The PILPS-Urban experience: implications for introducing a urban tile in NWP models

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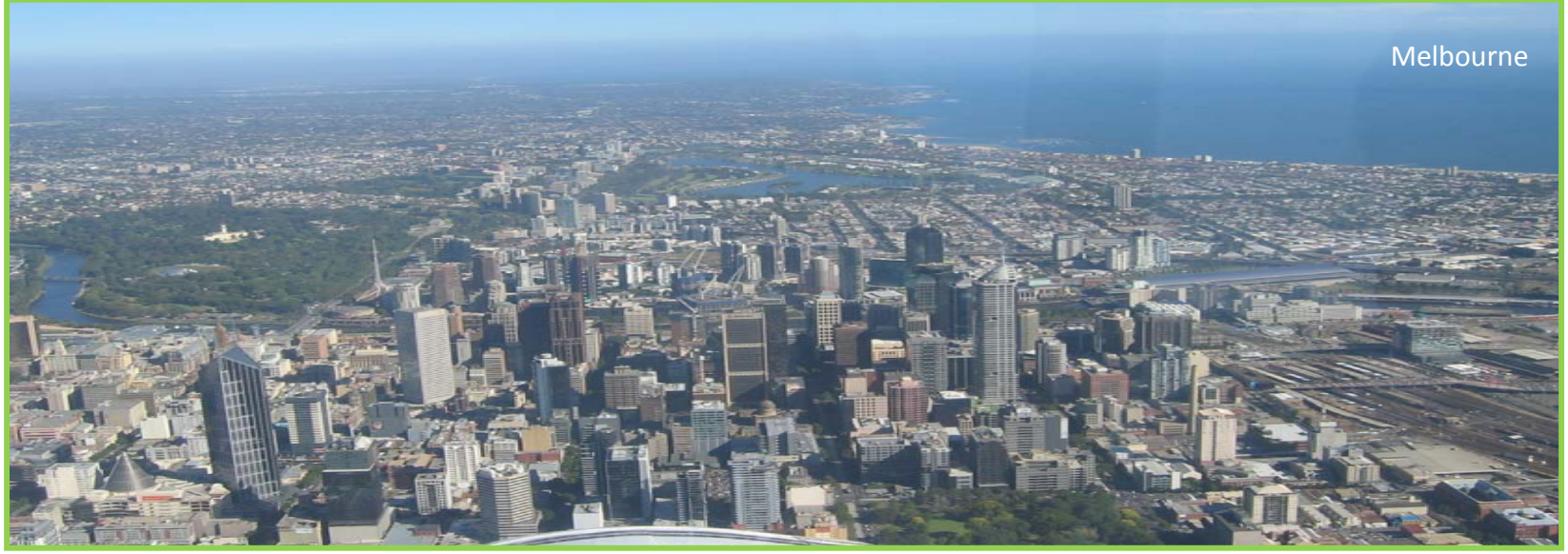
Rationale

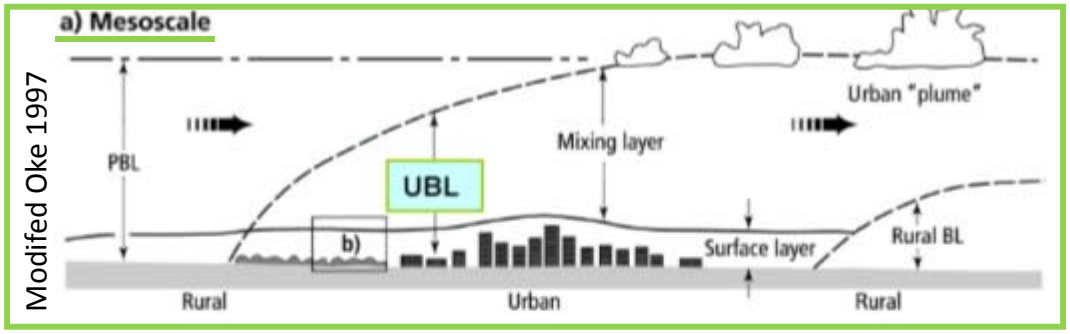
- Urban Land Surface Schemes used:
  - Weather forecasting
  - Climate modelling
  - Planning & Design
  - Management of urban areas
  - Air quality forecasts
  - Counter measures for urban heat islands , etc
- Possible to resolve urban areas
  - Increased computer resources & higher resolution model grids
  - Increasing area (suburban sprawl) and increasing urban population
- Evaluation ULSS
  - Essential to ensure the models are appropriate
  - Identify what type of approaches may be appropriate for future developments given objectives and resources

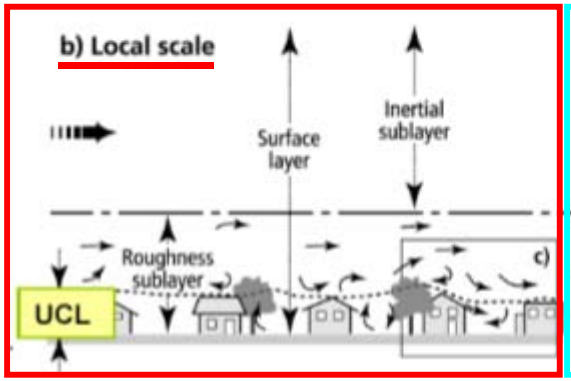

Melbourne

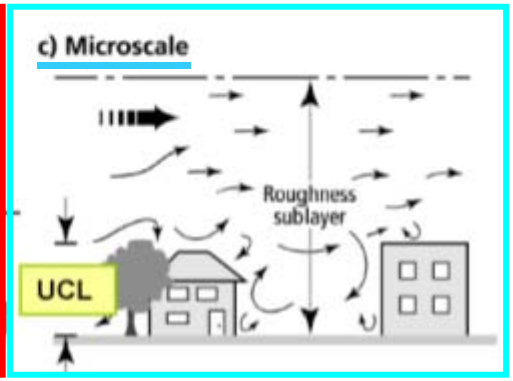
Scales


Chicago


Bremen


a) Mesoscale
Modifed Oke 1997
PBL
UBL
Mixing layer
Urban "plume"
b)
Surface layer
Rural BL
Rural
Urban
Rural


b) Local scale
Surface layer
Inertial sublayer
Roughness sublayer
c)
UCL

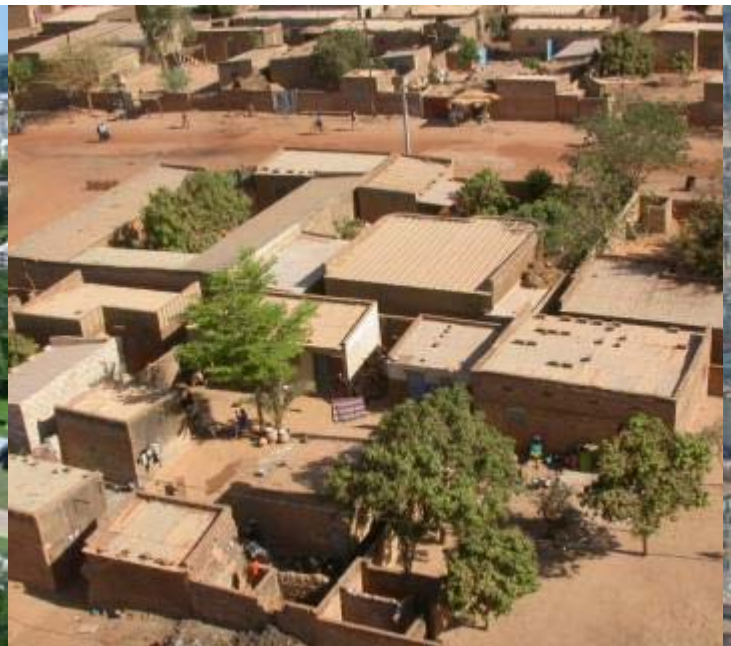

c) Microscale
Roughness sublayer
UCL


Gothenburg
Chicago

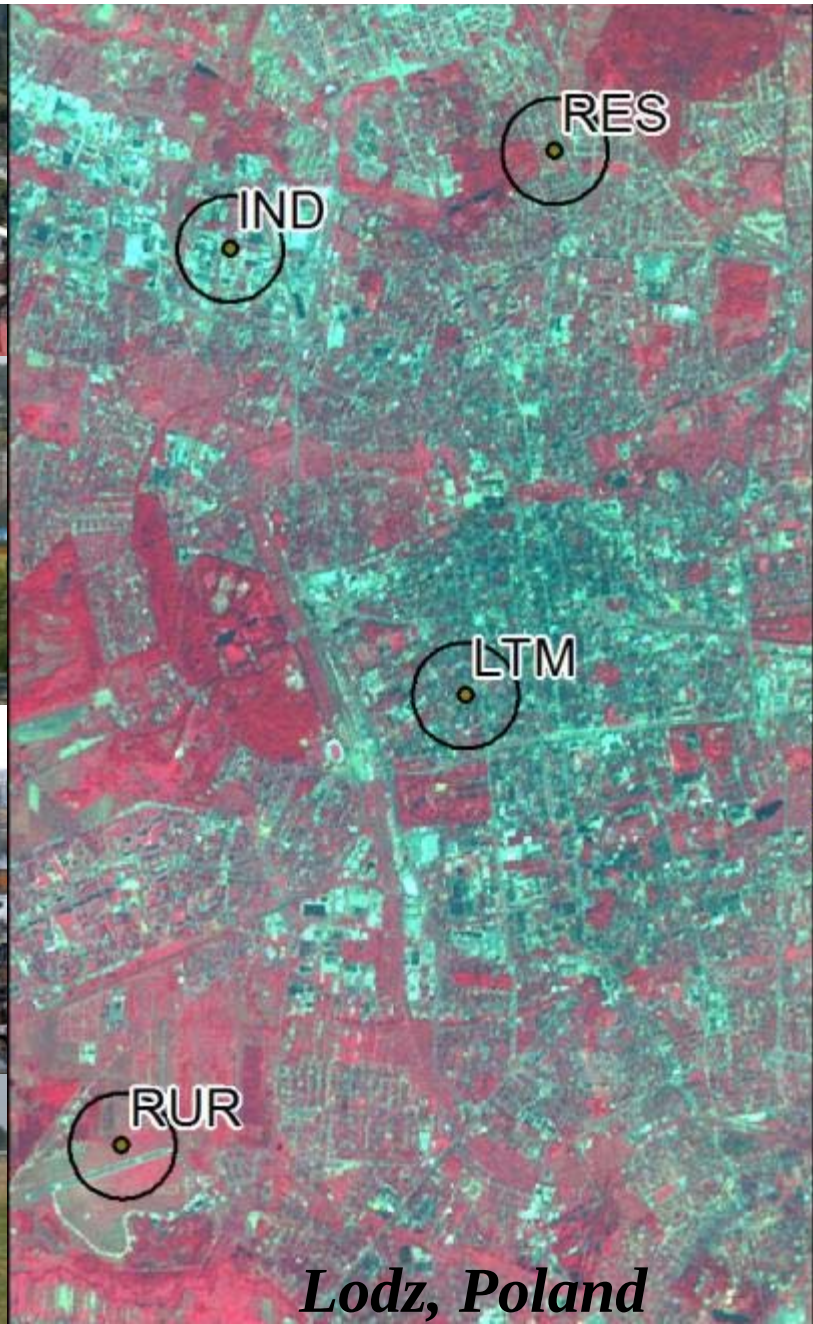
Spatial Variability in Urban Areas: Meteorological Perspective

Caused by:

- Differences in surface morphology
- Range of surface cover
- Additional anthropogenic sources of heat, water, other gases and particulates

