The Influence of Tree Crowns on Effective Urban Thermal Anisotropy

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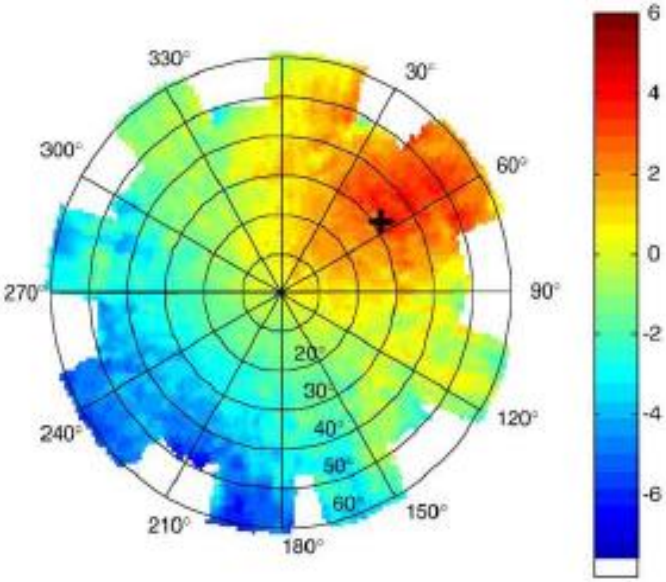
Western

Urban thermal anisotropy

- The three dimensional structure of cities creates large differences in radiometric temperature with view direction: *urban effective thermal anisotropy*
- Limited observations available over select urban areas, typically with low vegetation cover; model results also typically ignore vegetation

Google Maps: Toulouse



Observed Toulouse: Lagouarde et al. 2010

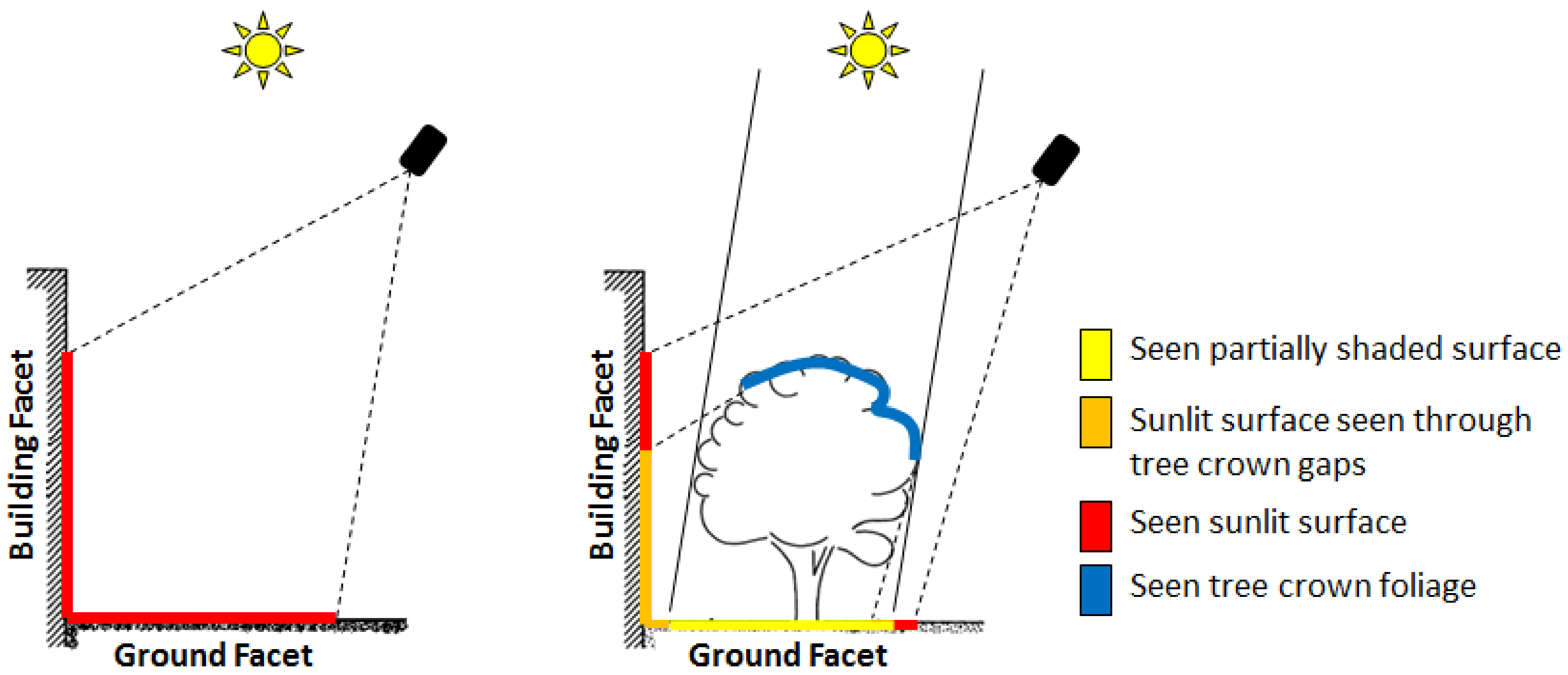
Urban Trees: An important component of urban surface structure

Note the location and relative height of urban vegetation

Photo: Bill Cobb SkylineScenes.com

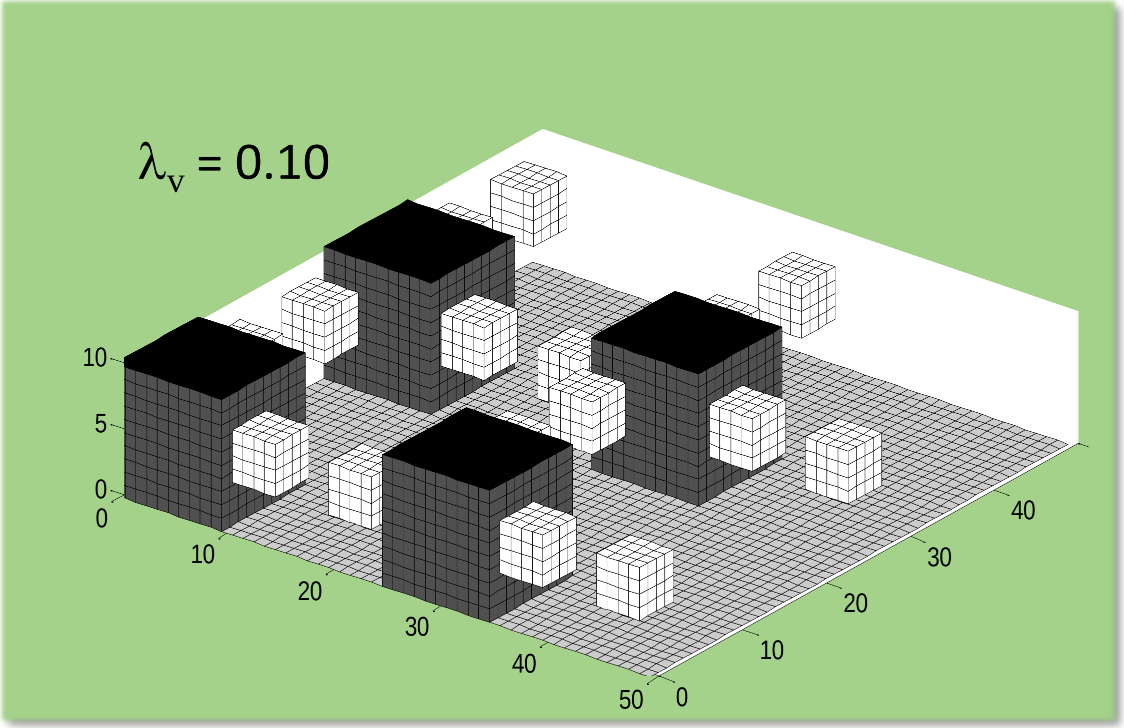
How do tree crowns influence urban effective thermal anisotropy?

