Modelling Radiative Exchange in a Vegetated Urban Street Canyon Model

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1: Introduction

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- Urban land surface models (ULSMs) poorly capture magnitude and temporal variability of Q_E (Grimmond et al. 2010; 2011)
- ULSMs have insufficient moisture to be evaporated or are not representing processes that impact on flux partitioning
- Improved representation of urban vegetation highlighted as a possible solution (Best & Grimmond 2014)

2: Vegetation in ULSMs

- Models with integrated vegetation had narrower range in performance relative to tile schemes (Grimmond et al. 2011)
- Not accurately representing feedbacks between urban surfaces and vegetation (e.g. impact on plant physiology and integrated impact of sub-grid processes)
- Urban modelling community has addressed this by developing more integrated vegetation scheme with promising results
  (e.g. Krayenhoff et al. 2014; Lemonsu et al. 2012; Wang et al. 2013)

3: Research Hypothesis

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An integrated urban vegetation scheme and an improved representation of moisture storage and flows within an urban canyon model will lead to improvement in RMSE of Q_E relative to observations and existing urban land surface schemes

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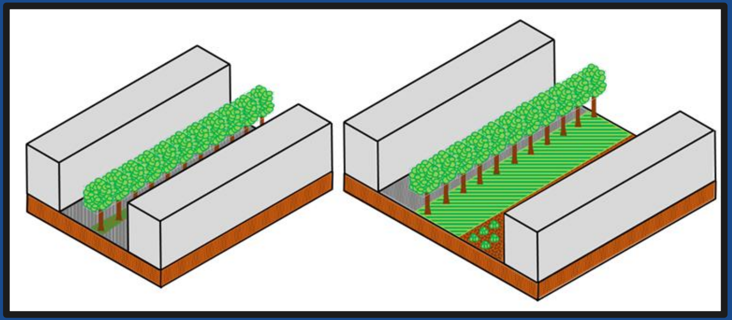
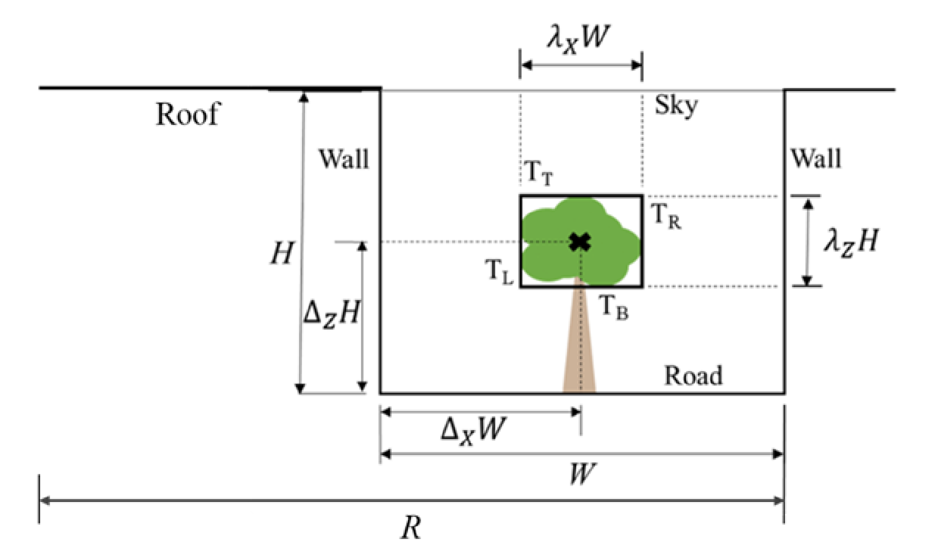
- Integrated urban vegetation scheme – TURBAN
- Inform future development of MORUSES within JULES
- Urban heat mitigation strategies and improved forecasting



4: TUrban Scheme

- Single layer 2D – Infinite street canyon
- Draws on work by Harman et al. 2004 & Porson et al. 2010
- Idealised tree representation (dimensions $\lambda_x W \times \lambda_z H$) with a transparent trunk
- Interaction and feedbacks between vegetation and urban surfaces



5: TURBAN Radiation Scheme

What impact does the addition of a tree or grass surface within a canyon model have on the urban radiation balance?

