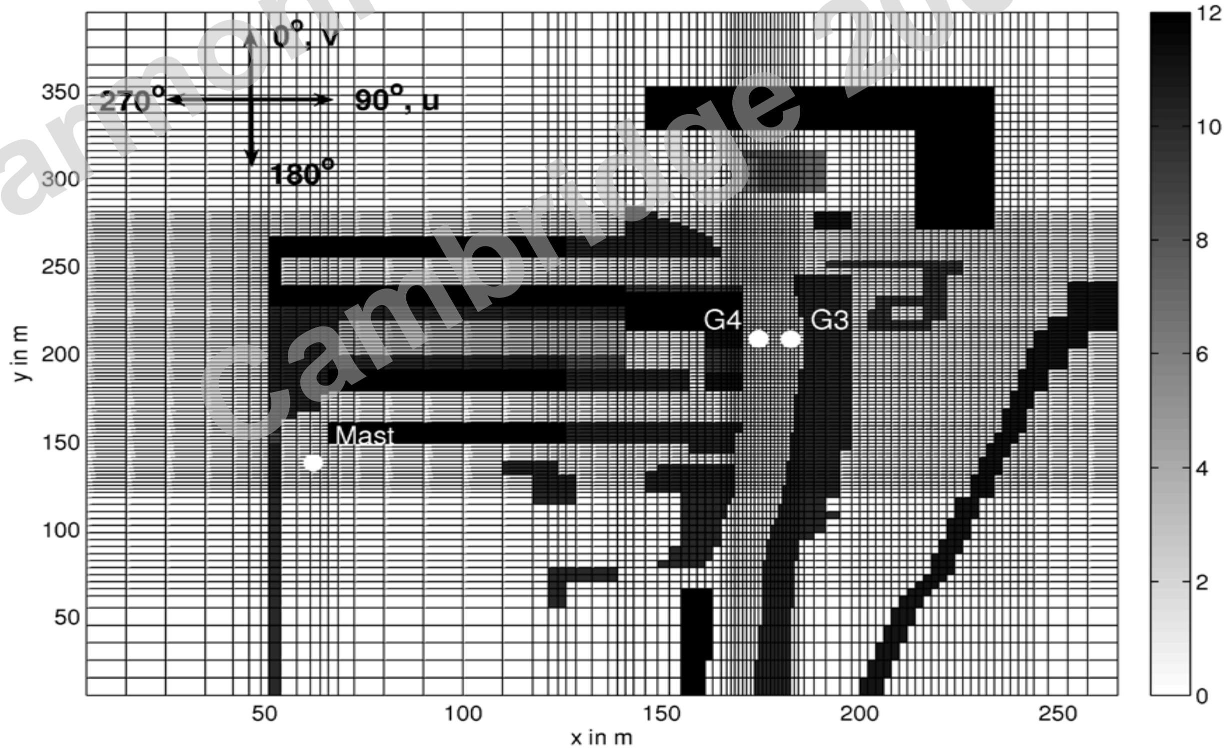
Input parameter	range
surface roughness length	0.5-50cm
building roughness length	0.5-10cm
inflow roughness length	5-50cm
background wind direction (θ)	$\theta \pm 10°$

- Uniform input parameter distributions.
- Ranges chosen based on model limitations and modellers experience.

Model domain grid setup

- Non-equidistant grid.
- Resolution 89 (270m) x 124 (400m) x 28 (100m) points.
- Measurement points at:
  - -G3 (183,211,5.5m), 2m from canyon wall.
  - -G4 (171,211,5.3m), 1m from canyon wall.



Sensitivity Techniques

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- Random Sampling Monte-Carlo (RS-MC) with regression analysis:

  -Pearson correlation coefficients.

  -Spearman ranked correlation coefficients.

- Random-Sampling High Dimensional Model Representation (RS-HDMR):

  -First order sensitivity indices (exact non-linear responses).

  -Second order sensitivity indices (details of interactions between parameters).

- Cross sectional sensitivity analysis of model domain (y=211m).

- Comparison to experimental results.