- How does urban effective anisotropy change as we add trees?



Incorporating Vegetation into a SSVM

Tree Biophysical Descriptors
- Crown height
- Crown radius
- Trunk height

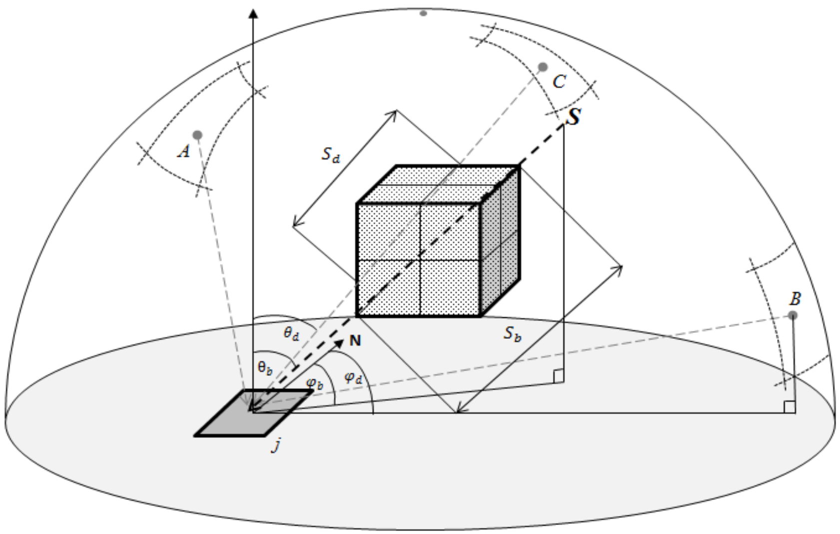


- Use *view factor analysis* and *solid angle geometry* to calculate the integrated brightness temperature based on surface-sensor-sun relations (Soux *et al.*, 2004)
- Trees are modelled as cuboid shapes consisting of plane-parallel cells

Vegetation Details

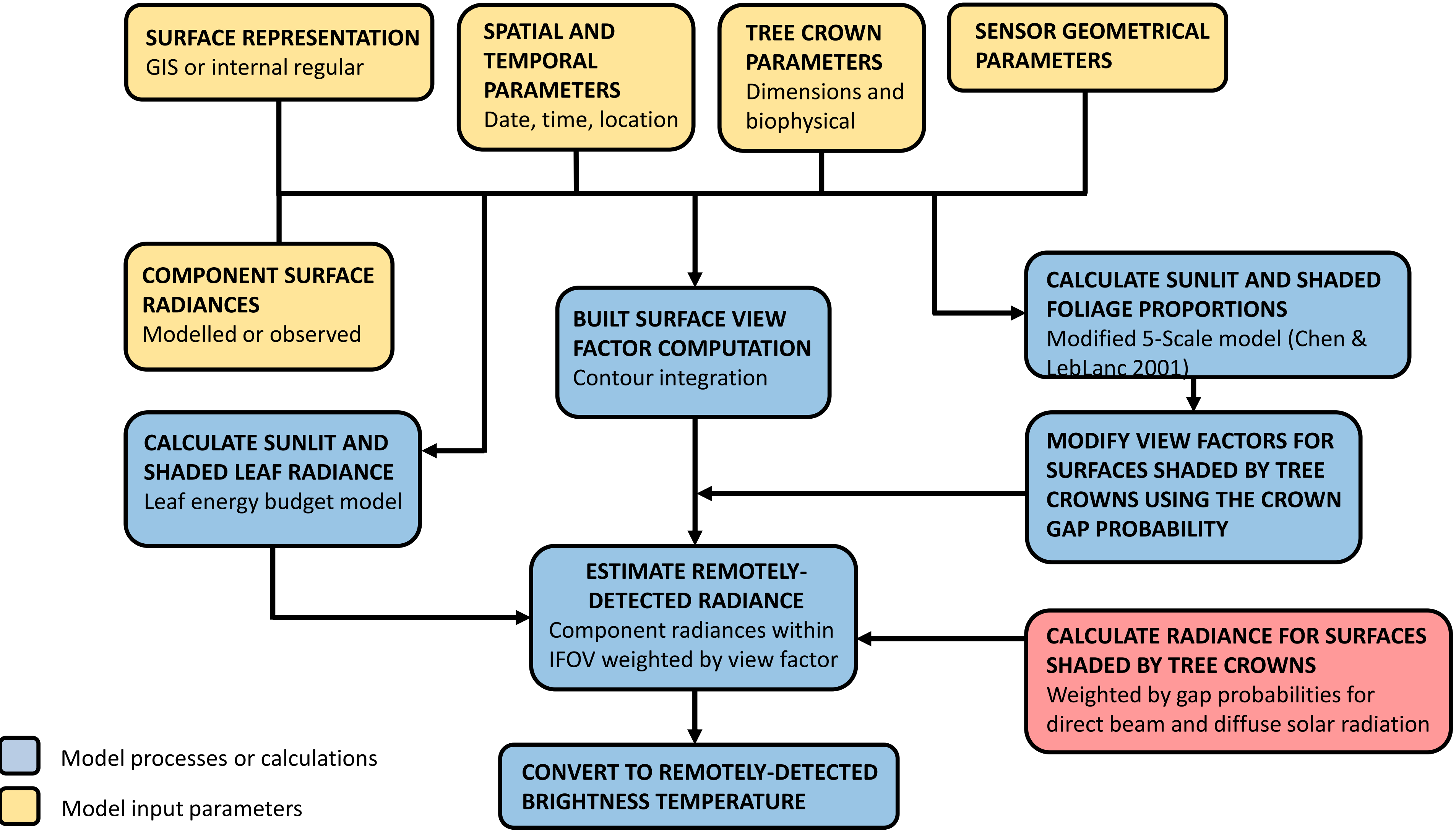
Leaf Biophysical Descriptors

- Foliage area density (μ_L)
- Leaf angle distribution
- Clumping Index (Ω_C)
- Foliage element width (f_w)



- Statistical gap probabilities determine the relative proportion of foliage and surface 'seen' through tree crown gaps—used to weight surface view factors