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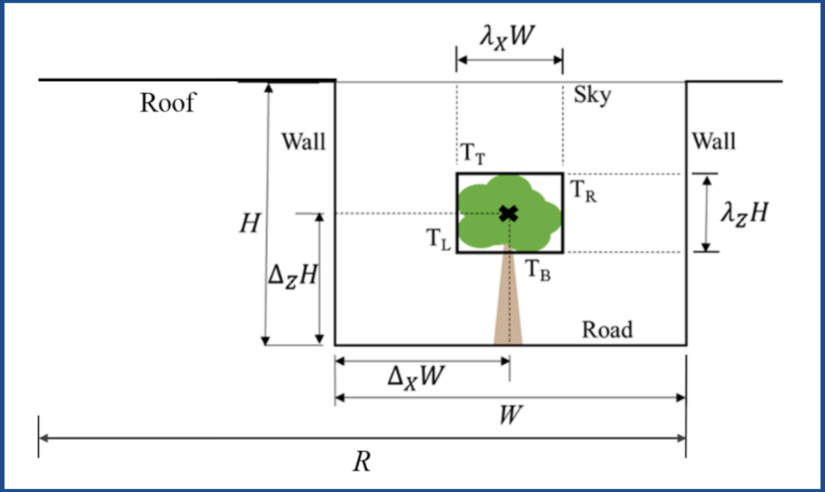
What impact does the addition of a tree or grass surface within a canyon model have on the urban radiation balance?

- Model complete longwave radiative transfer within treed canyon (Harman et al. 2004)
- Diagnose vegetation surface temperature
- Investigate impact on vegetation physiology



6: Radiation Heat Transfer

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- Consider the longwave radiative exchange for two arbitrary surfaces

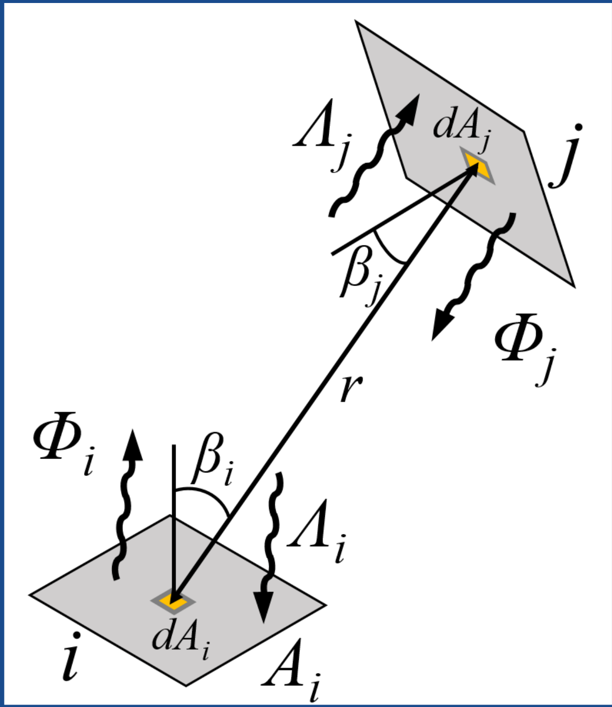
$$\Lambda_i = F_{ij}\Phi_j$$

then

$$Q_i = \Lambda_i - \left[\varepsilon_i \sigma {T_i}^4 + (1 - \varepsilon_i)\Lambda_i\right]$$

- View factor, F_{ij}, determined in general terms for dA_i and dA_j by

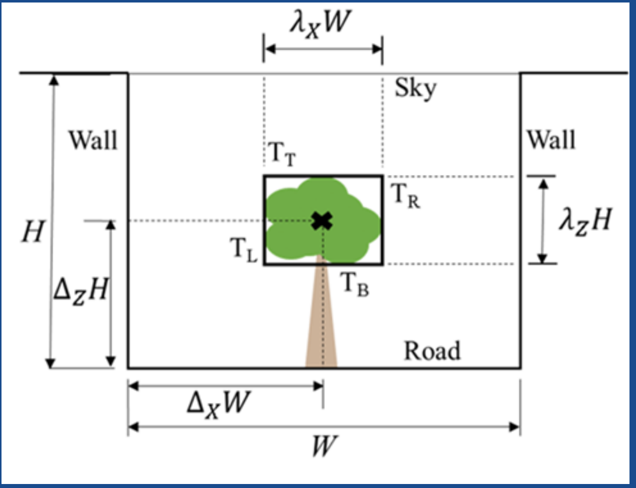
$$F_{ij} = \frac{1}{A_i}\int_{A_i}\int_{A_j}' \frac{\cos\beta_i \cos\beta_j}{\pi r^2} dA_i dA_j$$



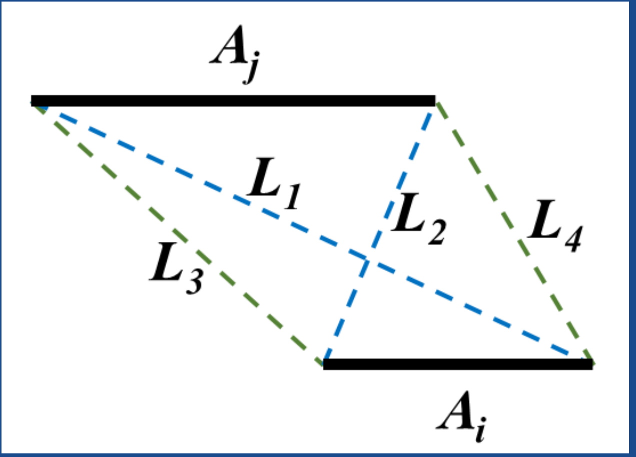
- Analytical solutions exist for simpler 2D geometries