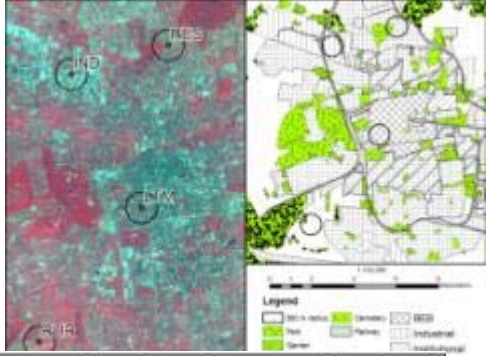

Variability Across a City

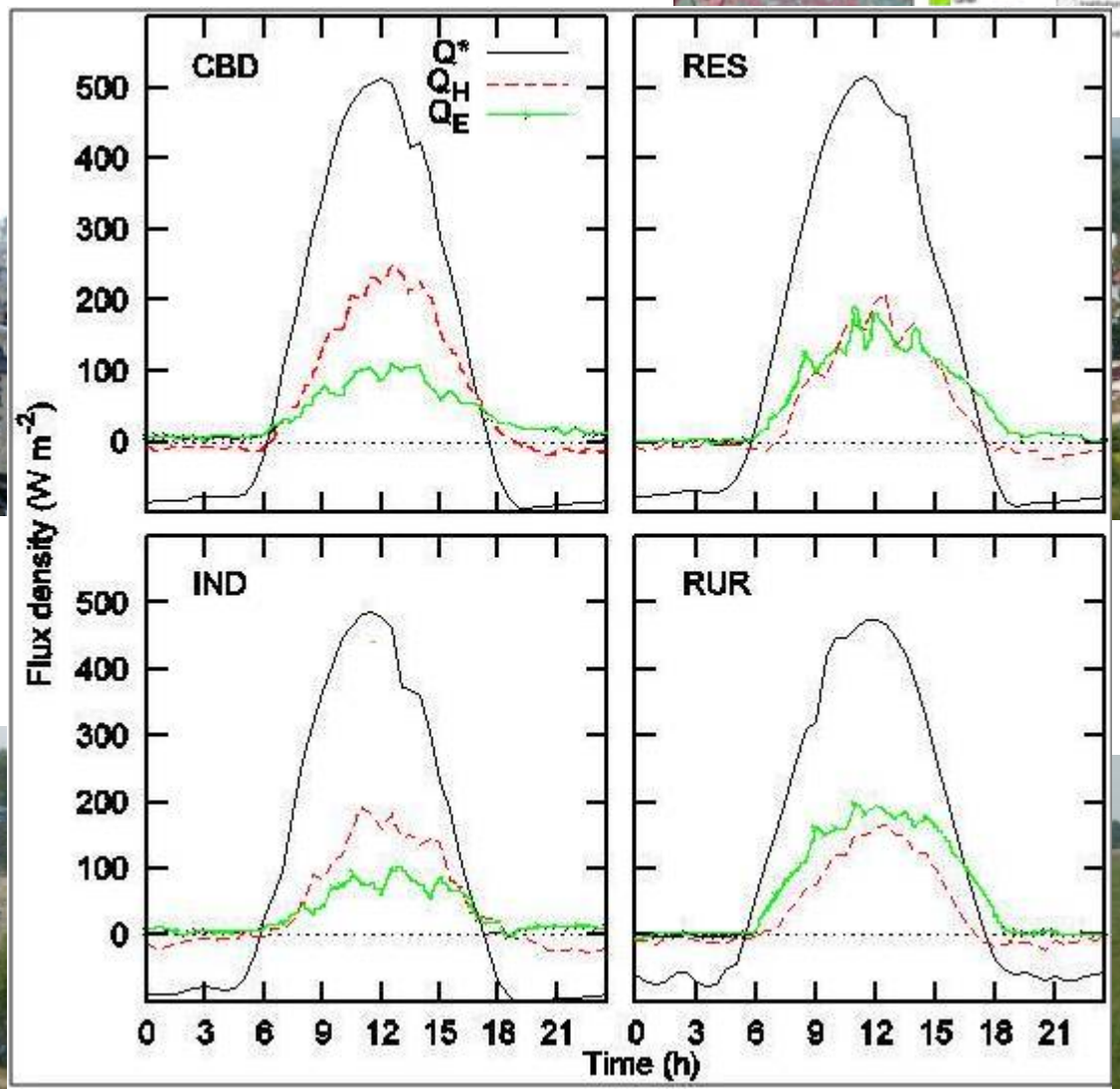


Variability Within a City
Ensemble Diurnal Fluxes: Lodz, Poland

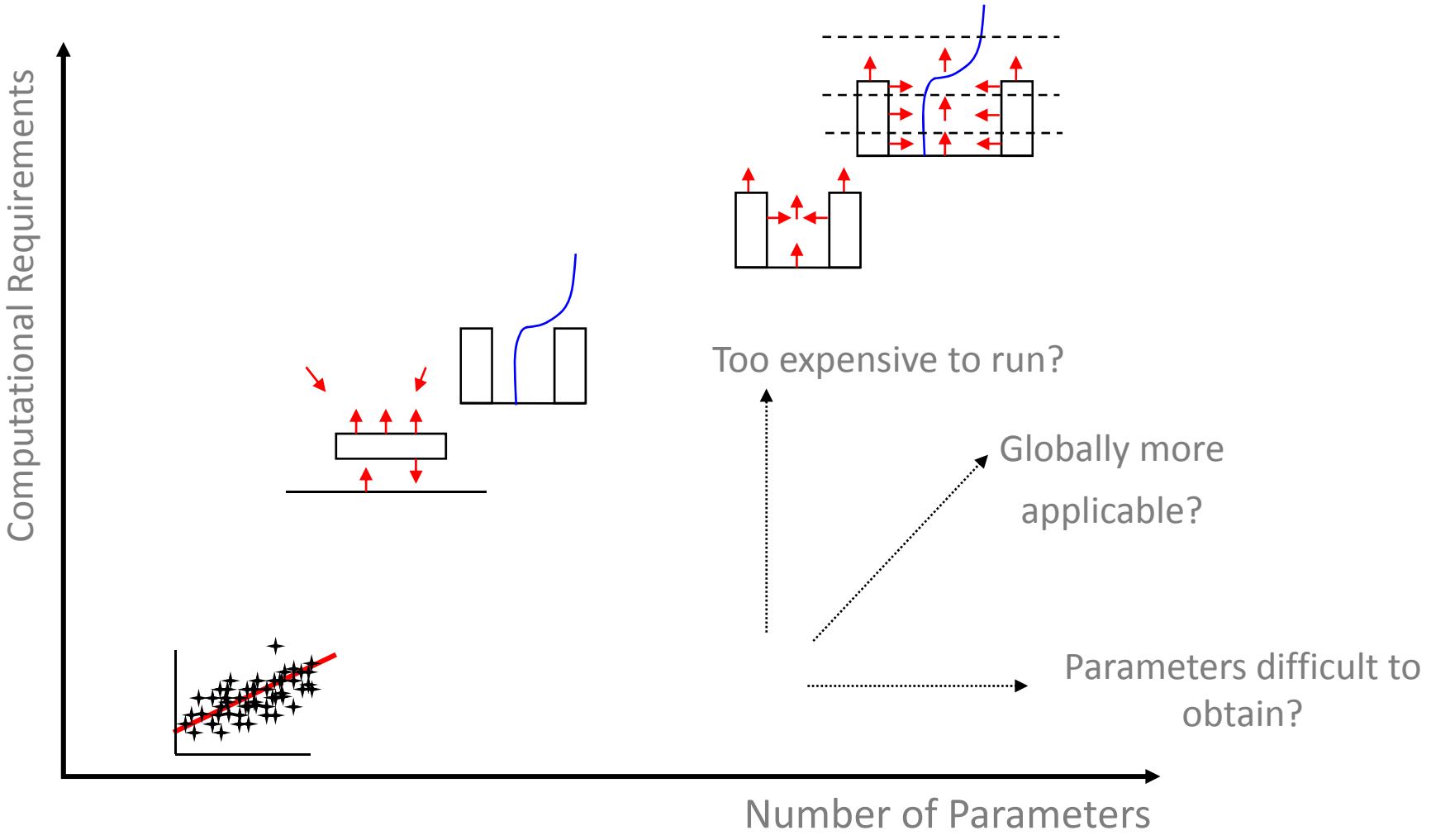
Offerle et al. 2006 JAMC

17 Aug – 2 Sept 2002





Urban Land Surface Schemes



Wide Spectrum of Urban Land Surface Schemes are Available

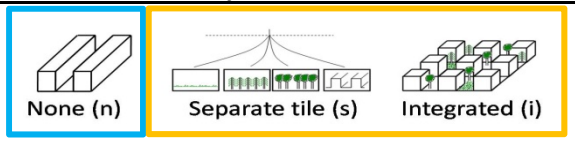
- Standalone models
  - TUF2D/ TUF3D
  - GCTTC
- Land surface schemes for
  - Mesoscale models
    - WRF
    - MM5
    - Meso-NH
  - Global Climate models
    - UM
    - CCSM
  - Operational Forecast Models
    - UK Met Office
    - Meteo France
    - Meteo Swiss

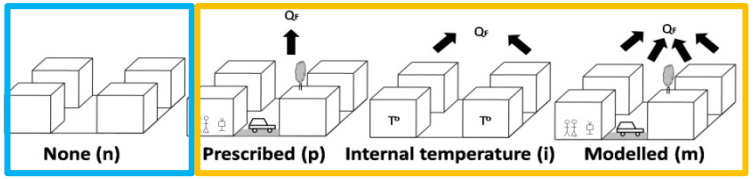
Model	*Participant(s)*
BEP02	Martilli
BEP_BEM08	Francisco
CLMU	Oleson
GCTTC	Shashua Bar
LUMPSv1	Loridan/Young
LUMPSv2	Loriidan/Young
MM5u	Dandou; Tombrou
JULES1K	Gouvea
JULES2K	Gouvea
JULES1T	Hendry; Best
JULES2T	Hendry; Best
JULES-Uv1	Porson
JULES-Uv1	Porson
IISUMC	Kawamoto
MUCM	Kondo
NJU-UCM-S	Zhang
NJU-UCM-M	Zhang
NSLUCM	Miao; Chen
NSLUCMK	Loridan
NSLUCMK-WRF	Steeneveld
RUM2	Bohnenstengel
RUM2v2	Bohnenstengel
RUM4	Bohnenstengel
RUM4v2	Bohnenstengel
SNUUCM	Ryu
SM2U	Calmet
SUEB	Fortuniak
SUMM	Kawai, Kanda
TEB	Pigeon; Masson
TEB07	Hamdi
TUF2D	Krayenhoff; Voogt
TUF3D	Krayenhoff; Voogt
VUCM	Lee; Baik

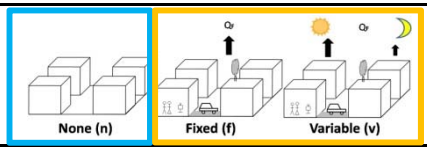
Wide Range of Ways to Classify, Varying Levels of Complexity

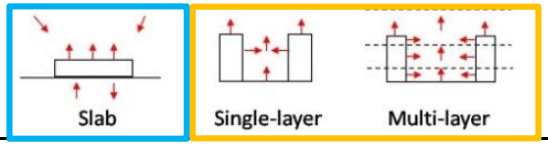
Category complexity: Simple → Complex

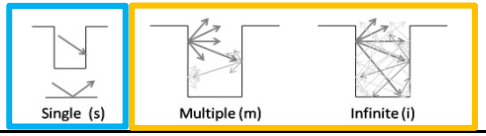
	Class	Capability	1	2	3	4	Representation
1	Vegetation (V)						
	Not included (n)	9	12	9	9	9	
	Separate tile (s)*	18	15	18	18	18	
	Integrated (i)*	5	5	5	5	5	
2	Q_F (AN)						
	Negligible or ignored (n)	12	21	21	21	21	
	Prescribed (p)*	5	2	2	2	2	
	Internal Temp. (i)*	4	4	4	4	4	
	Modelled (m)*	5	3	3	3	3	
	i,p*	6	2	2	2	2	
3	Temporal Q_F variation (T)						
	None (n)	12	21	21	21	21	
	Fixed (f)	6	3	3	3	3	
	Variable (v)	14	8	8	8	8	
4	Urban Morphology (L)						
	Slab(s)	11	11	11	11	11	
	Single layer(1)	12	13	13	13	13	
	Multiple layer (m)	9	8	8	8	8	
5	Facets & orientation (FO)						
	Whole (w)*	5	5	5	5	5	
	No orientation (n)*	12	16	16	16	16	
	Orientation (o) no intersections†	10	6	6	6	6	
	Orientation (i) with intersections†	5	5	5	5	5	
6	Reflection (R)						
	Single (s)	11	11	11	11	11	
	Multiple (m)	14	14	14	14	14	
	Infinite (i)	7	7	7	7	7	
7	Albedo, Emissisivity (AL)						
	Bulk (b)*	5	6	5	5	5	
	Two facets (2)*	6	6	6	6	6	
	Three or more facets (f)	21	20	21	21	21	
8	ΔQ_S (S)						
	Residual (r)*	5	6	6	6	6	
	Conduction (c)	24	23	23	23	23	
	Net radiation based (n)*	3	3	3	3	3	

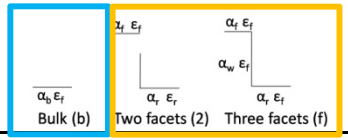


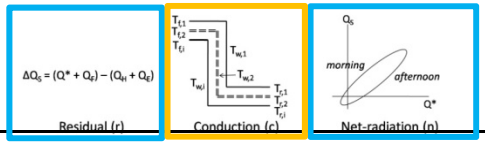








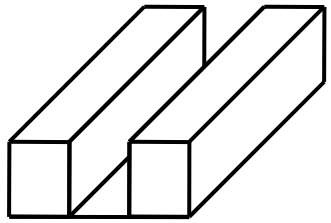




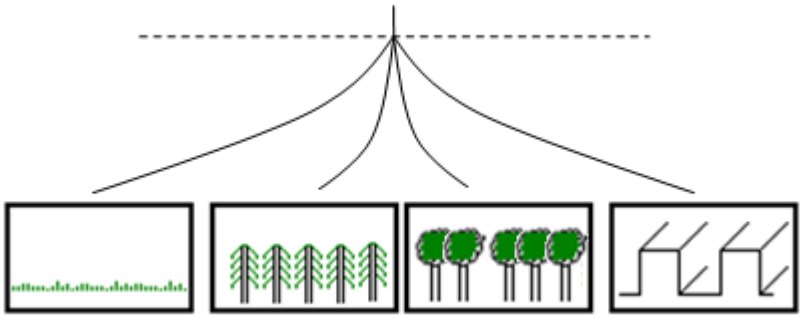
(Grimmond et al. 2009)