Model Framework



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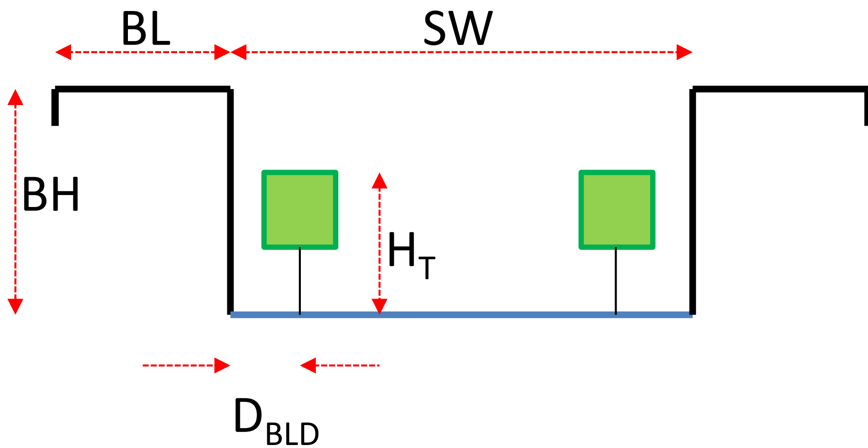
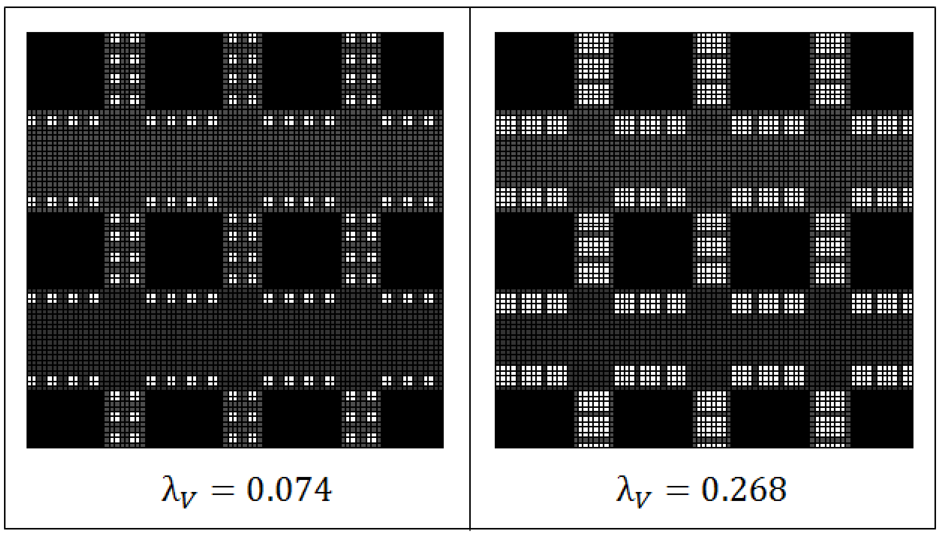
Tree Placement Options

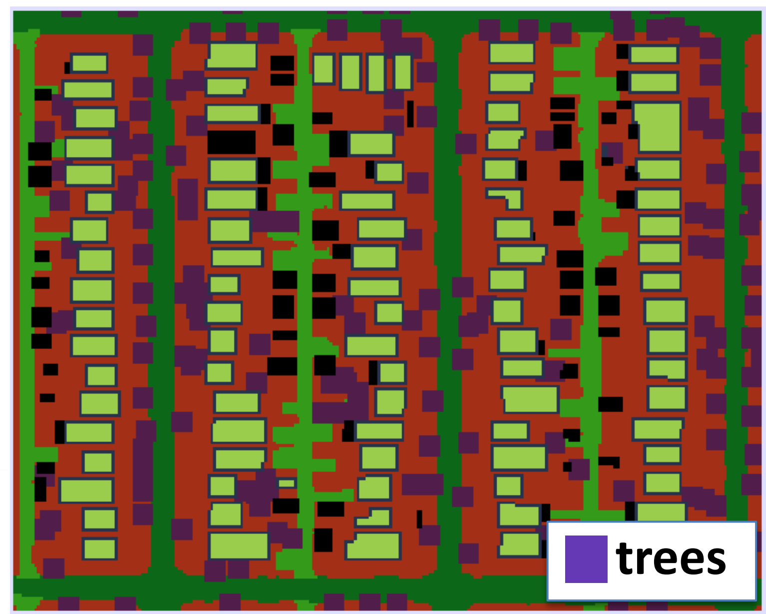
1. Regular, repeating block array surface

- *Tree crowns located on the edge of streets along the length of buildings; relative dimensions: H_T / BH, D_{BLD}*





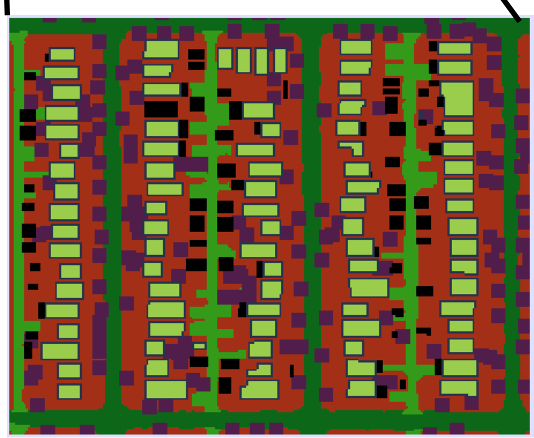
λ_V= Tree crown plan fraction

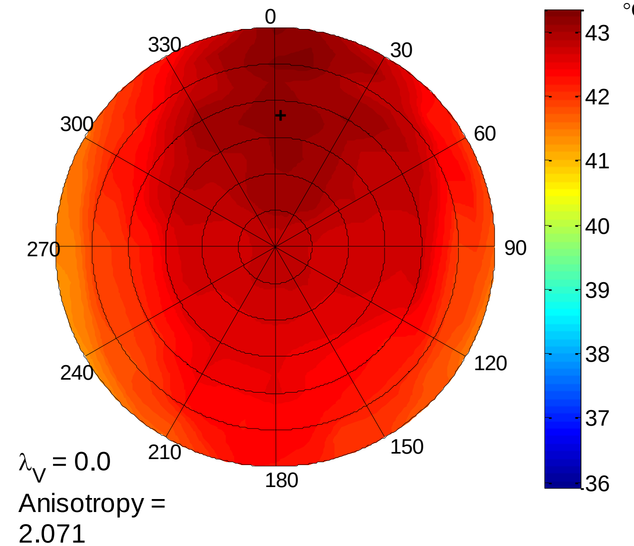


2. GIS surface

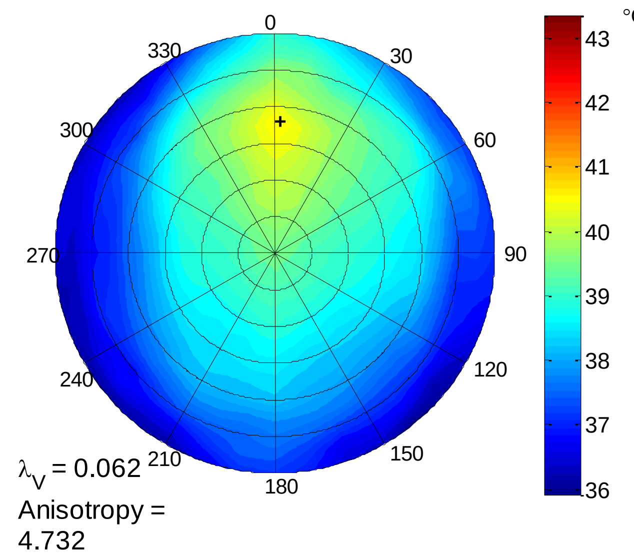
- *Specify individual tree crown centres*

How does the addition of vegetation change anisotropy?