Sensitivity Techniques - 2

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- 10000 runs at each wind angle for stable output means and variance.
- Random sampling.
  - Input parameter limits and distributions defined.
  - Samples generated for each parameter from above limits.
  - Model run using input parameters from samples.
- HDMR is a more effective way of determining sensitivities for non-linear models.
  - Less model runs required (1024 runs) for more sensitivity information.
  - Details of method in Poster Session – *T. Ziehn and A. S. Tomlin - Efficient methods for assessing uncertainties and sensitivities in environmental models.*

Comparison of model results and experimental field results

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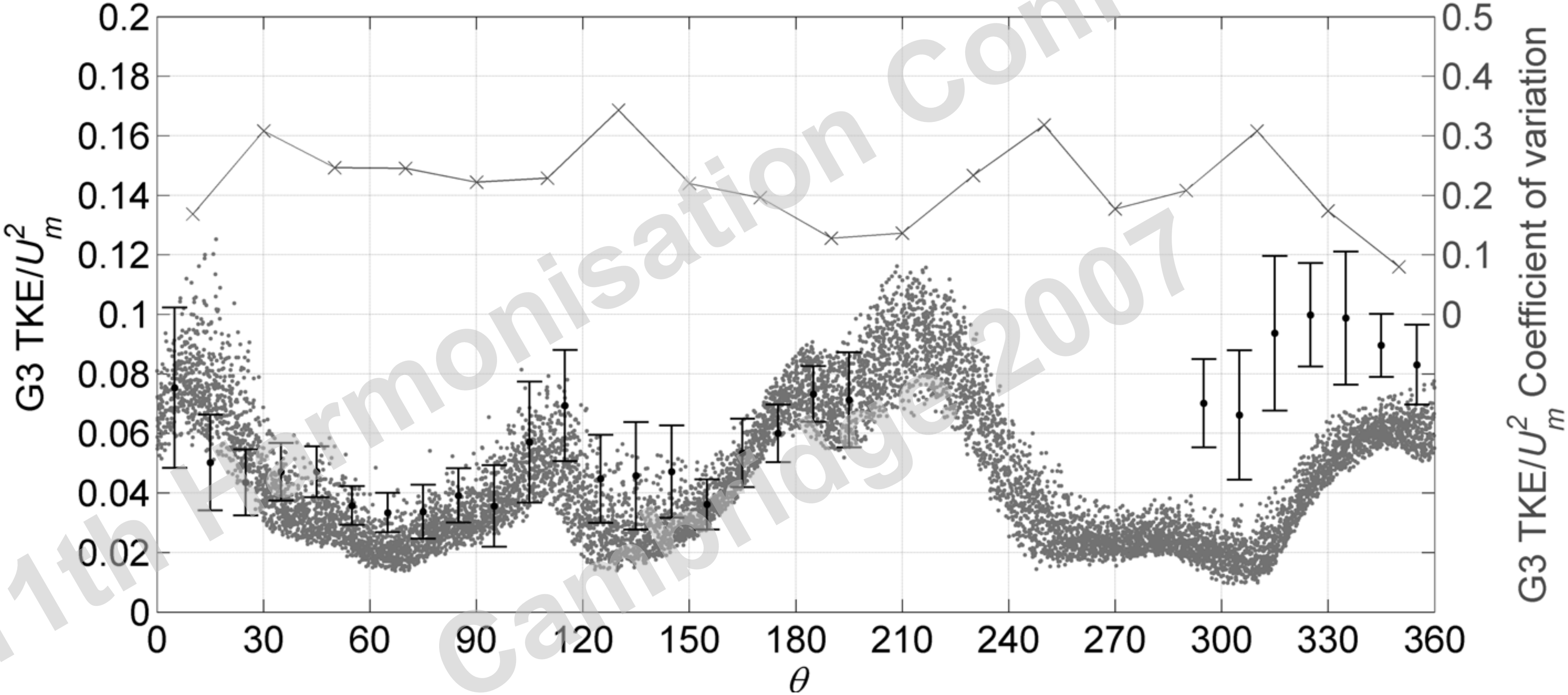

G3 TKE/U_m^2. Black circles: experimental 15 minute averages, grey dots: RS-MC model results. The error bars on the experimental data are 1 standard deviation from the mean. x - coefficient of variation for the model results.