Vegetation

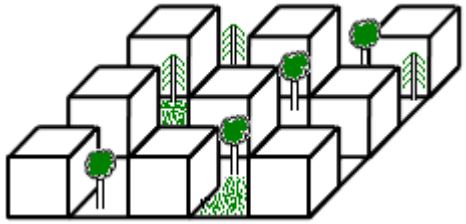
- **None**
  - Assumed no vegetation present



- **Separate Tile**
  - Vegetated and Built fractions treated separately
  - do not interact until above the LSS
  - fluxes are a spatially weighted mean



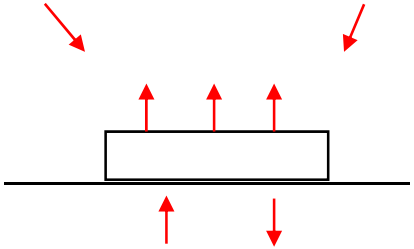
- **Integrated**
  - vegetation is within the tile that has the buildings
    - Built/vegetation exchanges can occur



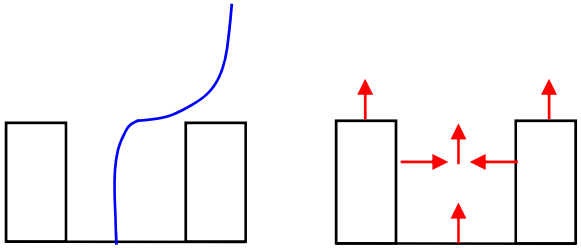
Grimmond et al. (2009)

Layers resolved

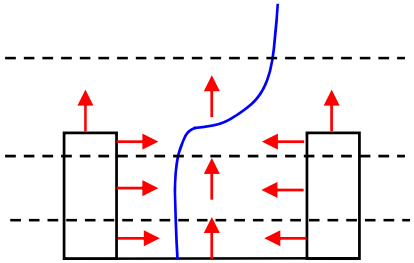
- Slab



- Single layer



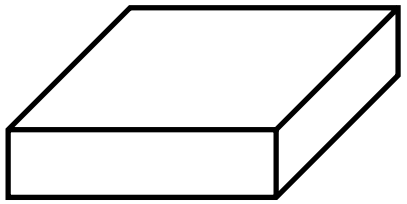
- Multi-layer



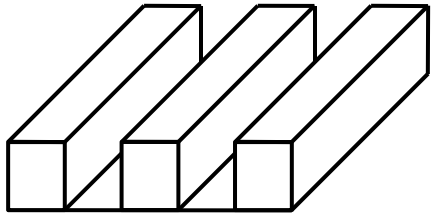
Grimmond et al. (2009)

Facets and Orientations Resolved

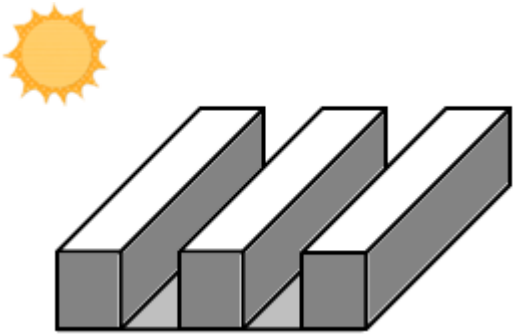
- **Whole/Bulk**
  - individual walls, roof, road are not resolved

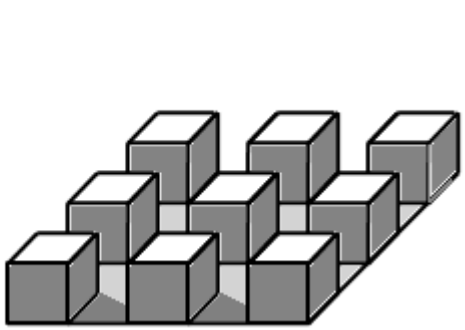


- **Roof, Wall and road are resolved but <u>without</u> orientation**
  - ⇒ sunlit and shaded facets not resolved



- **Roof, Walls and road are resolved <u>with</u> orientation**
  - ⇒ during the daytime there maybe sunlit and shaded facets

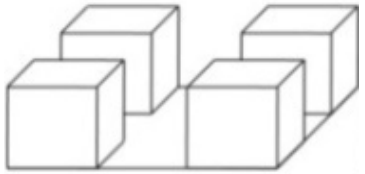




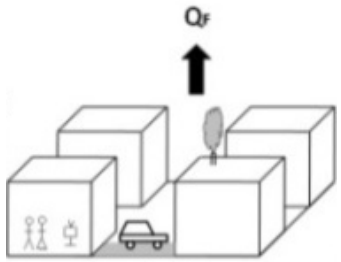
Grimmond et al. (2009)

Anthropogenic Heat Flux

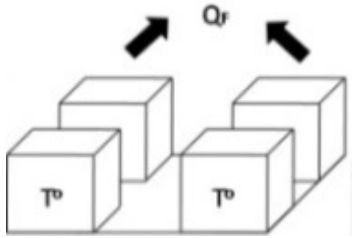
- **None**
  - Flux is assumed to be 0 W m^{-2} or not to exist



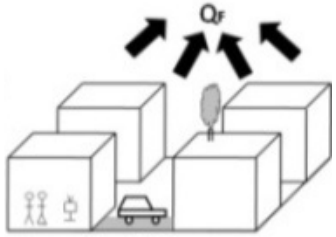
- **Prescribed**
  - Flux value is prescribed, consider either:
    - Some components (partial)
    - All components



- **Internal Temperature**
  - An internal temperature is prescribed which is used to calculate the other fluxes



- **Modelled**
  - All or components of the flux are modelled



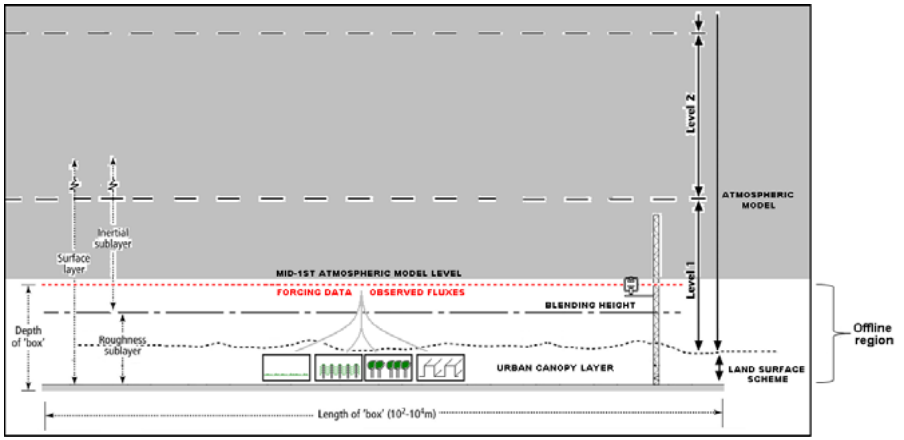
Grimmond et al. (2009)

Phase 1: International Urban Energy Balance Model Comparison: VL92

- Provided with: forcing & observational data for Vancouver Light Industrial site (VL92)
  - Short data set (+14 days)
  - Irrigation ban and limited vegetation present
  - Previously used for model evaluation
    - Voogt & Grimmond (2000, JAM) ARM
    - Grimmond & Oke (2002, JAM) LUMPS
    - Masson et al. (2002, JAM) TEB
    - Best et al. (2006, BLM) MOSES/JULES
    - Oleson et al. (2008, JAMC) CLMU
    - Porson & Belcher

⇒Reasonable estimate of parameter values

- Analysis using hourly values



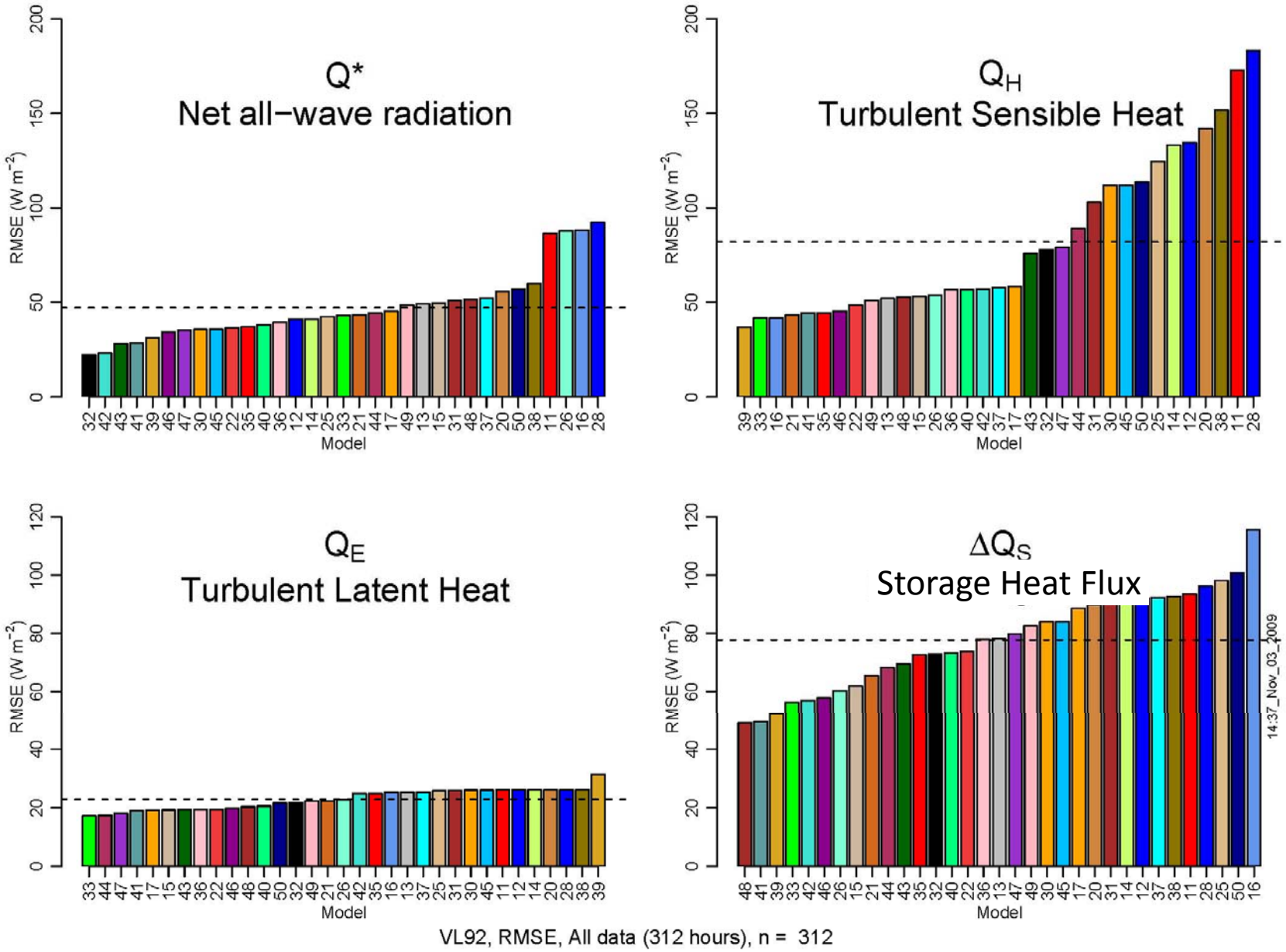
Summary RMSE (W m^{-2}), 33 Models: First & Final VL92 runs

ALPHA
(Phase 2)