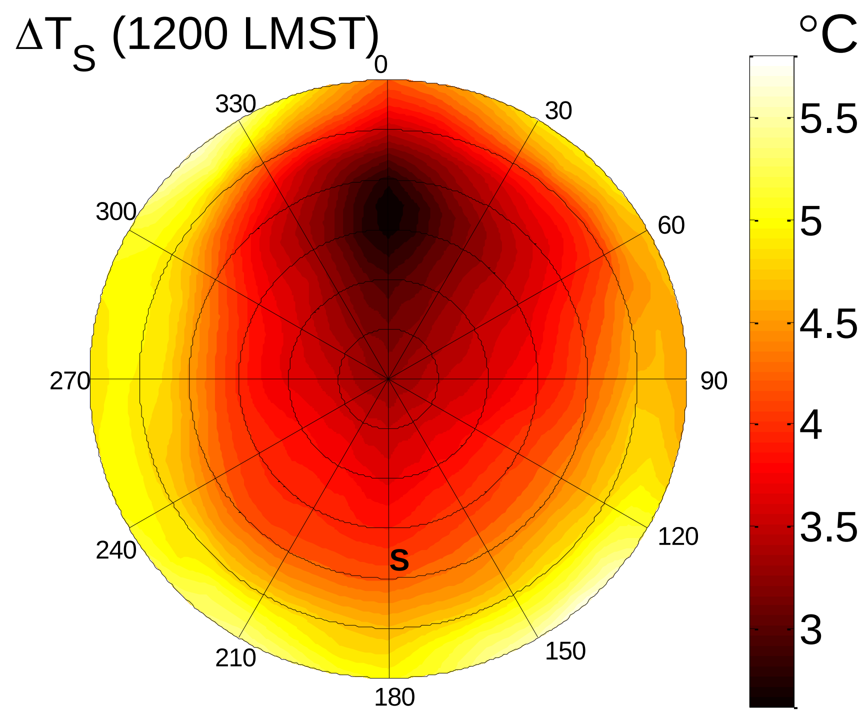


Unvegetated (top)
Vegetated (bottom)
polar plots and
anisotropy for Vancouver
Sunset study area
(λ_v = 0.062)



How does the addition of vegetation change anisotropy?

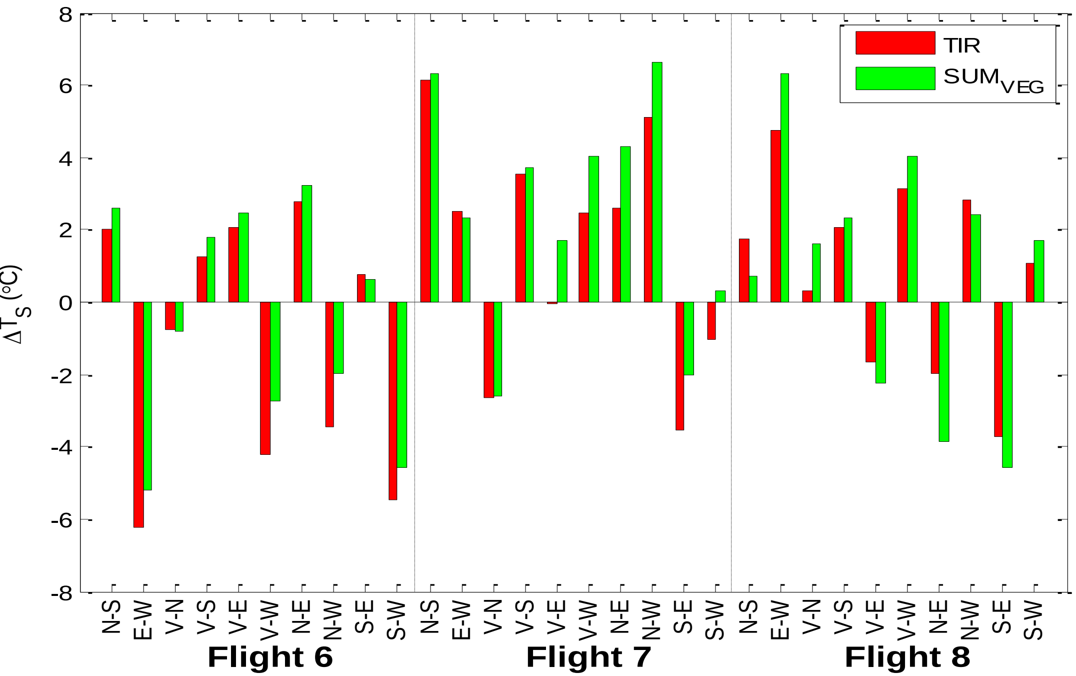
- Lower T_{rad} for every viewing direction.
- ΔT is smallest at the hot spot location and increases elsewhere with off-nadir viewing angle as T_{min} decreases
- Large (58%) increase in modelled anisotropy relative to its absolute magnitude despite only a small tree canopy increase ($\lambda_v = 0.06$)

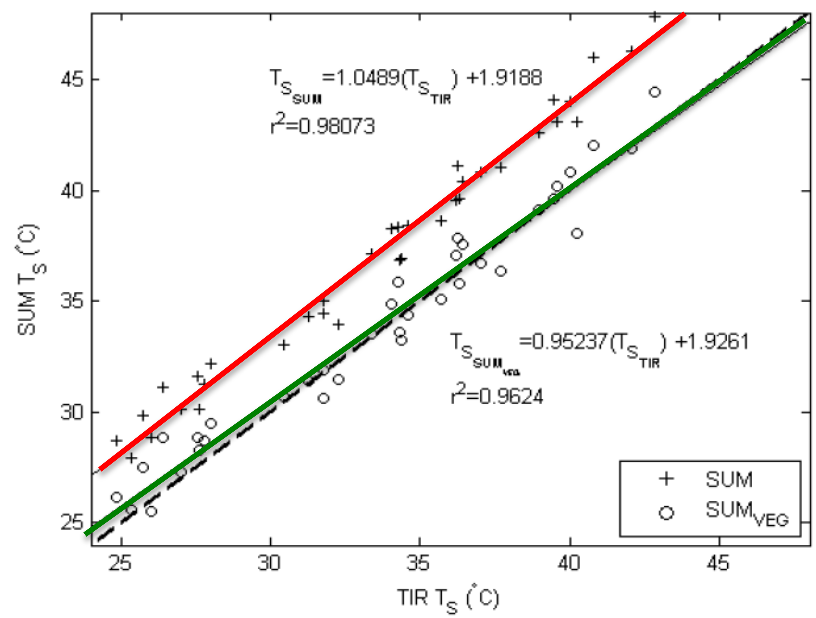


Difference due to addition of vegetation

Vancouver: Sunset Residential Area

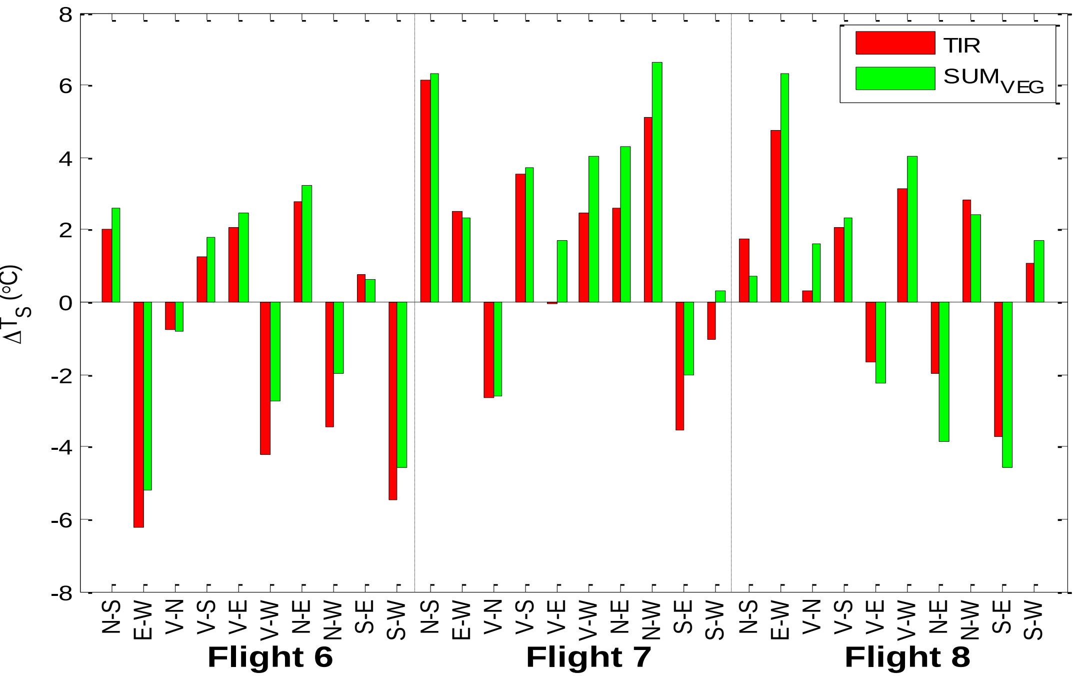
Model Evaluation





Test against airborne observations over the Vancouver Sunset residential area.