7: View Factor Calculation

- Calculate view factors for 8 facet system using analytical relations (Jones 2000; Howell et al. 2010)
- Based on Hottel's Crossed String Construction (Hottel 1954)



$$F_{ij} = \frac{1}{2A_i}[(L_1 + L_2) - (L_3 + L_4)]$$



- Reduce calculations by applying the reciprocity and summation relations

8: View Factor Results

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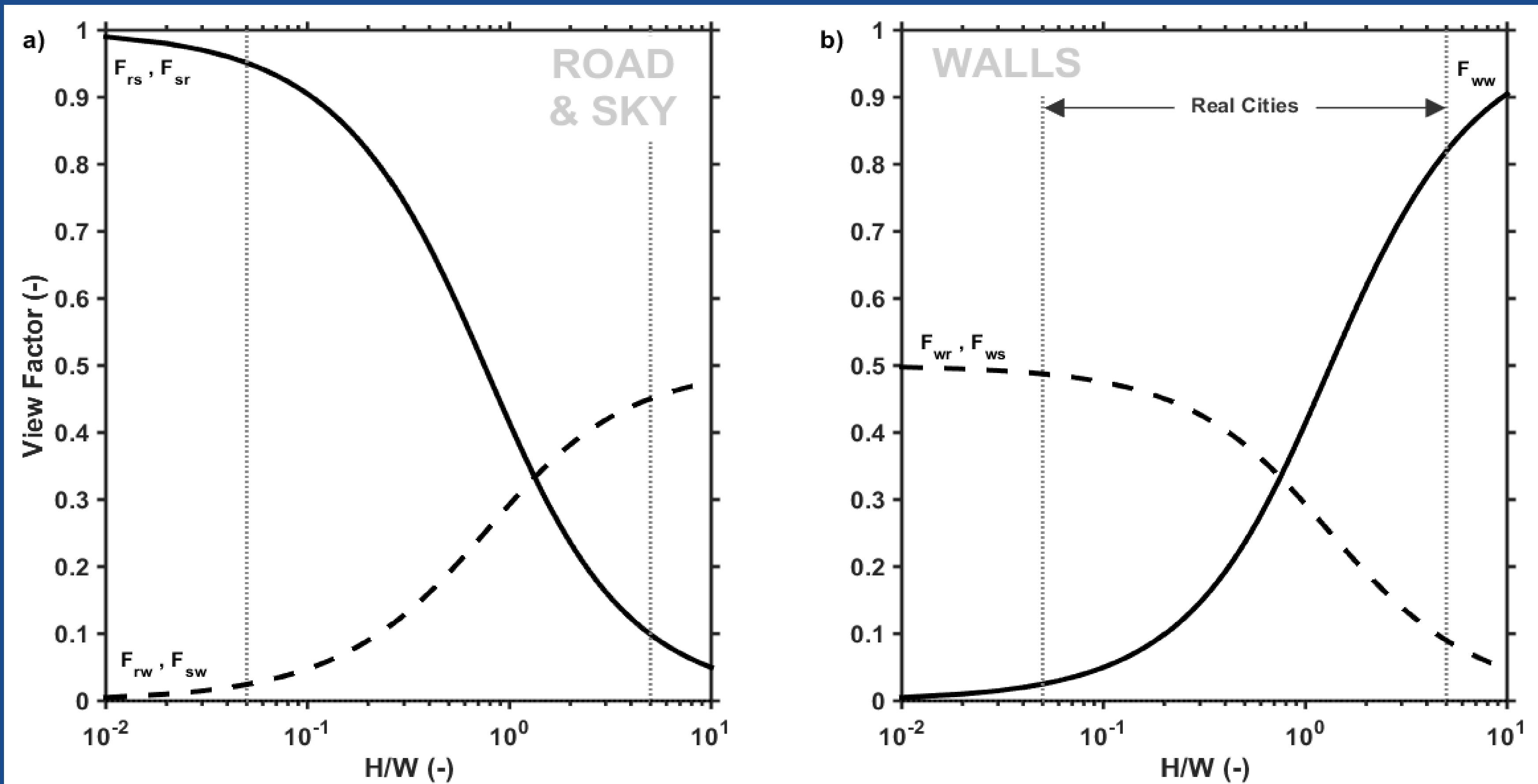
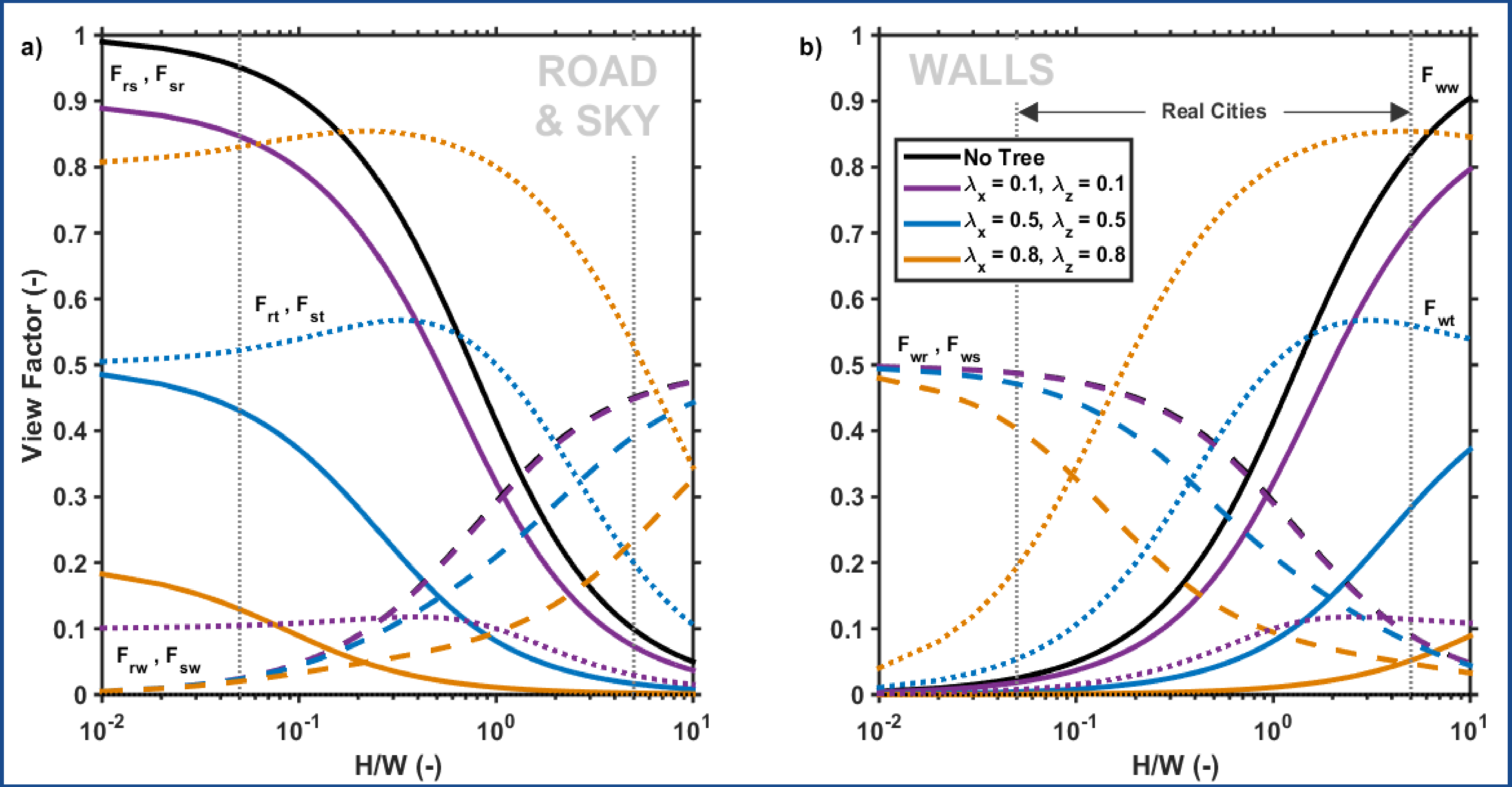