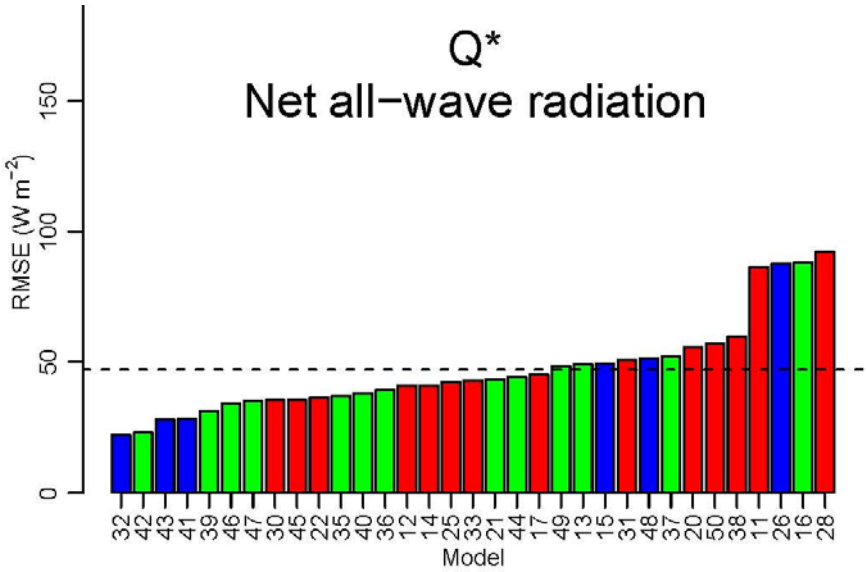
VL92 Results

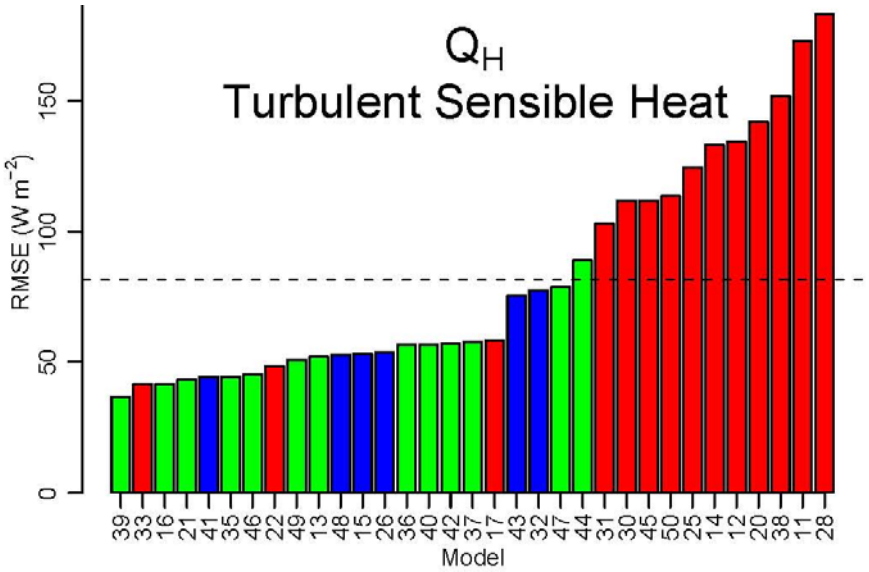
Statistic	1st Run	'Final' Run	Difference
Q* Net All Wave Radiation			
Mean	58.4	47.0	⇓
Maximum	177.9	92.3	⇓
Minimum	28.4	22.1	⇓
Q_H Turbulent Sensible Heat Flux			
Mean	95.5	81.7	⇓
Maximum	233.3	183.1	⇓
Minimum	39.3	36.8	⇓
Q_E Turbulent Latent Heat Flux			
Mean	30.0	23.0	⇓
Maximum	157.4	31.5	⇓
Minimum	17.2	17.2	
ΔQ_S Net Storage Heat Flux			
Mean	87.8	77.8	⇓
Maximum	311.4	115.7	⇓
Minimum	49.1	49.1	⇓

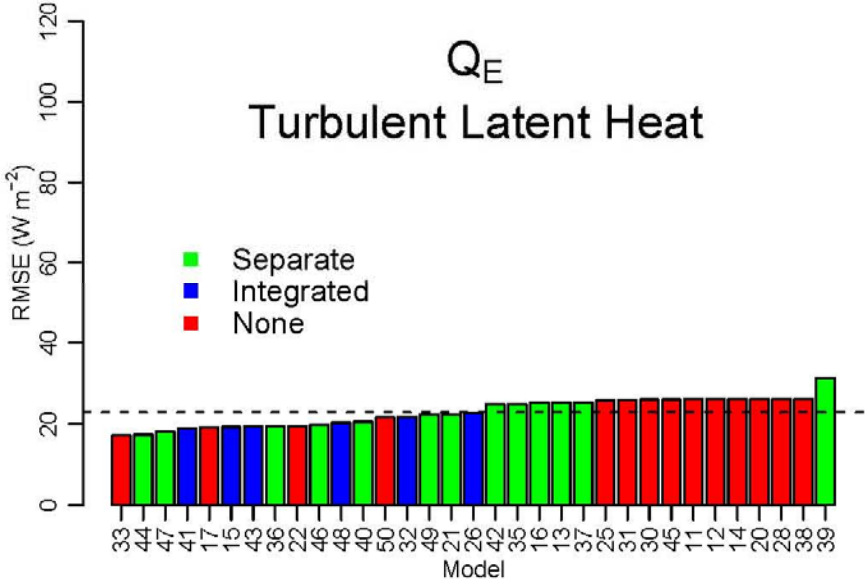
VL92: Ranked RMSE (W m^{-2}), All hours

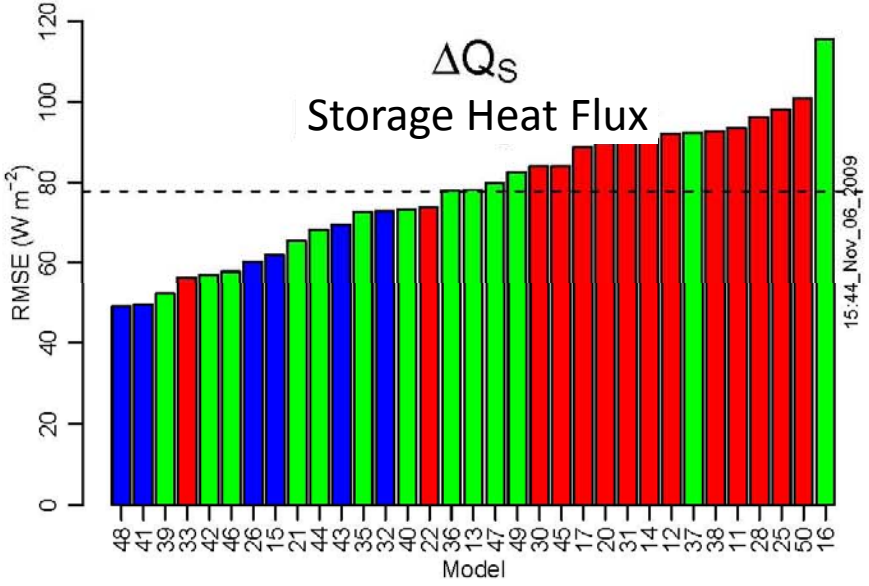


VL92: RMSE (W m^{-2}) – classified by Vegetation method, All hours

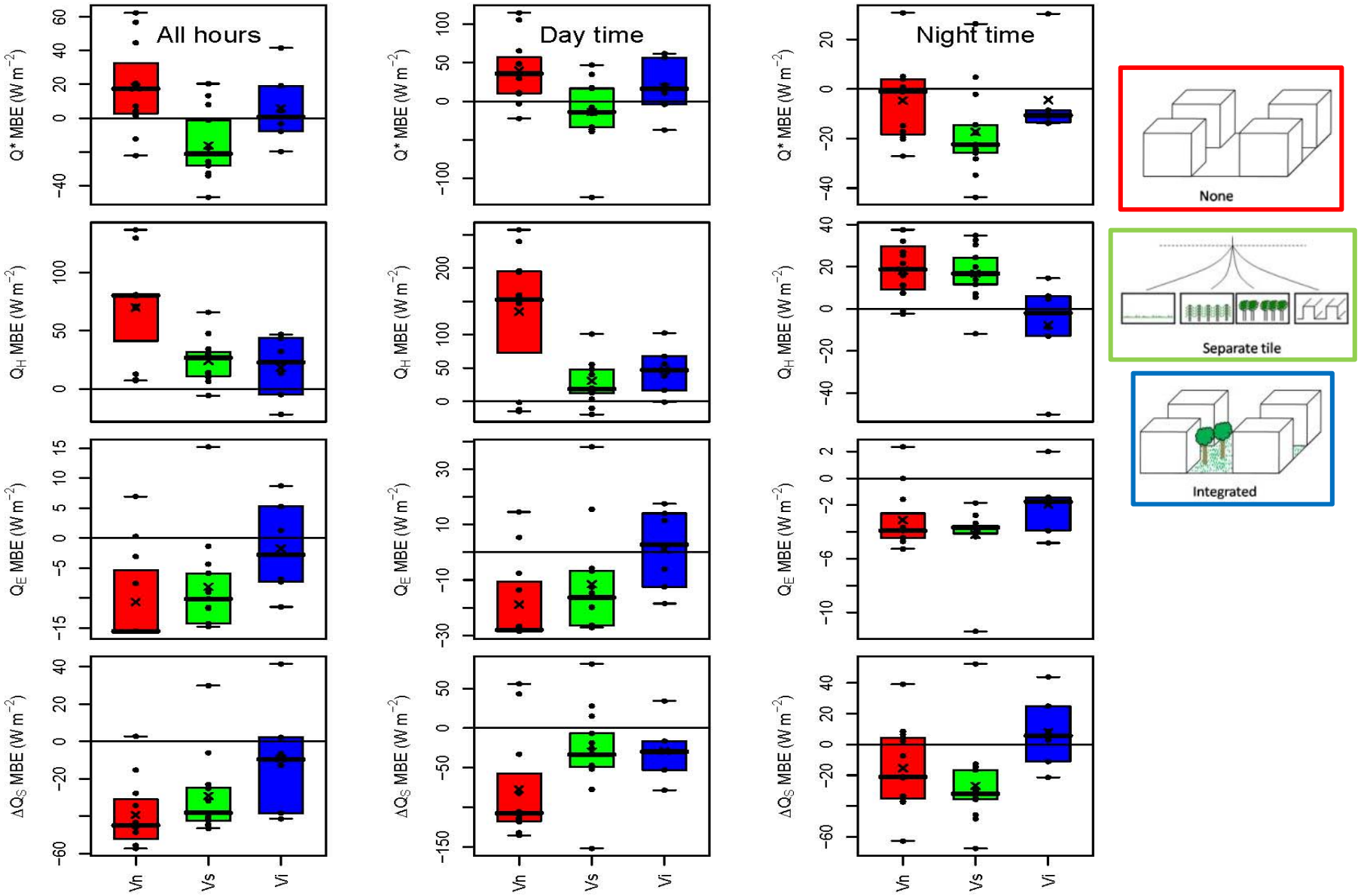




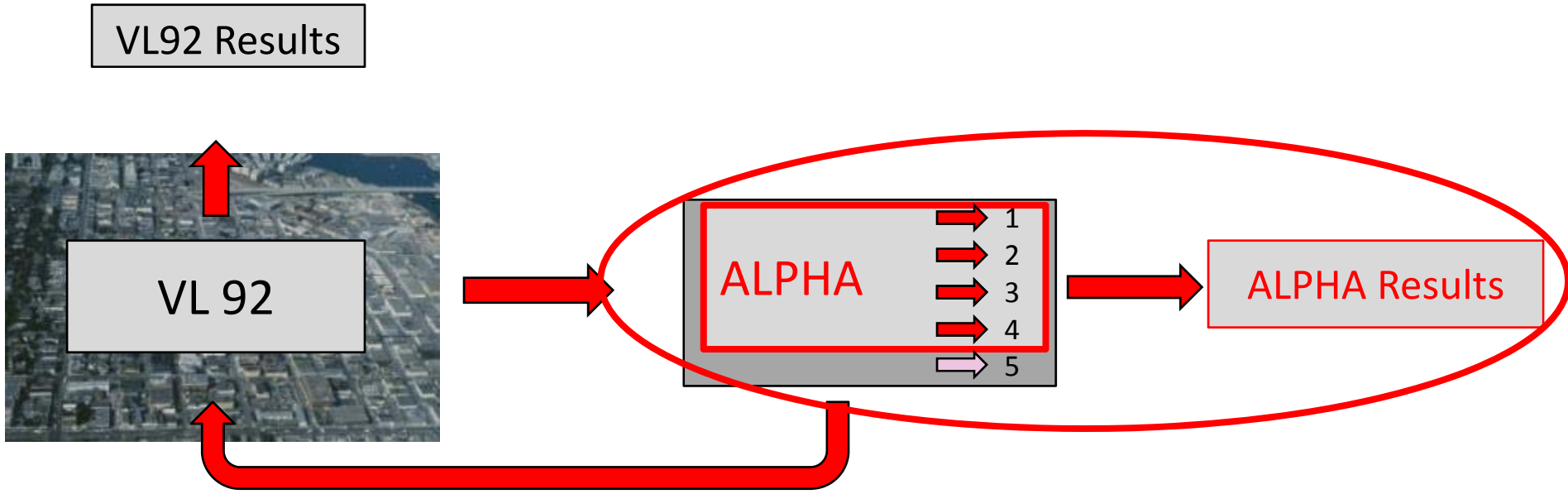




VL92: MBE (W m^{-2}), Vegetation method, All, Day, Night



Alpha Runs



Alpha data:

- Unknown site
- 18 months, 30-min data
- Last 12 months analysed

Day n = 3010
Night n = 4407

Alpha Stages

Forcing data – netcdf or ASCII

K↓	L↓	Wind (N)	Wind (E)	Station Pressure	T_{air}	q_{air}	Rainfall

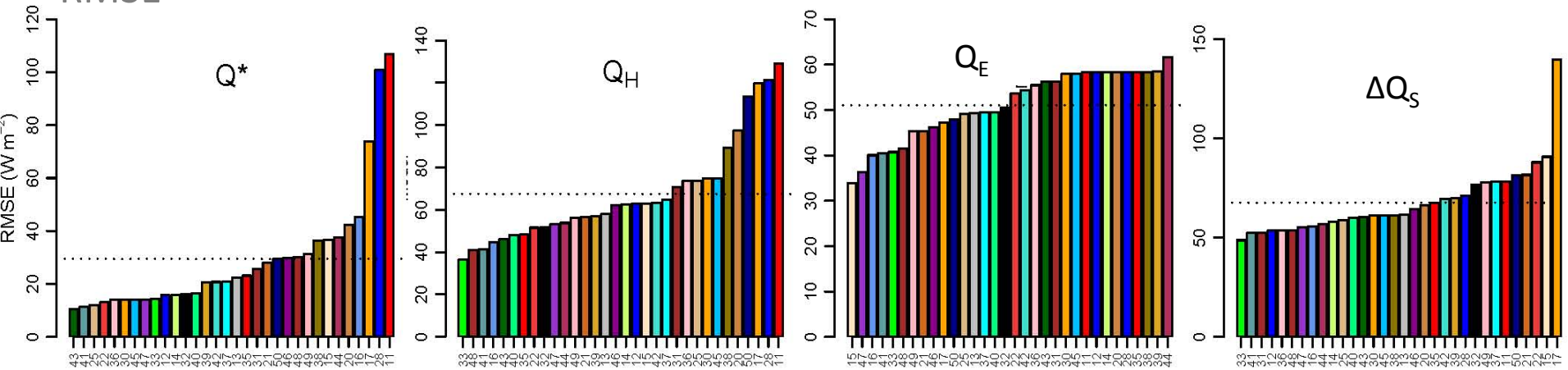
Stages: Parameter Data

	Category	Data provided
1	**Observations**	Forcing data
	Site	Latitude, Longitude, $z_m=6.25z_0$
2	**Plan area fraction**	Pervious, Impervious.
3	**Heights**	z_m, z_0, z_H, z_B, H:W, W:P
	Plan area fraction	Buildings, concrete, road, vegetation (excl. grass), grass and other (bare, pools)
	Other	UCZ; population density
4	**Material characteristics**	d, C, volumetric heat capacity, λ, type: road, roof and wall layers

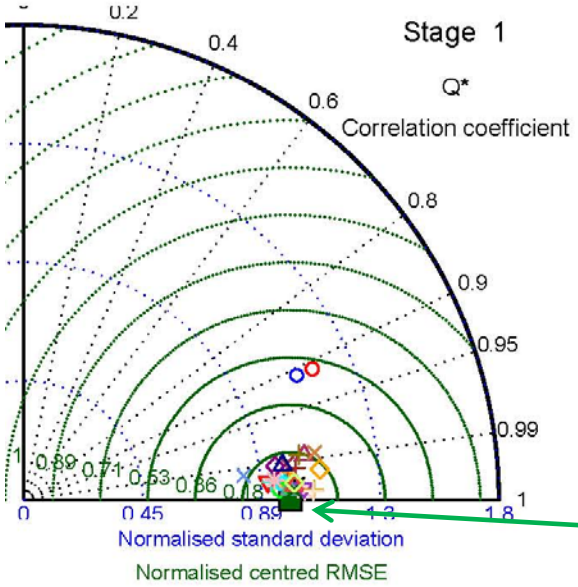
Increasing amount of information about the site, no knowledge of flux measurements

Alpha Stage 1 Results: All hours last 12 months n=8520

- RMSE



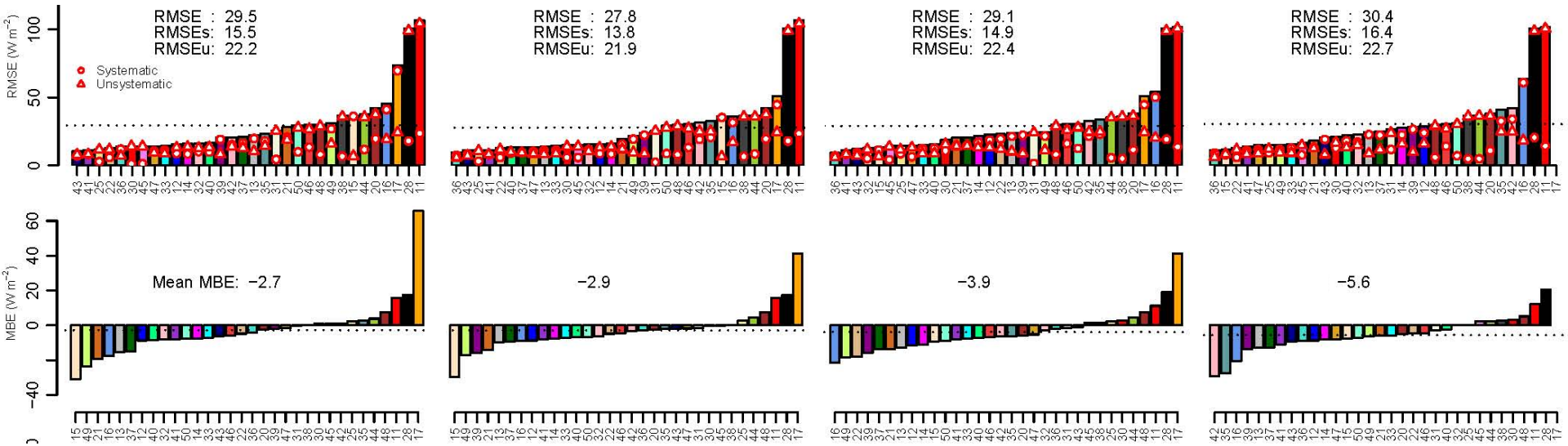
- Taylor Plot

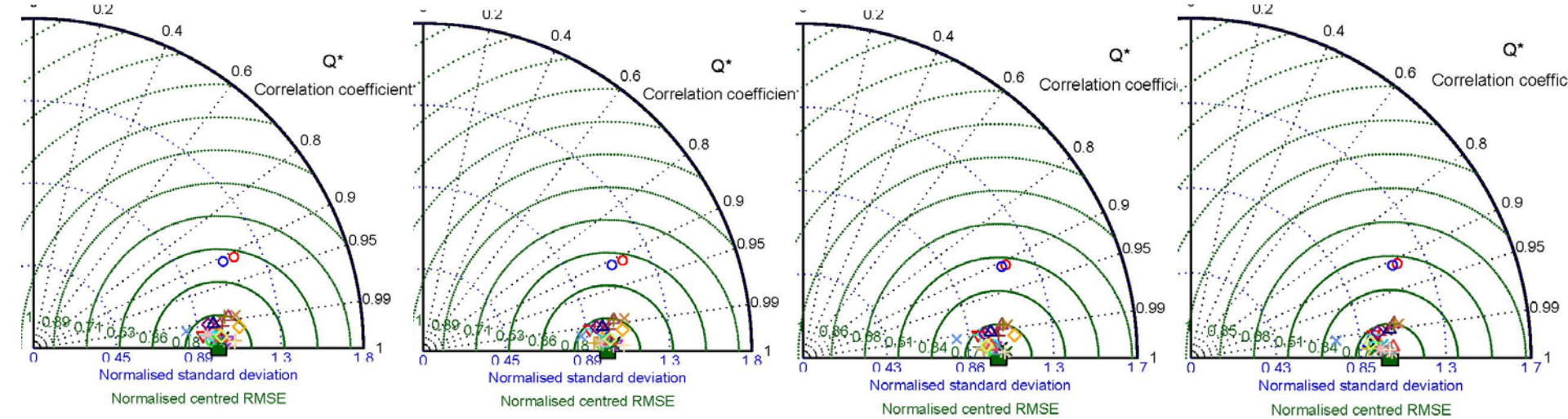


Green square (observations)

Alpha Stages 1-4 Q* Results: All hours last 12 months n=8520 Mean Observed Flux= 78.9 W m^{-2}

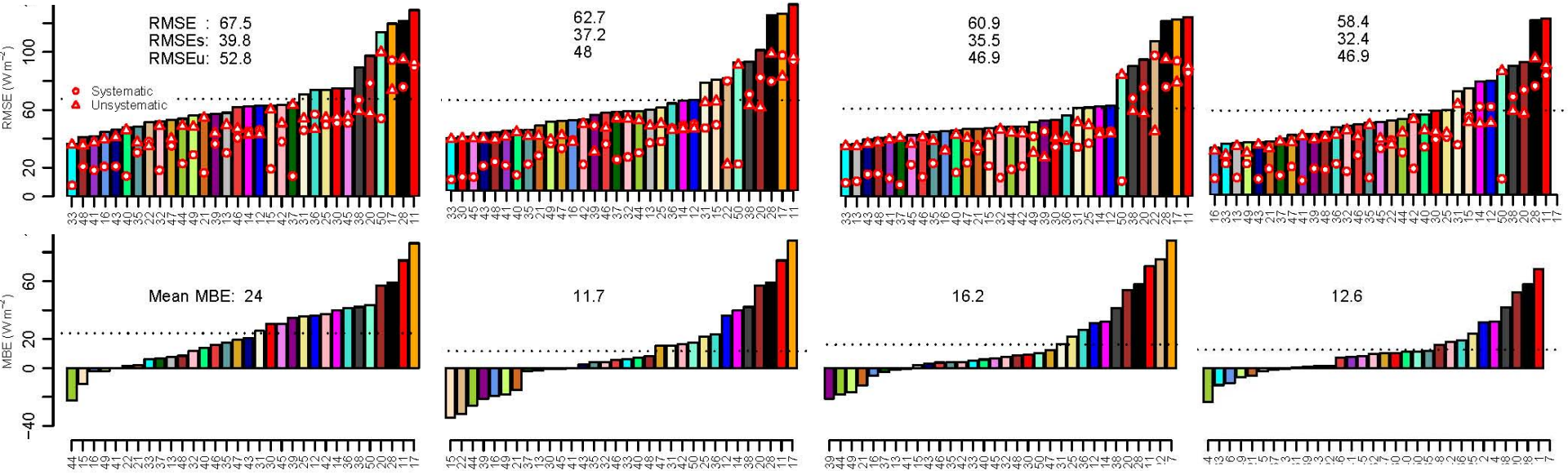
Stage 1	Stage 2	Stage 3	Stage 4
• Forcing data • Ltd. site details	• Plan area fractions (pervious/impervious)	• More areal fractions • Heights, population	• Material characteristics

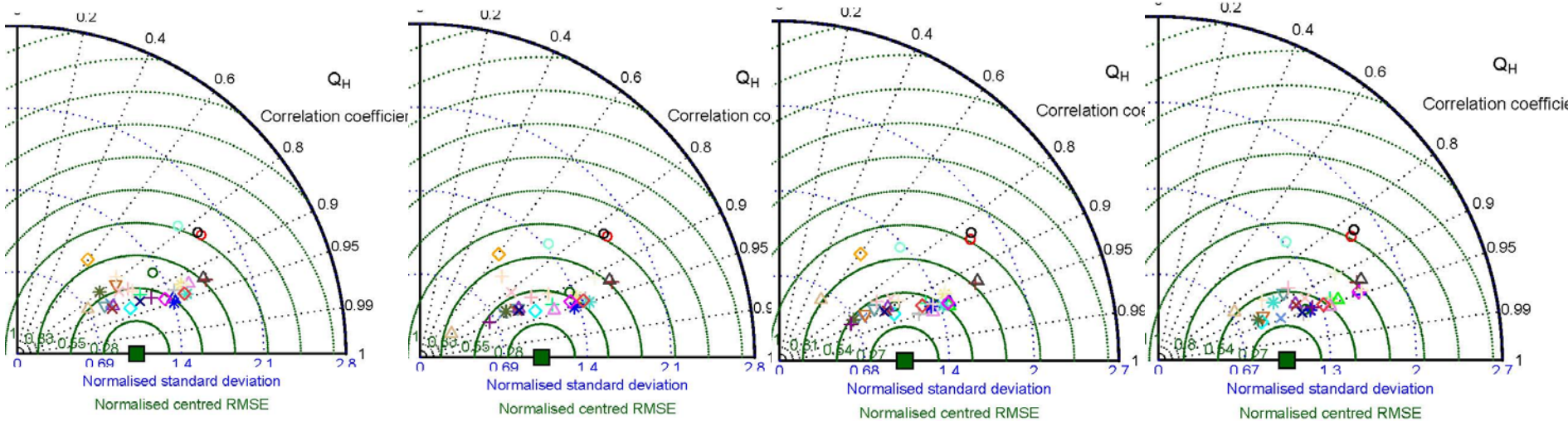




Alpha Stages 1-4 Q_H Results: All hours last 12 months n=8520 Mean Observed Flux= 37.9 W m^{-2}