Mean TKE model results for $\theta = 90\pm10°$

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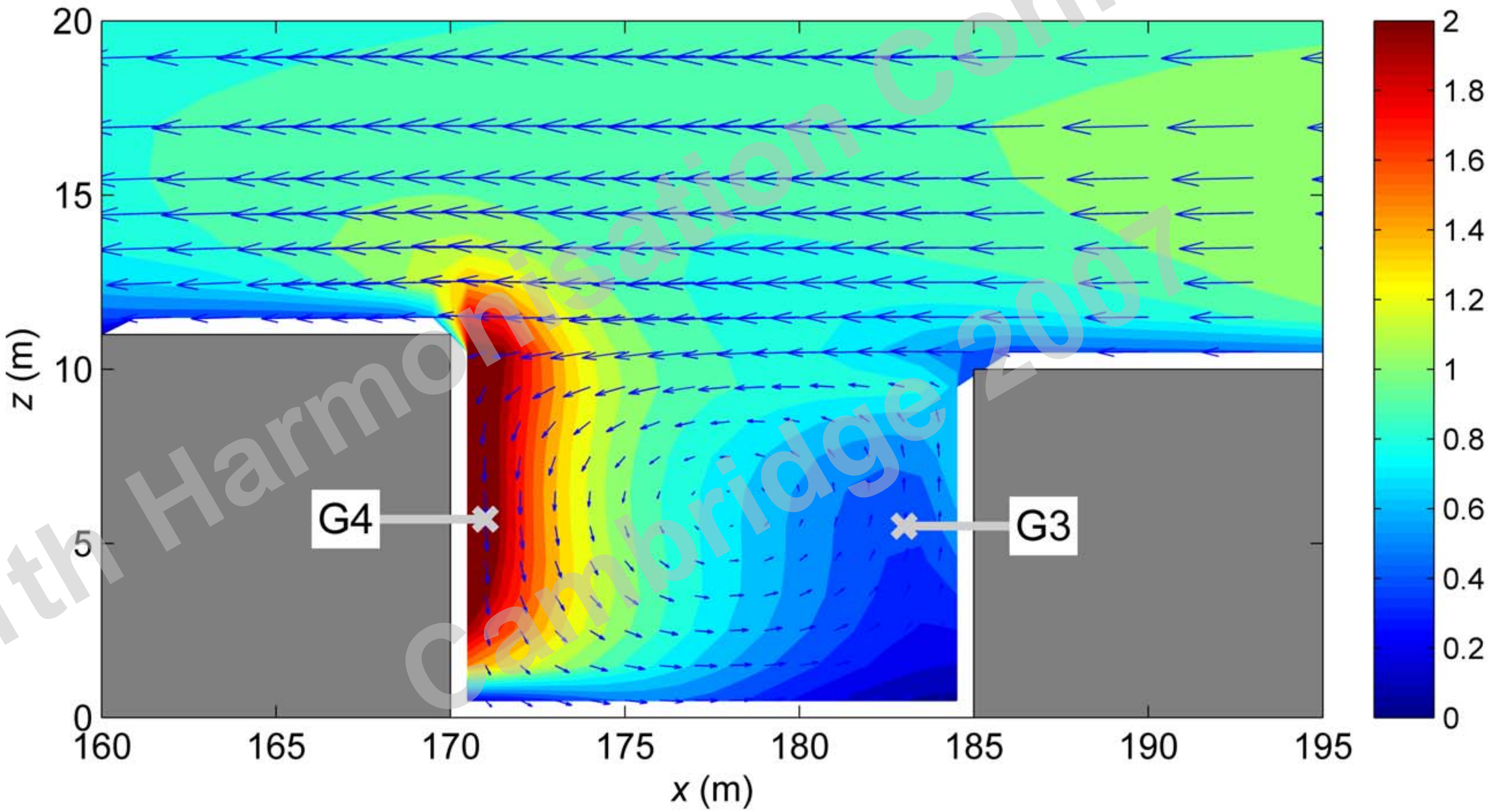