Model Evaluation



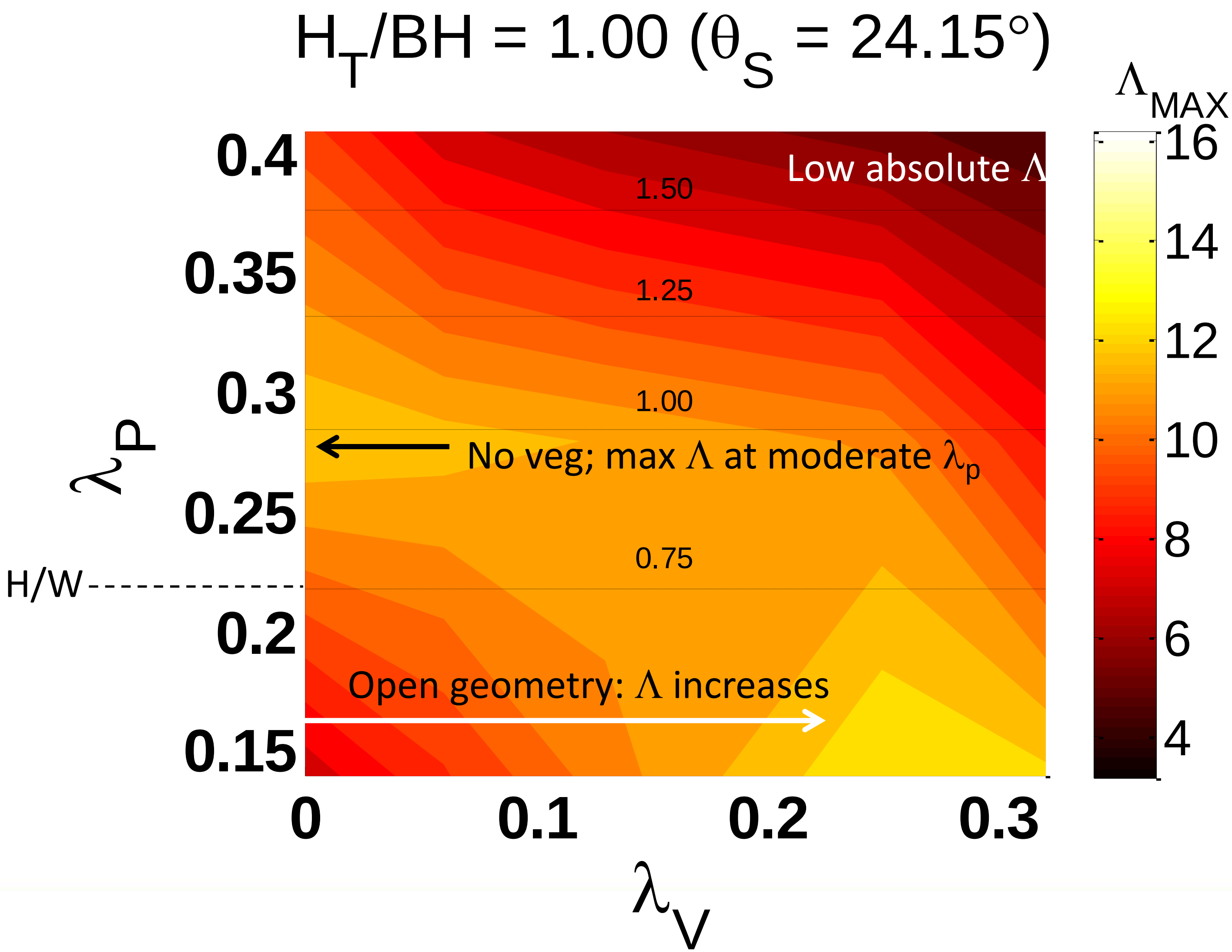
Statistic	T_S		ΔT_S
	SUM_{VEG}	SUM	SUM_{VEG}
RMSE	1.06	3.65	1.06
$RMSE_S$	0.41	3.57	0.49
$RMSE_U$	0.98	0.77	0.83
MAE	0.87	3.56	0.88
b (slope)	0.95	1.05	1.00
a (intercept)	1.93	1.92	0.54
d (Index of agreement)	0.99	0.88	0.97
r^2	0.96	0.98	0.92

Test against airborne observations over the Vancouver Sunset residential area.

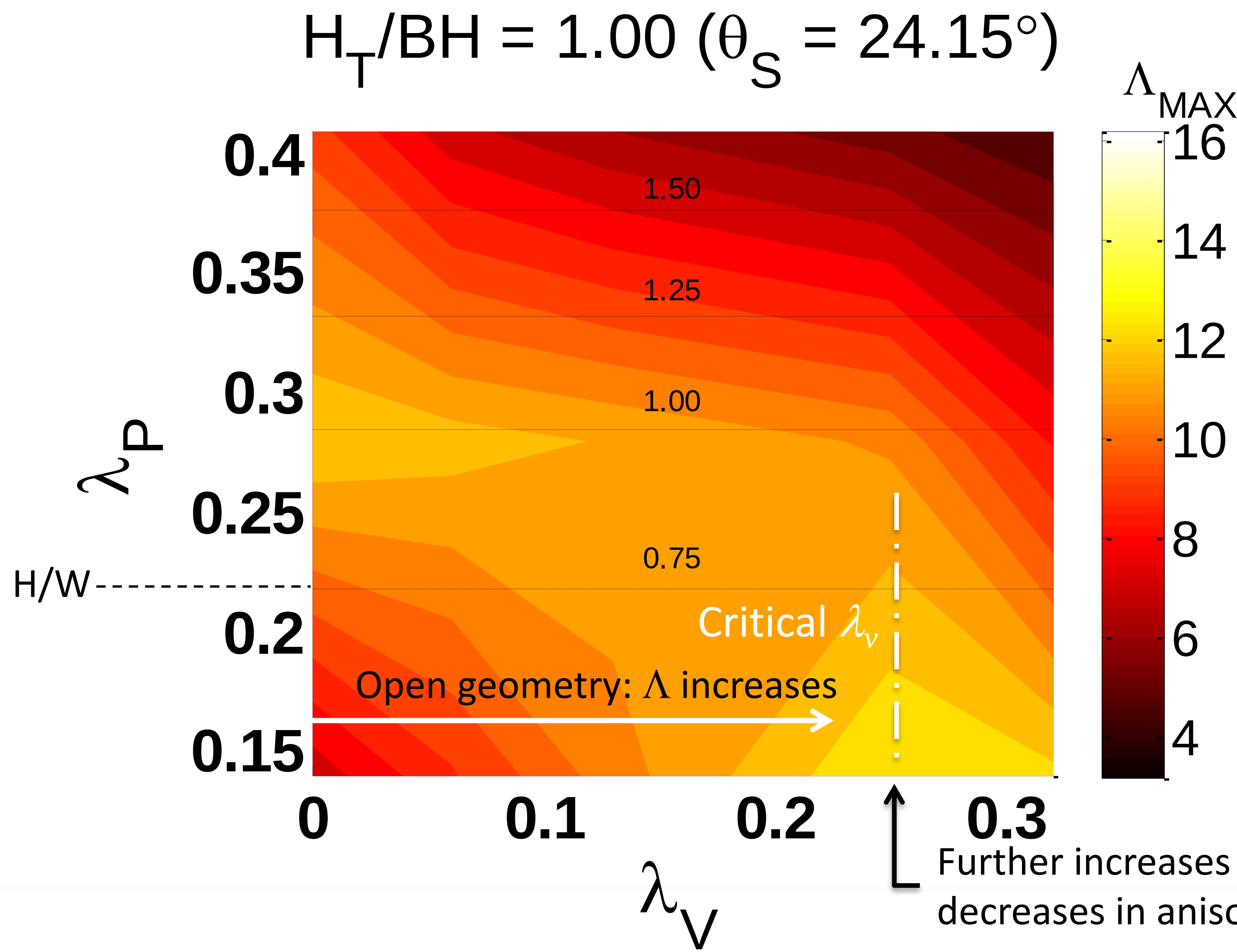
How does vegetation impact anisotropy for a range of urban geometries?