r = road   s = sky   w = wall   t = tree

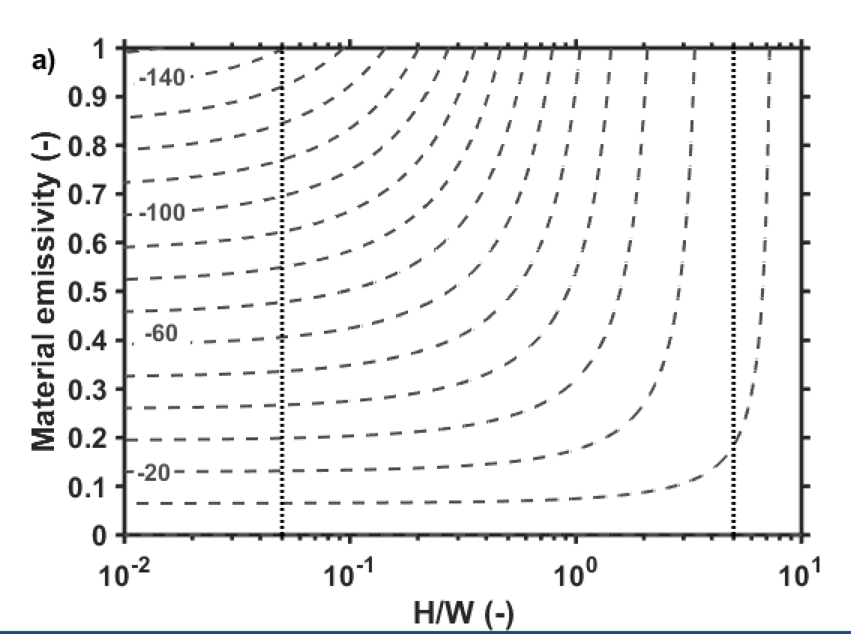
8: View Factor Results



r = road s = sky w = wall t = tree

9: Idealised Simulations

- $L_{\downarrow} = 275$ W m^{-2}
- $T_i = 295$ K
- $0 \leq \varepsilon \leq 1$
- $0.01 \leq H/W \leq 10$
- Top of canyon net longwave radiative flux density



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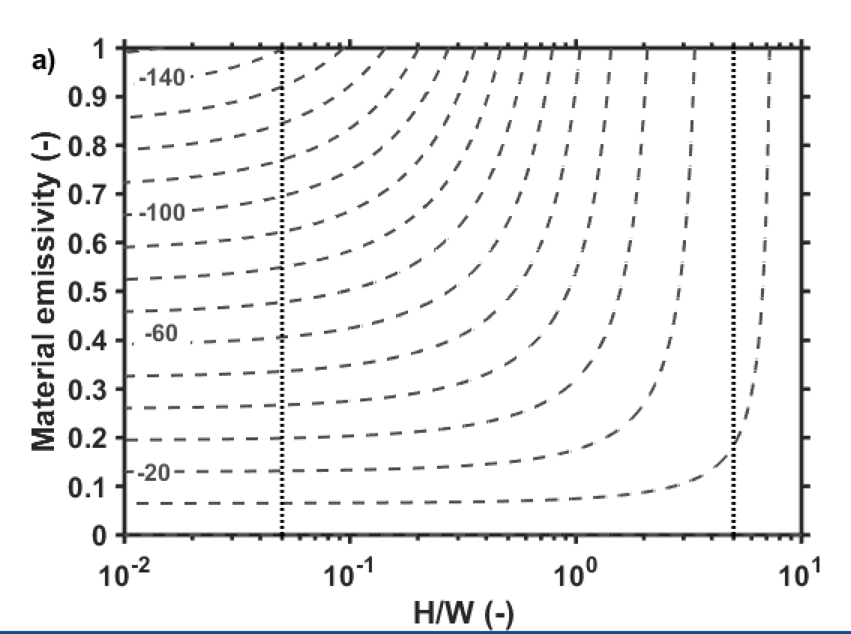
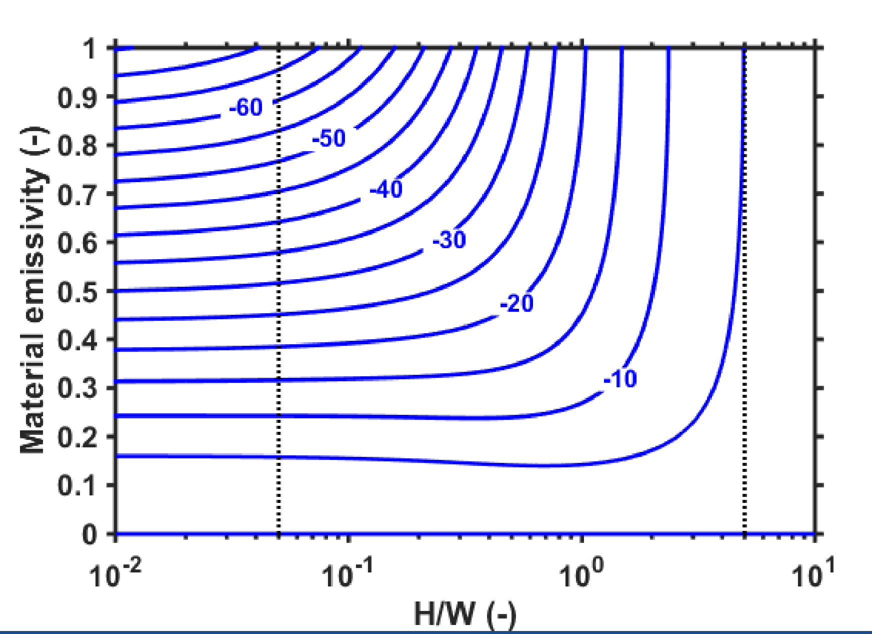
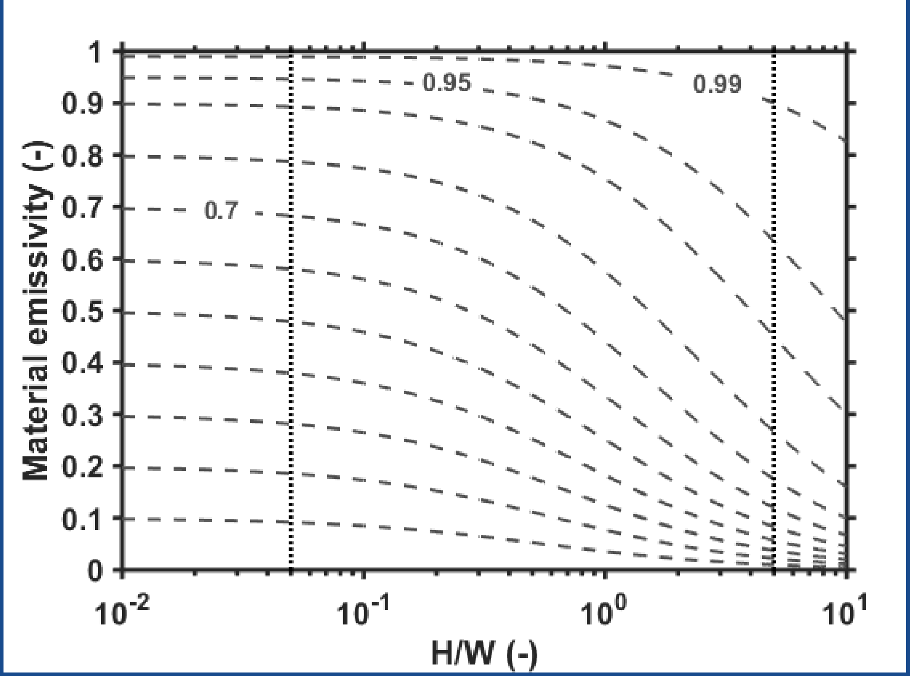
- Difference between no tree and tree of dimensions $\lambda_x = 0.5; \lambda_z = 0.5$