Canyon cross-section of mean TKE and *u*, *w* wind vectors for θ=90±10°

Measurement point sensitivity analysis results – G3 TKE at θ=90±10°

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Sensitivity method	Pearson correlations		Spearman Ranked correlations		HDMR first order
	r	r^2	r_{sp}	r_{sp}^2	S_i
surface roughness	-0.5578	0.3112	-0.5690	0.3238	0.4258
building roughness	-0.3091	0.0955	-0.2803	0.0786	0.1154
inflow roughness	0.5131	0.2632	0.5542	0.3071	0.2533
wind direction (θ)	0.3689	0.1361	0.3643	0.1327	0.1610
total		0.8060		0.8422	0.9555

Sensitivity of mean TKE at G3 to each parameter given by Pearson and Spearman Ranked Correlation coefficients and RS-HDMR first order sensitivity indices for θ=90±10°.

HDMR first order component function for G3 TKE at θ=90±10°

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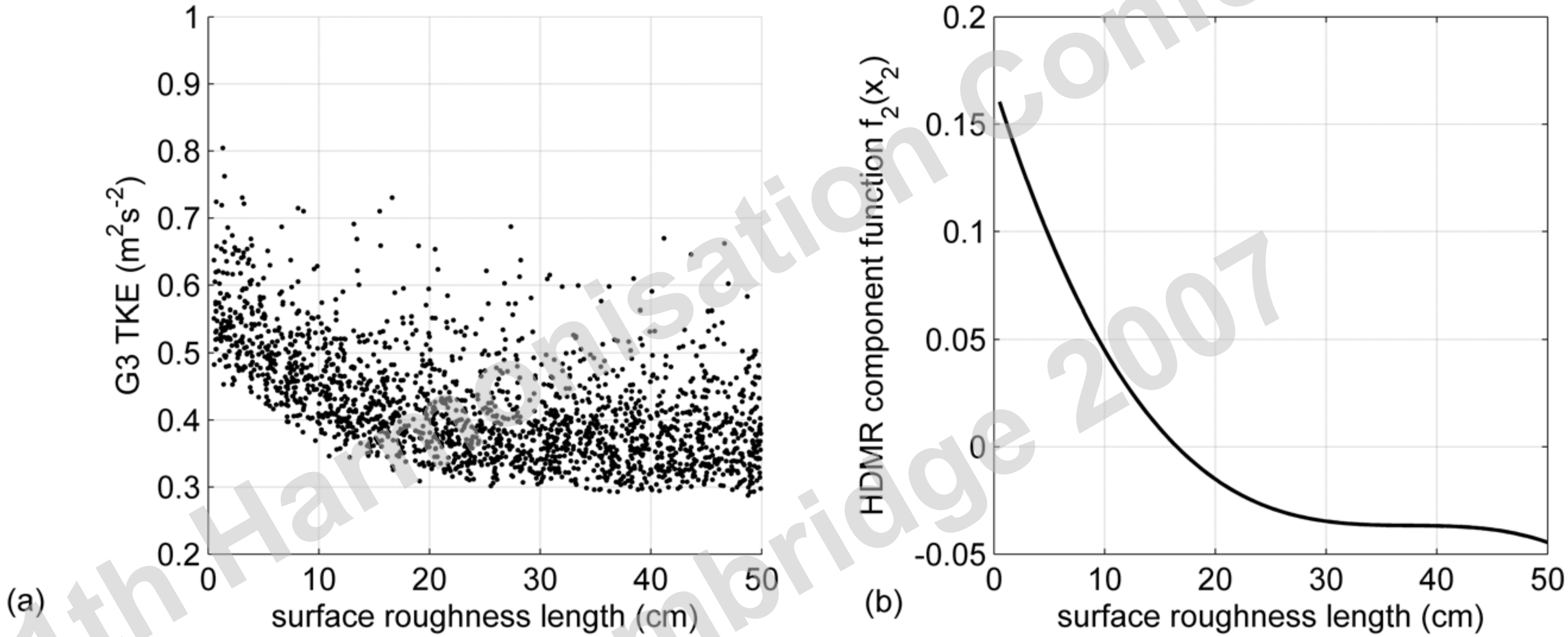

Scatter plot (a) and RS-HDMR component function (b) for surface roughness length and un-normalised TKE at G3 for θ = 90±10°.