- Suite of simulations:
  - λ_p 0.15 – 0.4
  - λ_v 0.0, 0.06, 0.13, 0.25, and 0.32.
  - H_T/BT = 0.5, 1, 1.5
  - Summer solstice and equinox simulations at subtropical and mid-latitude locations
  - 0-60° ONA, 10° azimuthal steps; 12°FOV
- Use TUF3d (Krayenhoff & Voogt 2007) to specify built surface temperatures
- Vegetation shaded temperatures – semi-empirically determined

Anisotropy as a function of λ_p and λ_v

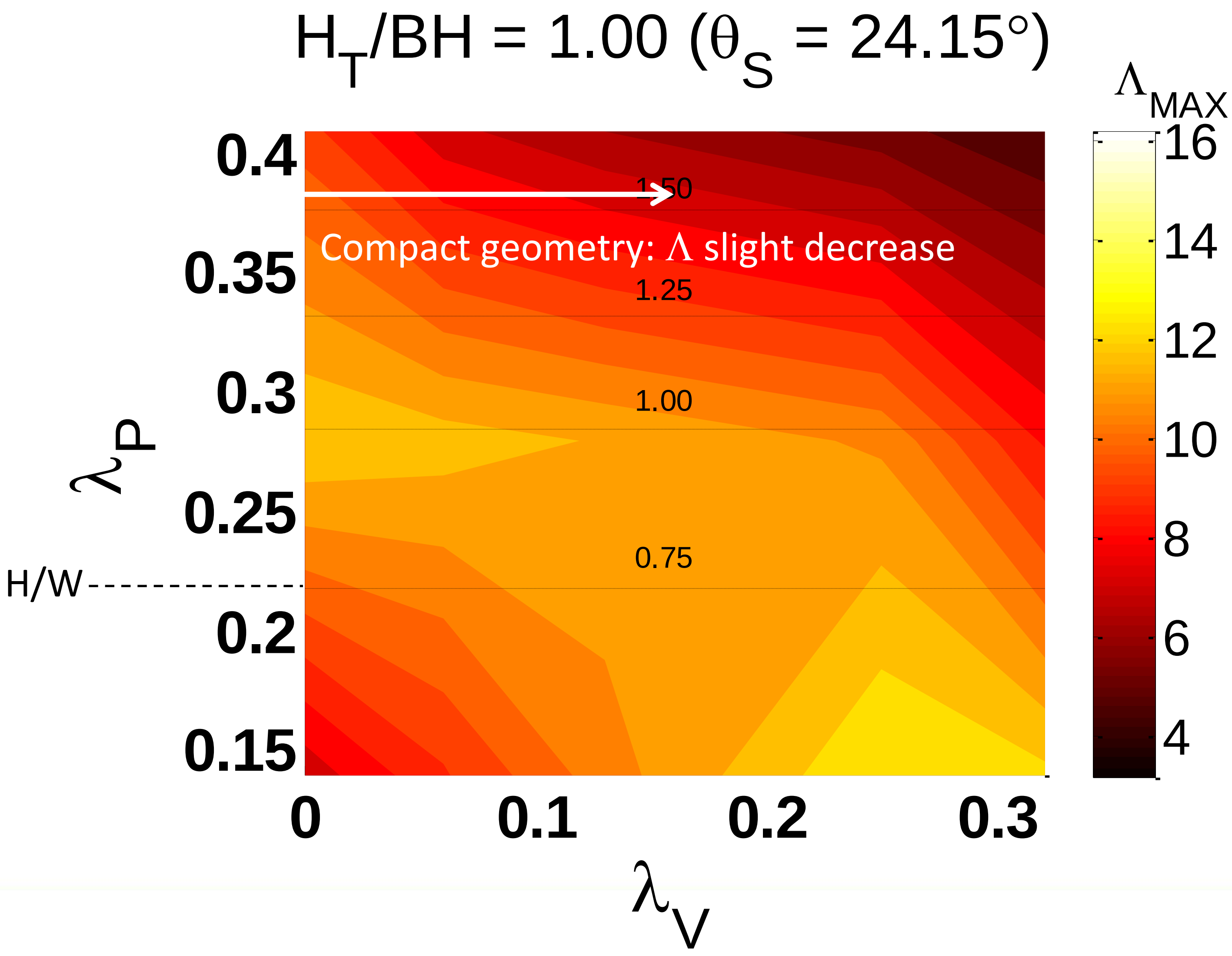


Anisotropy as a function of λ_p and λ_v

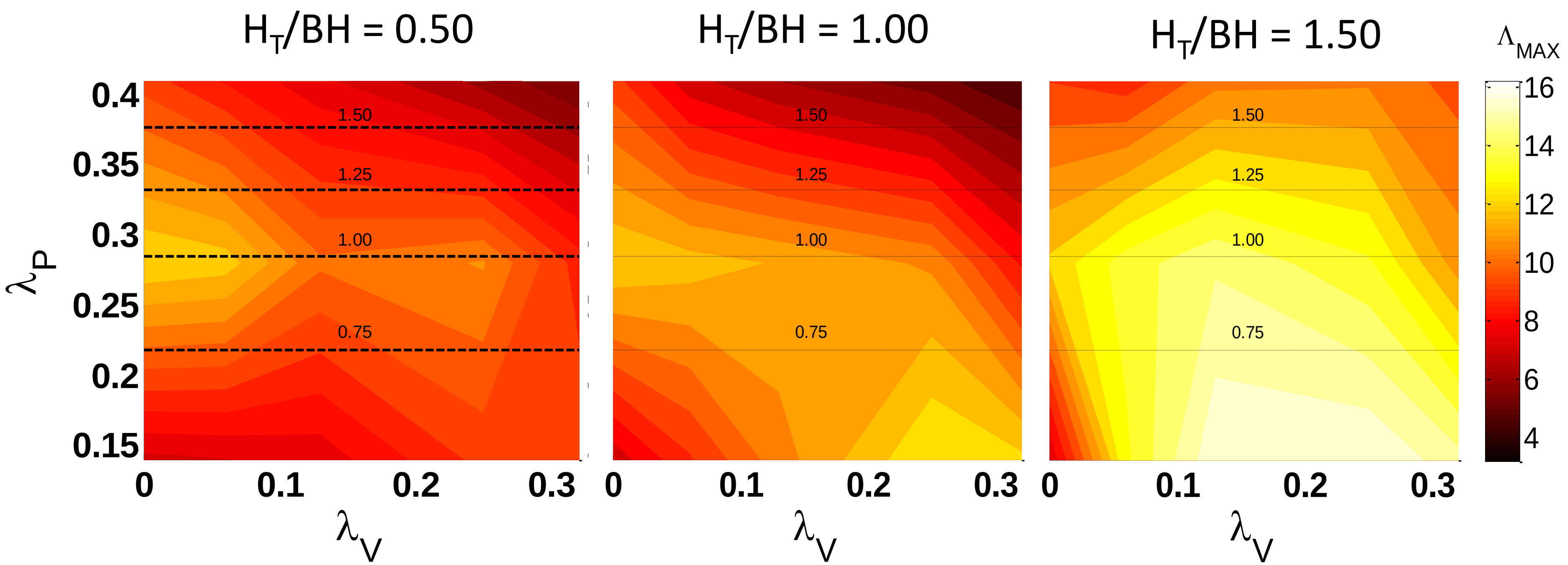


Further increases in λ_v lead to decreases in anisotropy

Anisotropy as a function of λ_p and λ_v

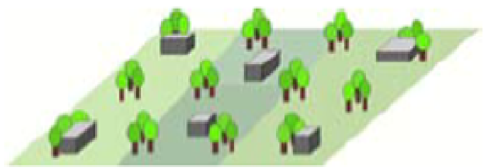
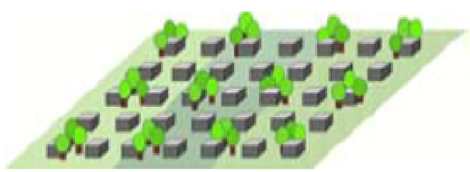
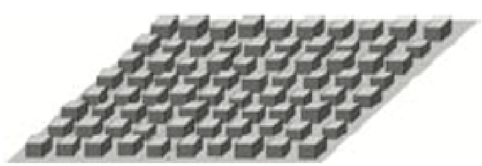


Increase relative tree height



$\theta_s = 24.15°$

Linking results to Local Climate Zones

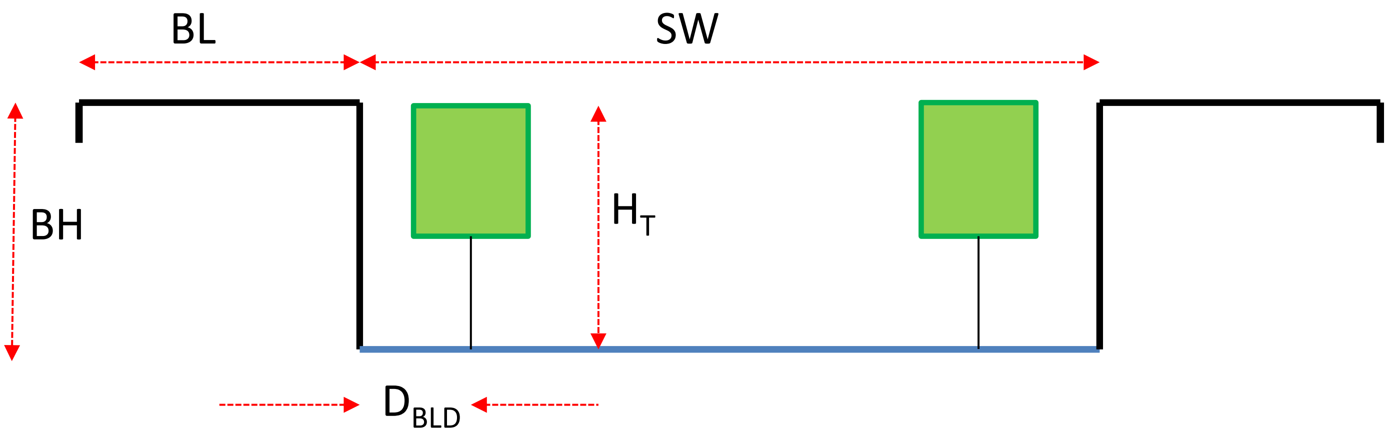