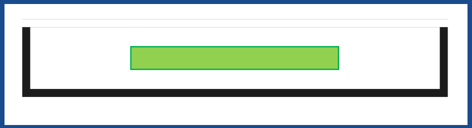
9: Idealised Simulations

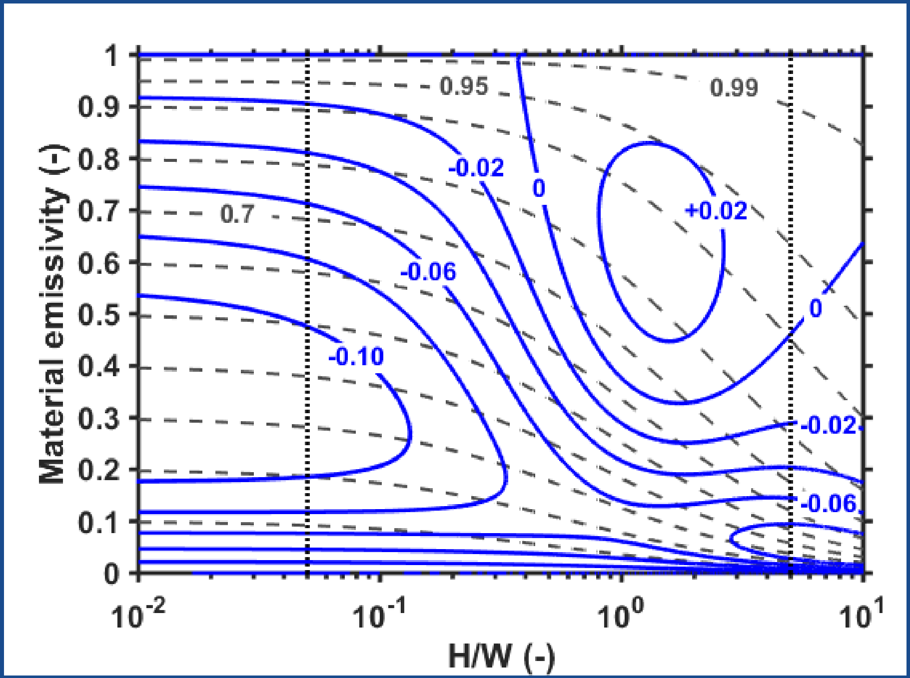
- Effective canyon emissivity (ε_{eff}) relative to a flat surface radiating as a blackbody

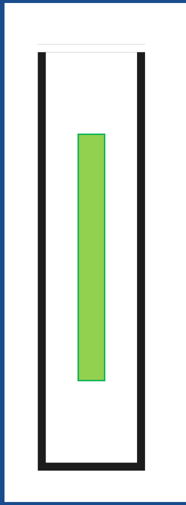


9: Idealised Simulations

- Difference in ε_{eff} between no tree and tree of dimension $\lambda_x = 0.5; \lambda_z = 0.5$