Cross section of TKE sensitivity at θ=90±10°

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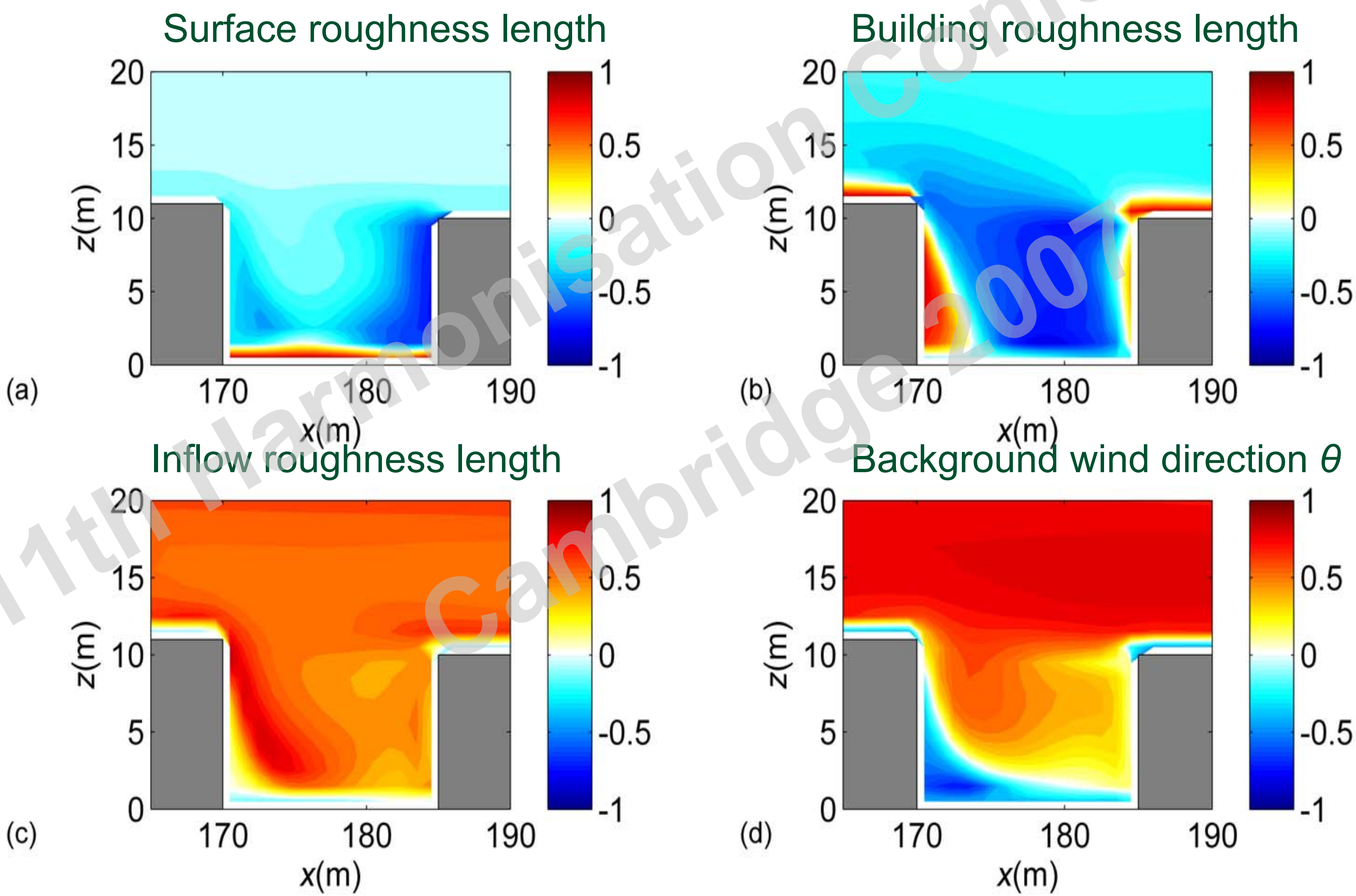