Local Climate Zone (Index)	λ_P	H_T/BH	Λ_{MAX} (°C) ($\lambda_V = 0.0$)	Λ_{MAX} (°C) ($\lambda_V = 0.32$)	Critical Value
Sparsely Built (9) 	0.10–0.20 (0.14)	0.50	7.5	9.5	No
		1.00	7.5	12.5	Yes
		1.50	7.5	15.1	Yes
Open Lowrise (6) 	0.20–0.40 (0.28)	0.50	12.3	8.9	–
		1.00	12.3	8.4	–
		1.50	12.3	11.2	Yes
Compact Lowrise (3) 	0.40–0.70 (0.41)	0.50	9.4	5.5	–
		1.00	9.4	4.7	–
		1.50	9.4	9.9	Yes

Images from Stewart and Oke (2012)

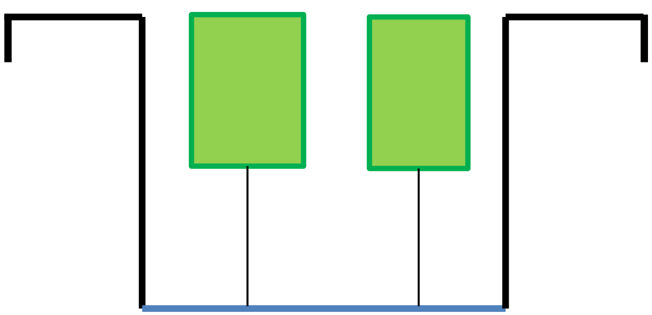
Summary

- Representation of tree canopy improves model performance
- Addition of a small fraction of tree canopies led to large relative changes in anisotropy for our test site
- Anisotropy changes depend on λ_v in conjunction with λ_P, H_T/BH and zenith angle.
  - Low building densities, anisotropy increases with λ_v and more so for trees higher than buildings
  - High building densities, anisotropy decreases as λ_v increases
  - As tree height increases relative to building height, anisotropy increases