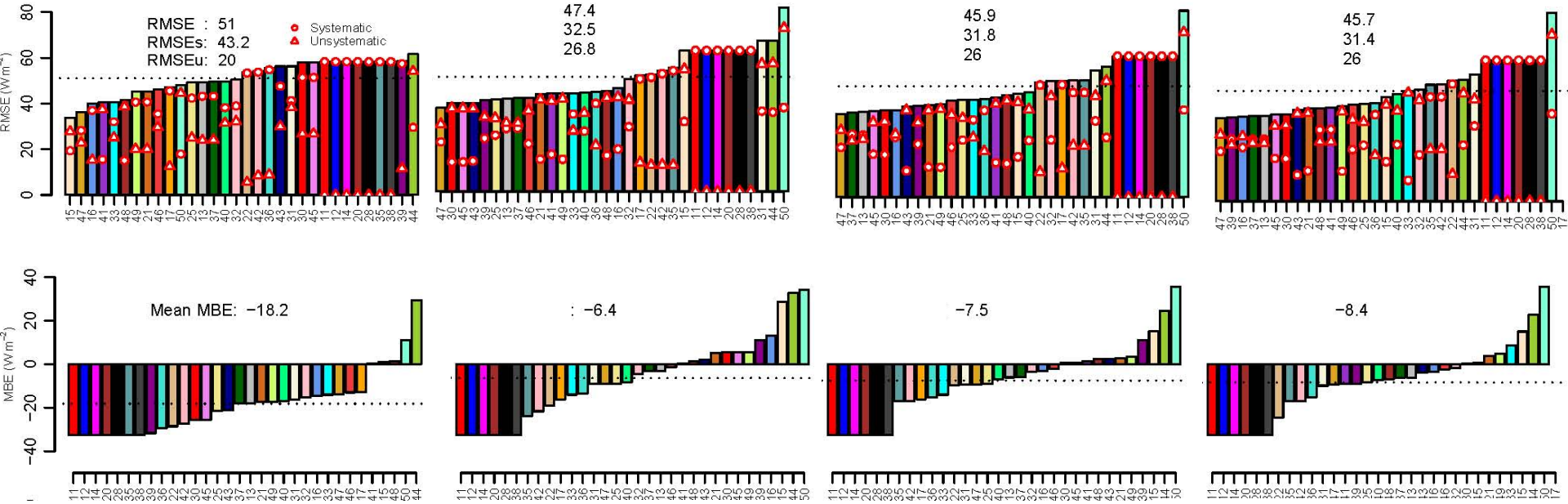
Stage 1	Stage 2	Stage 3	Stage 4
• Forcing data • Ltd. site details	• Plan area fractions (pervious/impervious)	• More areal fractions • Heights, population	• Material characteristics

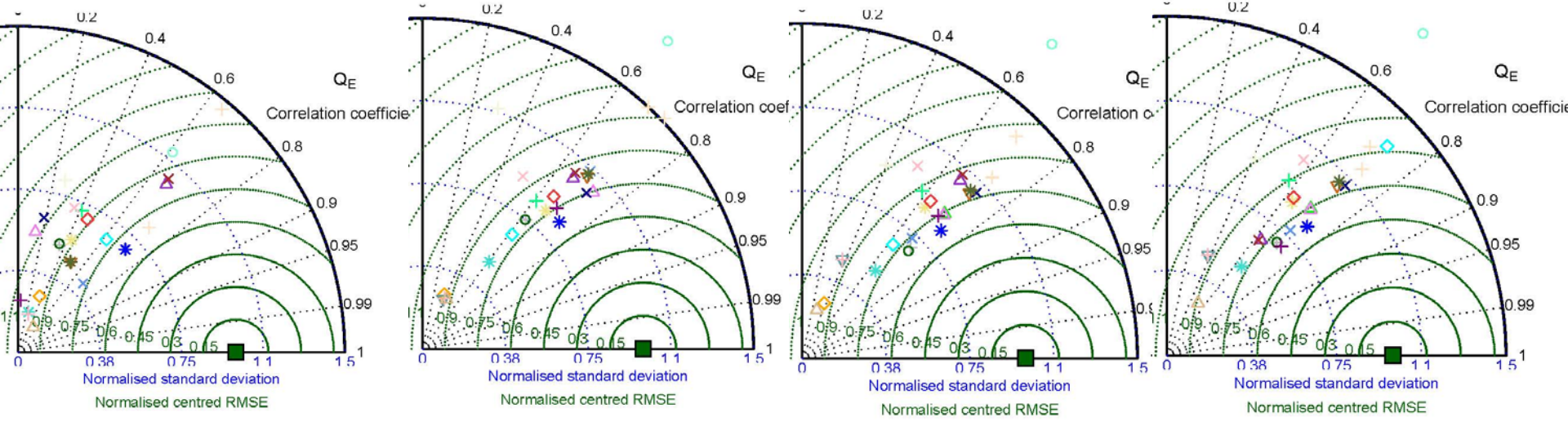




Alpha Stage 1-4 Q_E Results: All hours last 12 months n=8520 Mean Observed Flux = 32.5 W m^{-2}

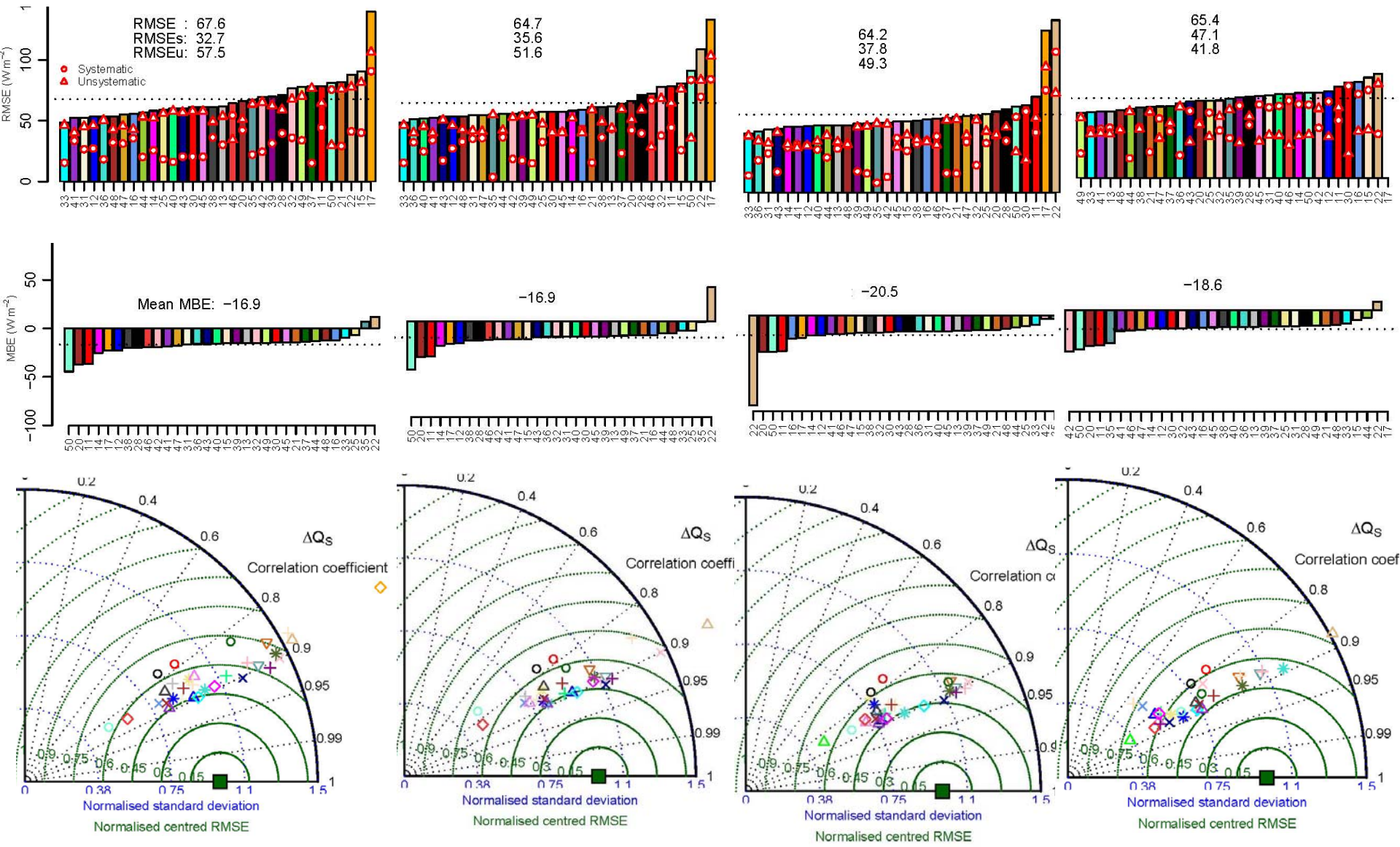
Stage 1	Stage 2	Stage 3	Stage 4
• Forcing data • Ltd. site details	• Plan area fractions (pervious/impervious)	• More areal fractions • Heights, population	• Material characteristics



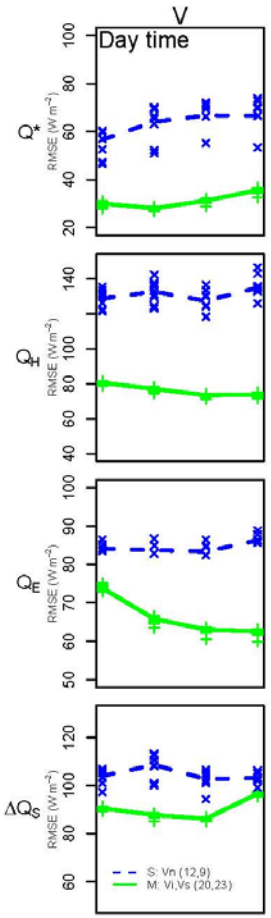


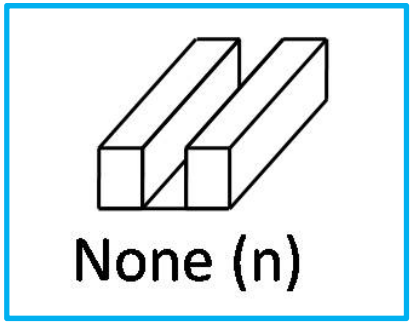
Alpha Stage 1-4 ΔQ_S Results: All hours last 12 months n=8520 Mean Observed Flux= 19.0 W m^{-2}

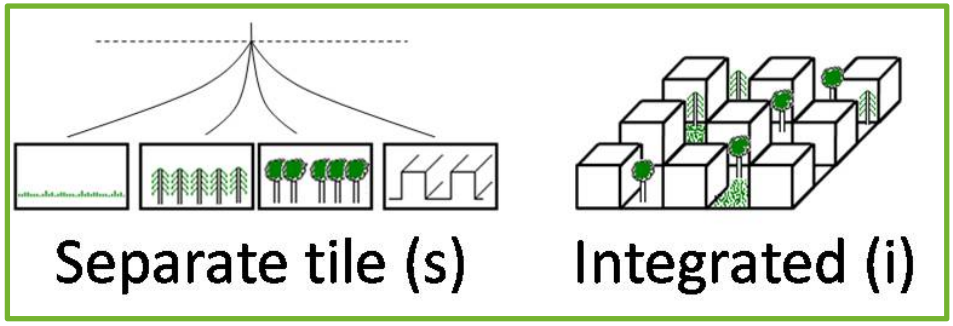
Stage 1	Stage 2	Stage 3	Stage 4
• Forcing data • Ltd. site details	• Plan area fractions (pervious/impervious)	• More areal fractions • Heights, population	• Material characteristics