Cross section of U sensitivity at $\theta=90\pm10°$

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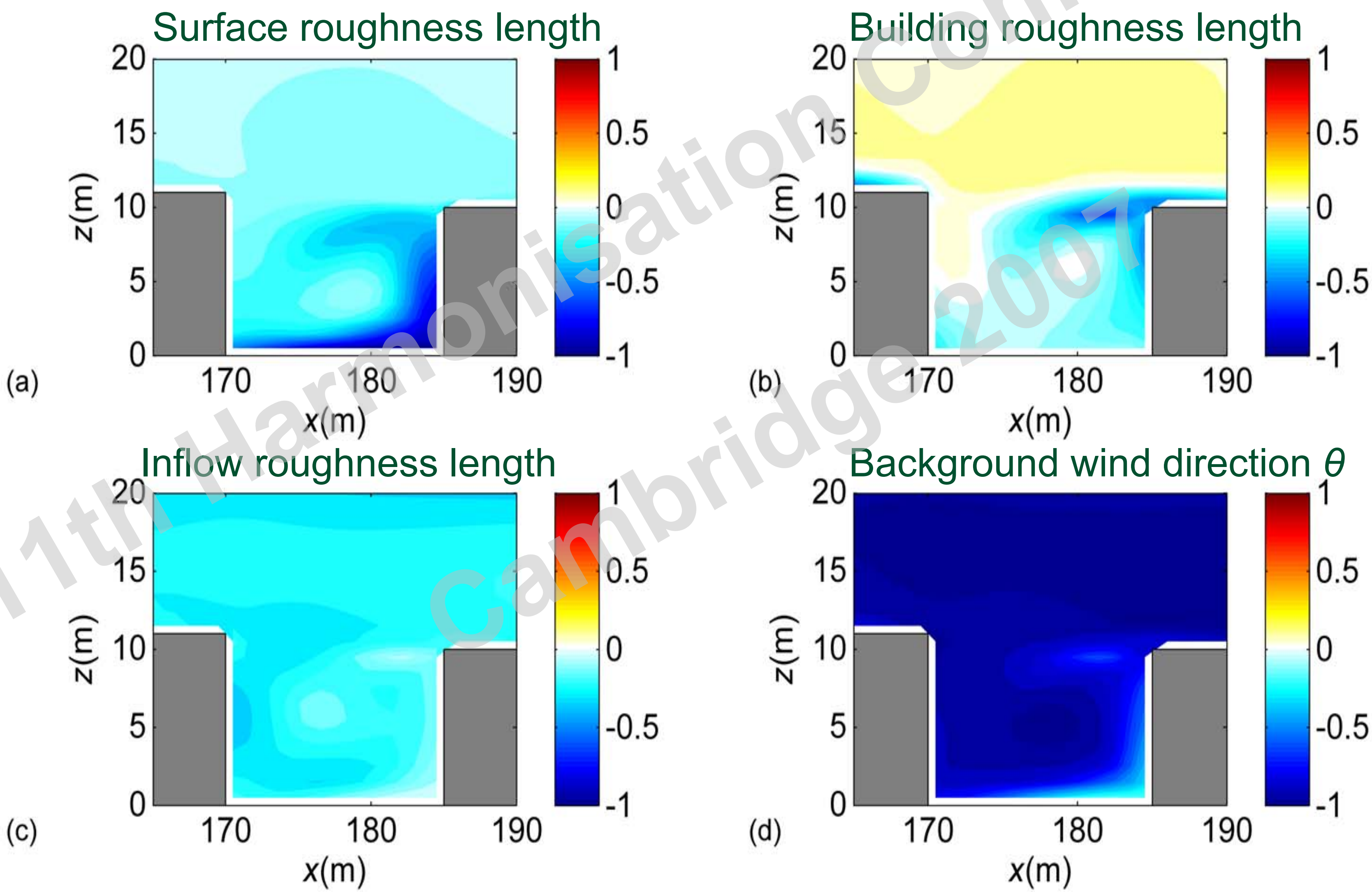