Simplified Summary of Effects: $H_T/BH = 1$

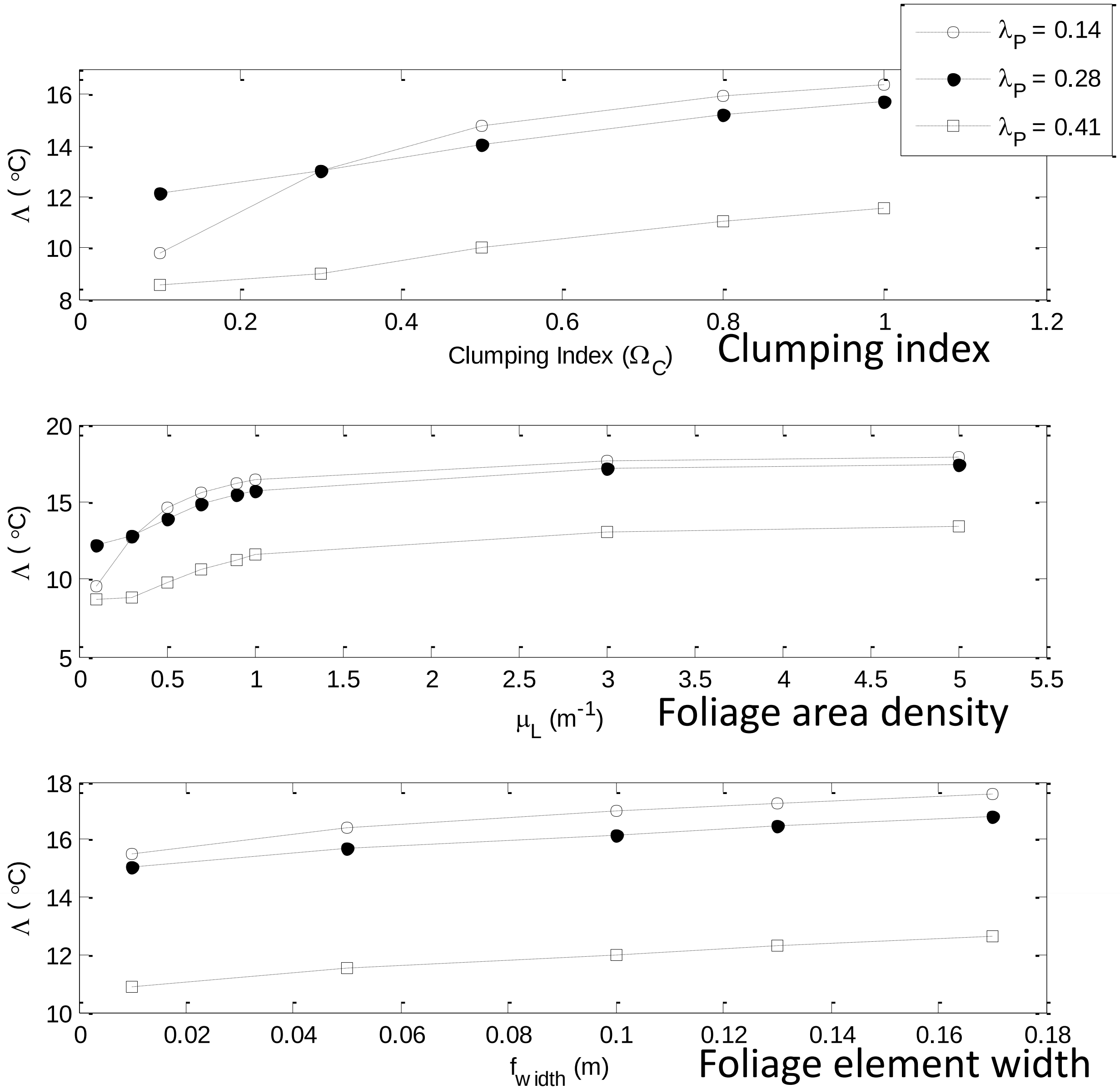


Open Geometries: anisotropy increases with λ_v sometimes up to a critical value; the critical value of λ_v decreases with increases in λ_P



Compact Geometries: maximum anisotropy occurs in the absence of tree crowns; crown vegetation reduces contrast in T_{rad};
A critical value of λ_v depends on λ_P

Sensitivity of Anisotropy to Tree Biophysical Parameters

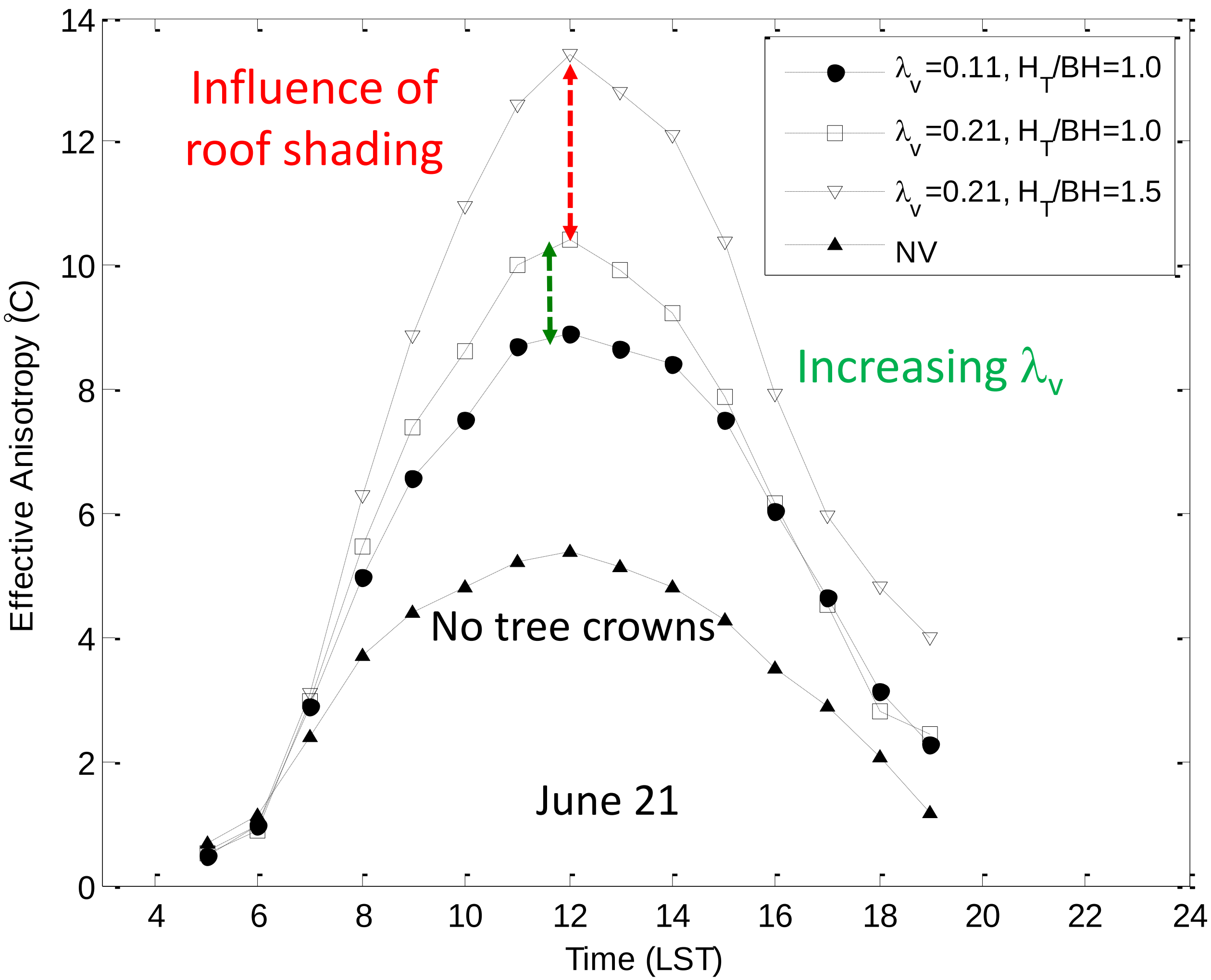


These tests use
HT = 1.5 BH

Model Steps

- Define the urban surface and relative location and dimensions of tree crowns
- Compute view factors for the ‘bare’ urban surface
- Add vegetation, identify surface patches that are partially obscured by foliage
- Calculate sunlit and shaded leaf proportions (modified 5-scale model Chen & LeBlanc 2001)
- Calculate sunlit and shaded leaf temperatures (Campbell & Norman 1998 single leaf EBM)
- Calculate P_{gap} and weight view factors for surfaces shaded by tree crowns by P_{gap}
- Determine T_{rad} from component radiances weighted by view factors in the FOV

Diurnal Variation of Anisotropy with Vegetation



“**high density detached residential**” (λ_P = 0.176) for several λ_V and H_T/BH. Geometric and radiative surface properties from Arnfield (1982).

NV= No tree crowns

H_T/BH= Tree to building height ratio