Alpha Day-time mean RMSE by Model Class: Vegetation

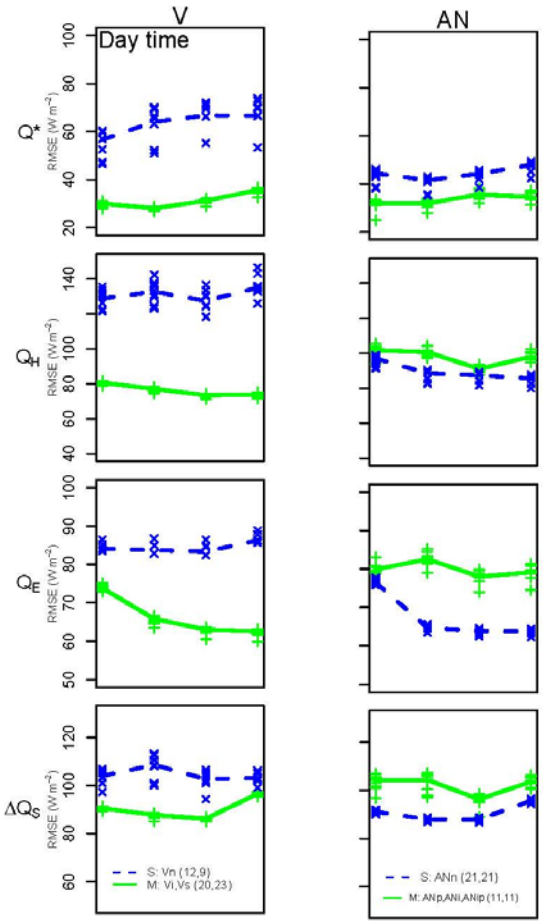




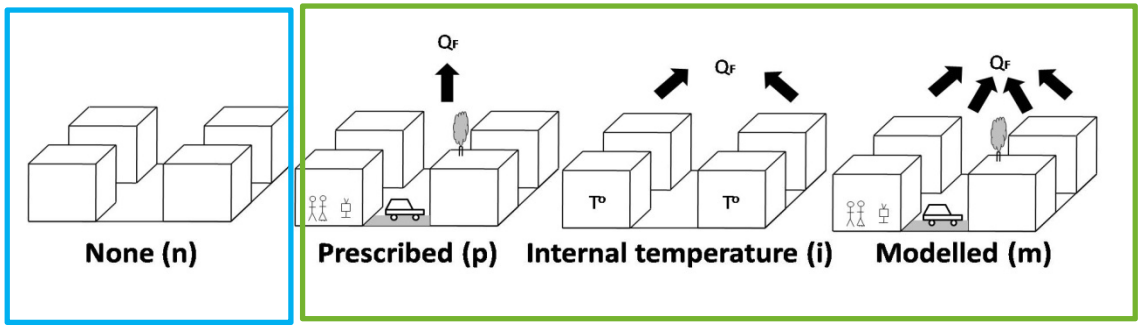


	Vegetation
Simple	None (n)
Medium	Integrated (i)
Complex	

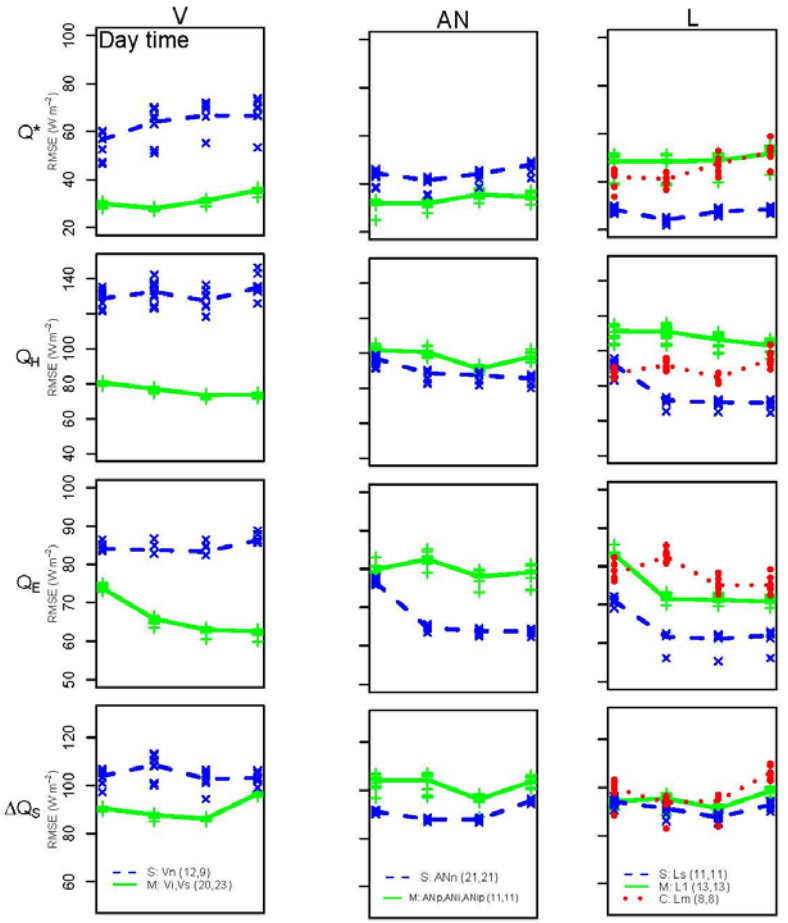
Alpha Day-time mean RMSE by Model Class: Anthropogenic Heat Flux

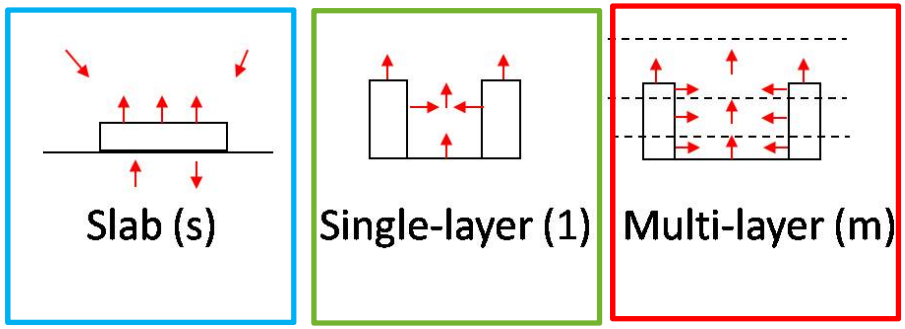


	Vegetation	Anthrop flux
Simple	None (n)	None (n)
Medium	Integrated (i)	Modelled (m)
Complex		



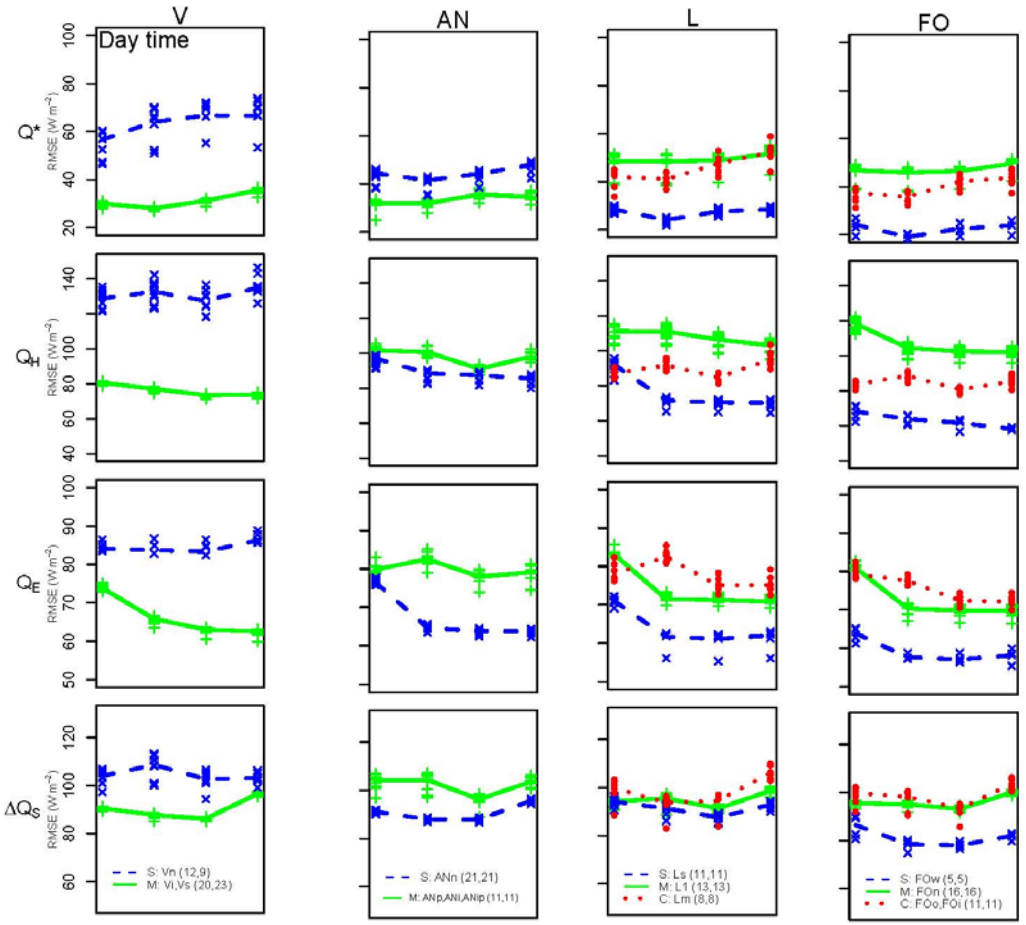
Alpha Day-time mean RMSE by Model Class: Urban Morphology

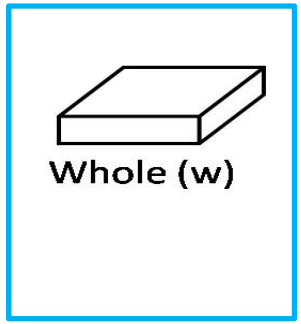


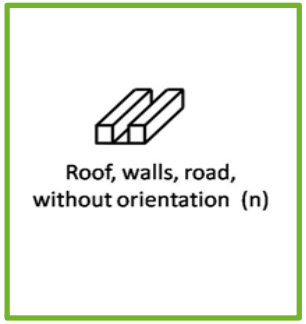


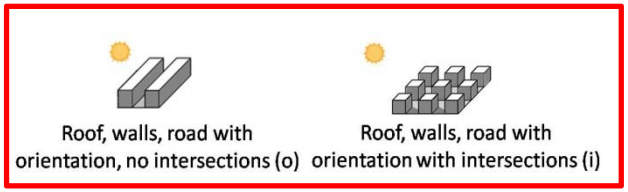
	Vegetation	Anthrop flux	Urban morph
Simple	None (n)	None (n)	Slab (s)
Medium	Integrated (i)	Modelled (m)	Single (1)
Complex			Multiple (m)