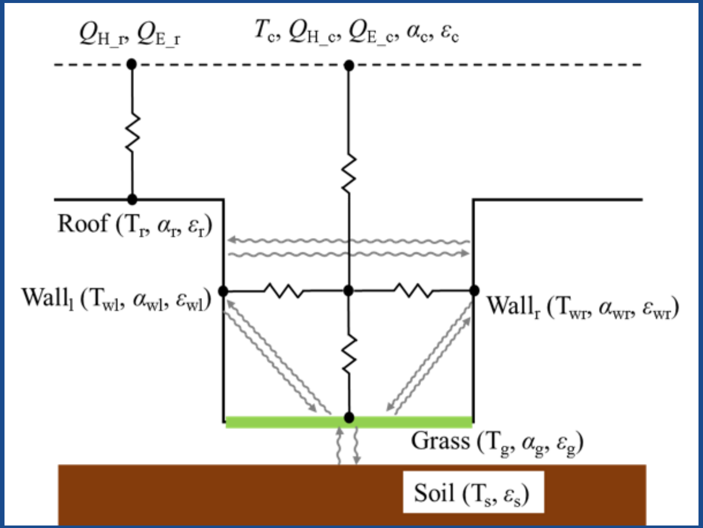




- Two regimes identified that account for patterns in difference in ε_{eff}

10: Future Work

- Realistic simulations with vegetation and urban surfaces with different surface temperatures
- Develop shortwave radiative exchange (e.g. shadowing and tree canopy effects)
- Continued development of TUrban including vegetation physiology and surface exchange parameterisation



11: Conclusions

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- Current ULSMs don't accurately capture magnitude and temporal variability of Q_E
- Developing TUrban to model the interactions and feedbacks between vegetation and urban surfaces
- Calculated complete longwave radiative exchange using analytical view factors
- Tree altered canyon longwave radiation balance and the effective canyon emissivity