Sensitivity across all wind angles

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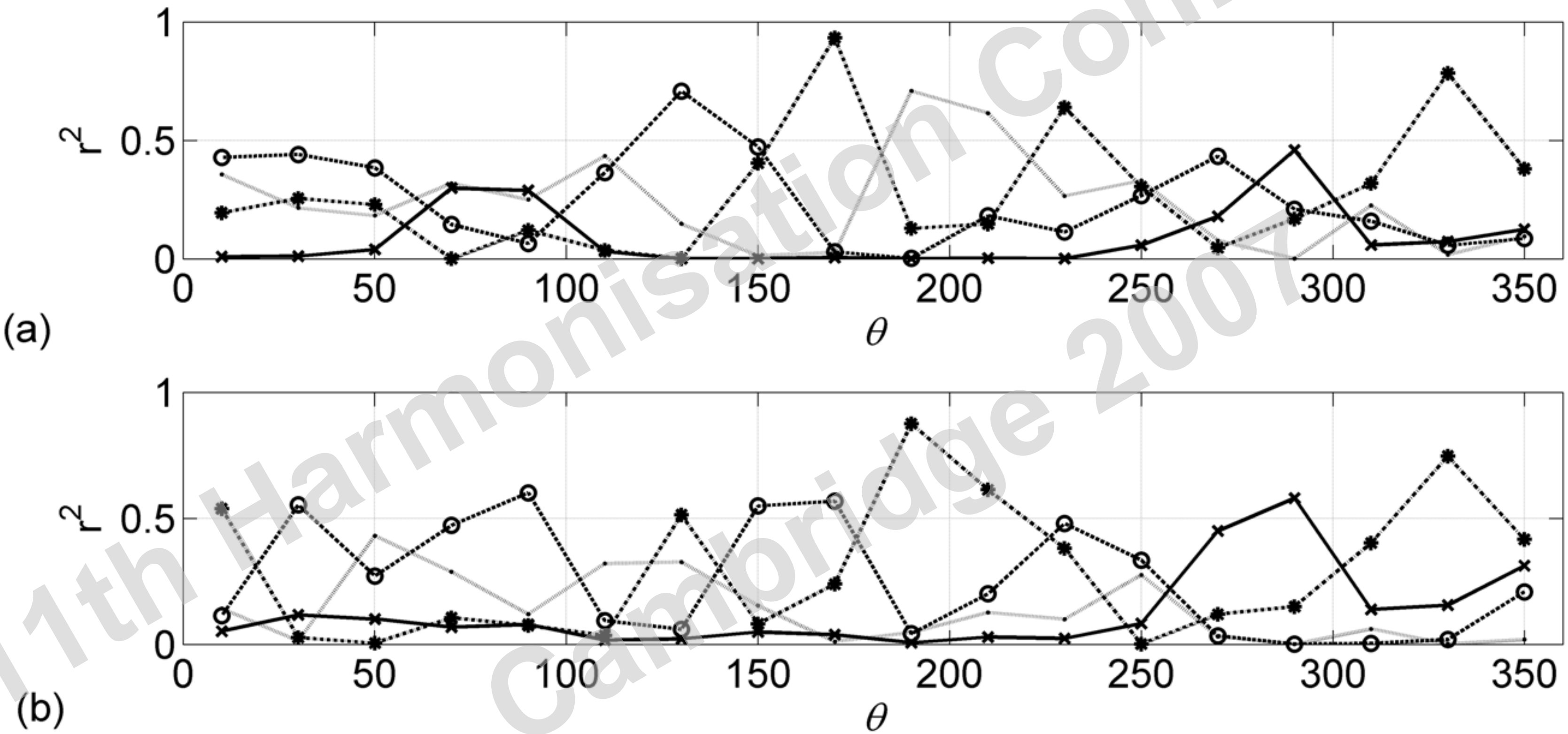

Relative sensitivity at (a) G3 and (b) G4 of un-normalised TKE (m^2s^{-2}) to all input parameters across all background wind angles.x - surface roughness length,o - building surface roughness length, ●–inflow roughness length, * - θ

Conclusions

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- Overall uncertainty is small in comparison to model output means even with all possible parameter uncertainty included.
- Sensitivity is highly location dependant.
- Sensitivity is highly wind direction dependant.
- HDMR method provides more detailed sensitivity information including non-linear and second order effects with reduced computational expense.

Acknowledgements

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