Alpha Day-time mean RMSE by Model Class: **Facets/Orientation**



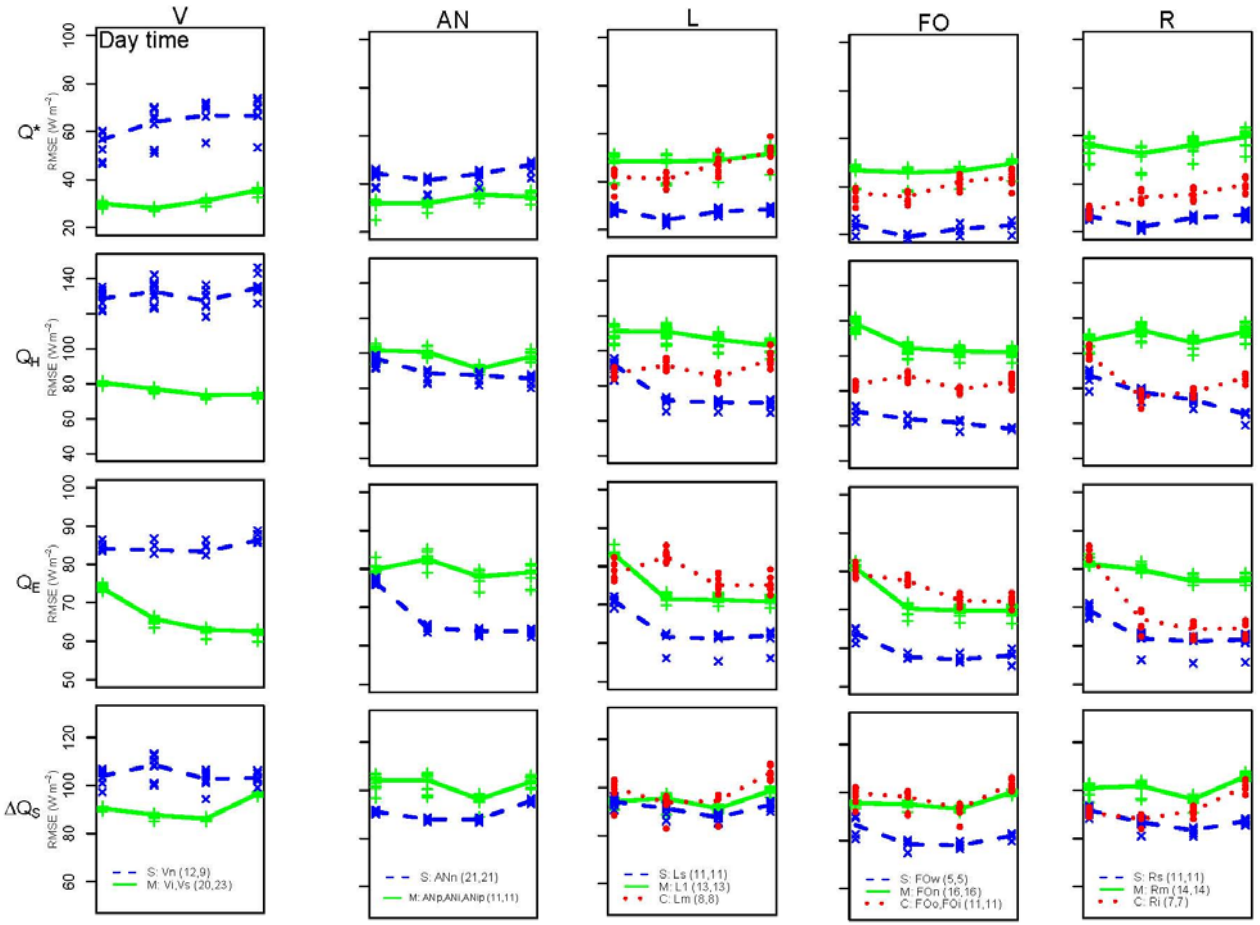


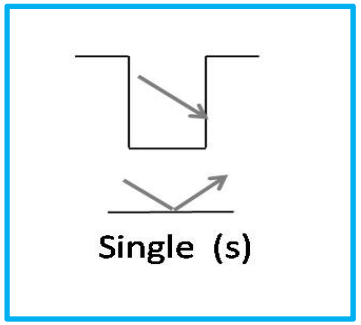


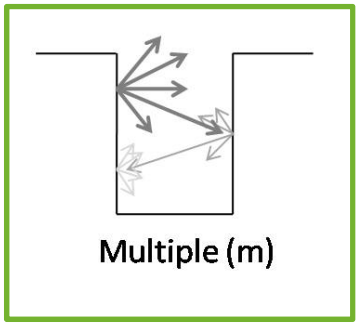


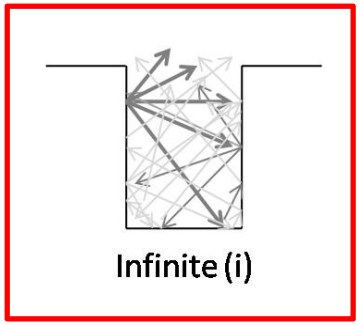
	Vegetation	Anthrop flux	Urban morph	Facets/orient
Simple	None (n)	None (n)	Slab (s)	Whole (w)
Medium	Integrated (i)	Modelled (m)	Single (1)	No orien. (n)
Complex			Multiple (m)	Orient & Inters (i; o)

Alpha Day-time mean RMSE by Model Class: Reflections



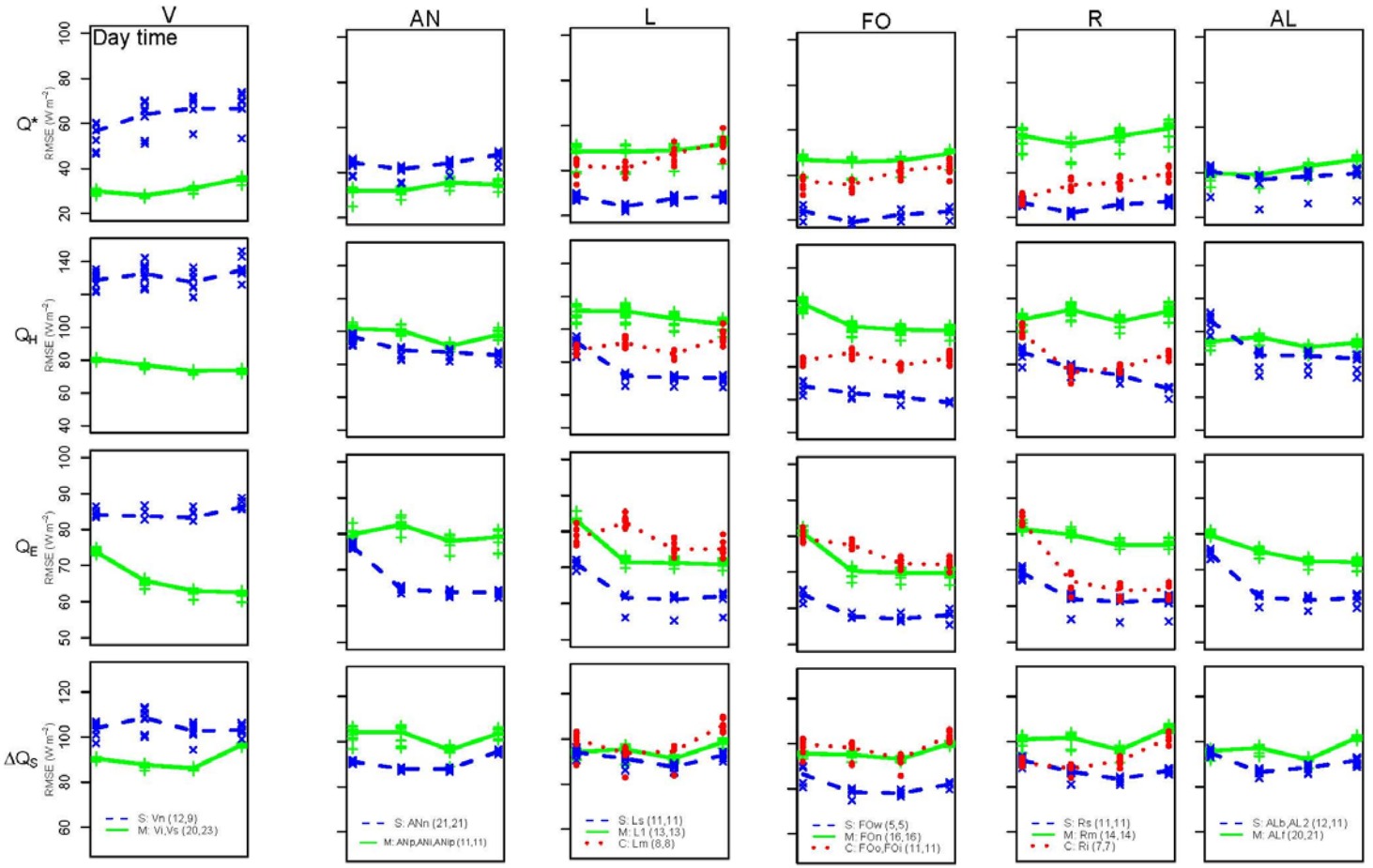






	Vegetation	Anthrop flux	Urban morph	Facets/orient	Reflection
Simple	None (n)	None (n)	Slab (s)	Whole (w)	Single (s)
Medium	Integrated (i)	Modelled (m)	Single (1)	No orien. (n)	Multiple (m)
Complex			Multiple (m)	Orient & Inters (i; o)	Infinite (i)

Alpha Day-time mean RMSE by Model Class: Albedo/emissivity



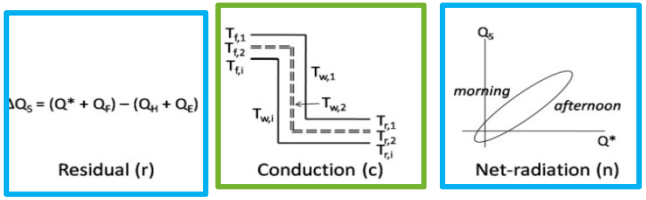
$\overline{\alpha_b\ \varepsilon_f}$
Bulk (b)

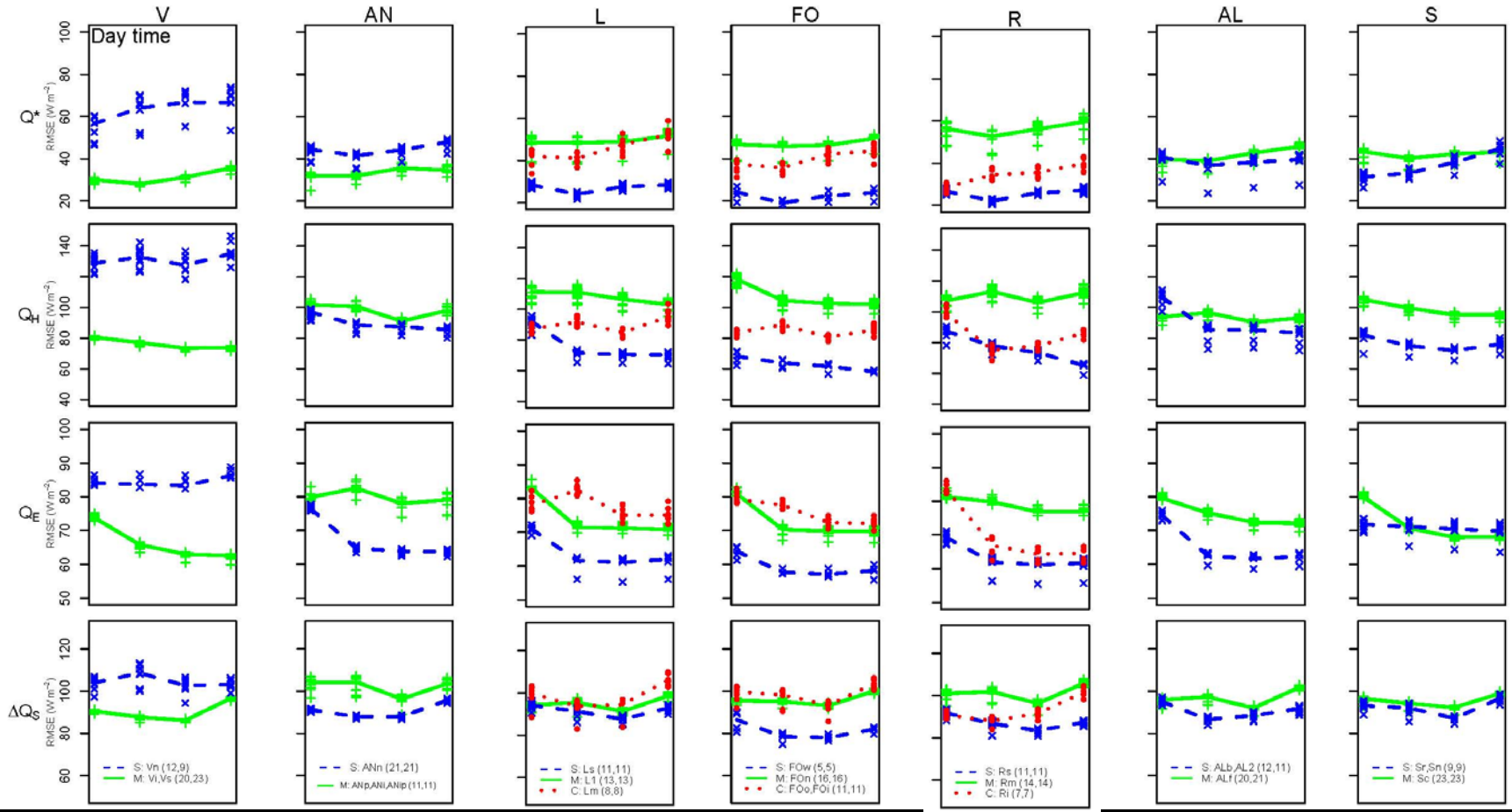
$\alpha_f\ \varepsilon_f$
$\alpha_r\ \varepsilon_r$
Two facets (2)

$\alpha_f\ \varepsilon_f$
$\alpha_w\ \varepsilon_f$
$\alpha_r\ \varepsilon_f$
Three facets (f)

	Vegetation	Anthrop flux	Urban morph	Facets/orient	Reflection	Albedo/emisiv
Simple	None (n)	None (n)	Slab (s)	Whole (w)	Single (s)	≤ 2facets (2)
Medium	Integrated (i)	Modelled (m)	Single (1)	No orien. (n)	Multiple (m)	> 2 facets (f)
Complex			Multiple (m)	Orient & Inters (i; o)	Infinite (i)	

Alpha Day-time mean RMSE by Model Class: ΔQ_S





	Vegetation	Anthrop flux	Urban morph	Facets/orient	Reflection	Albedo/emisiv	ΔQ_S
Simple	None (n)	None (n)	Slab (s)	Whole (w)	Single (s)	≤ 2facets (2)	Residual & net (r, n)
Medium	Integrated (i)	Modelled (m)	Single (1)	No orien. (n)	Multiple (m)	> 2 facets (f)	Conduction(c)
Complex			Multiple (m)	Orient & Inters (i; o)	Infinite (i)		

Final Comments

	Alpha RMSE (W m^{-2})				
	Largest Sys/Uns	Stage 1	Stage 4	Improvement ?	General Observations
Q*	U	29.5	30.4	✘	• **Best modelled flux** • Mean (small) underestimation
Q_H	U	67.5	58.4	✓	• Generally overestimation • Inconsistent trends with stage
Q_E	S	51	45.7	✓	• General underestimation • Consistently, lowest R^2 • Many schemes do not model this
ΔQ_S	U	67.6	65.4	✓	• General underestimation • Systematic RMSE becomes poorer • Consistent behaviour across models

- Overall: 'Simplest' models performed best (lowest RMSE), daytime
- Trends between stages similar for the model classes
  - Individual simple characteristics are not necessarily always the best
- Wide range of approaches
- General improvement in the models during the comparison
- Project is ongoing (Stage 5)