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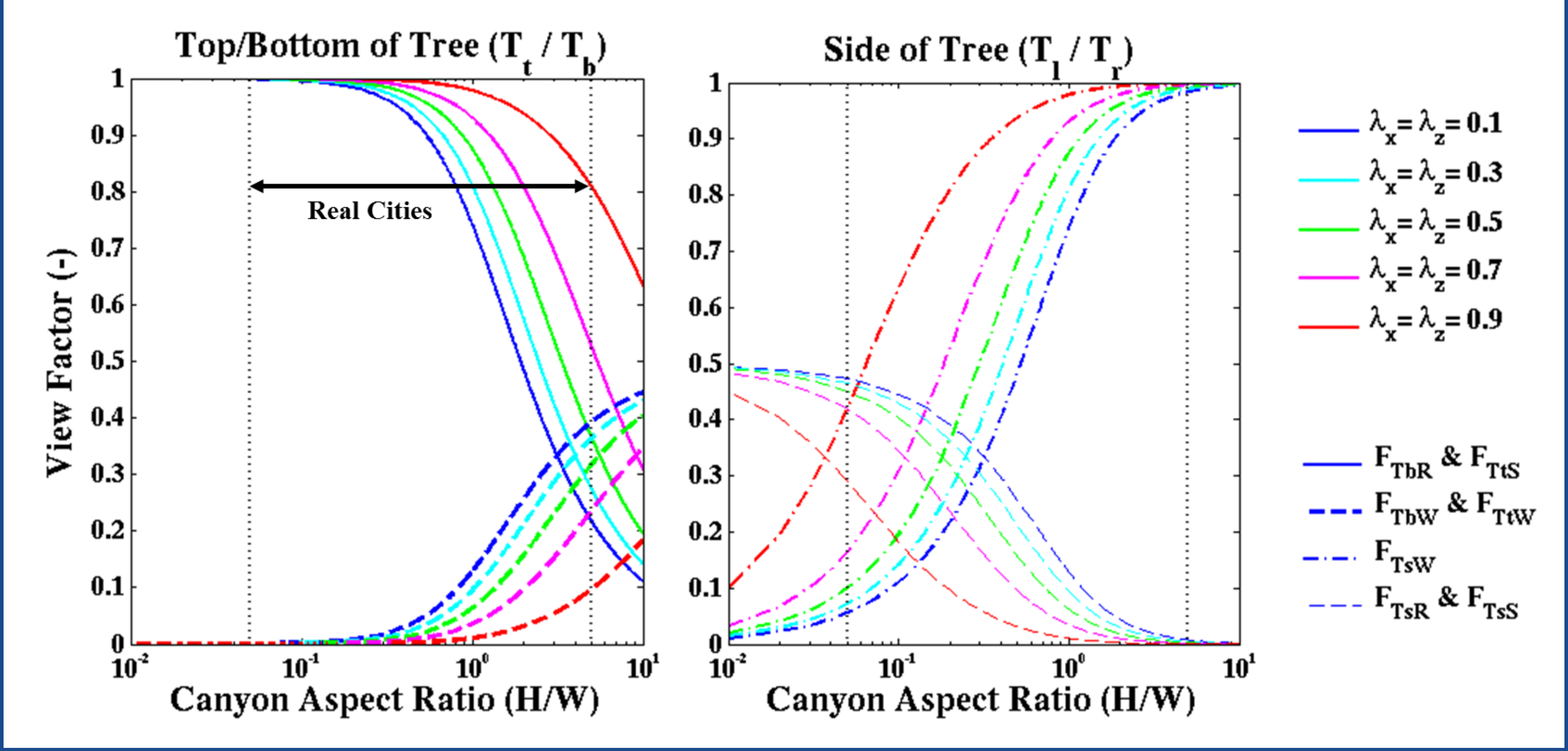
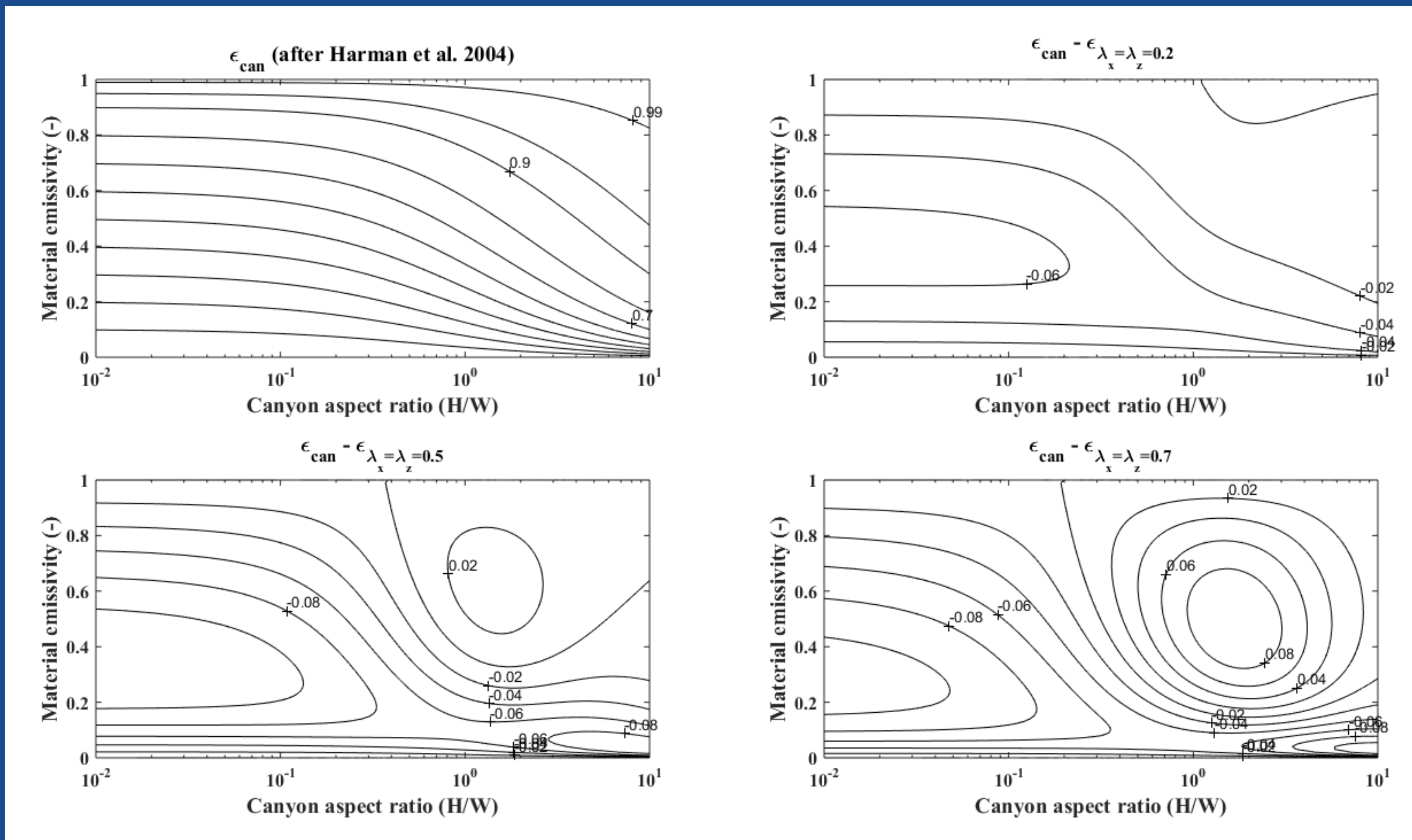
View Factor Results



Idealised Simulations

- $K_{\downarrow} = 275\ \mathrm{W\ m^{-2}}$; $T_i = 295\ \mathrm{K}$; $0.01 \leq H/W \leq 10$; $0 \leq \varepsilon \leq 1$



10: Tree Position

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