Improving urban water process representations in land surface models with the SIMPEL soil water balance module

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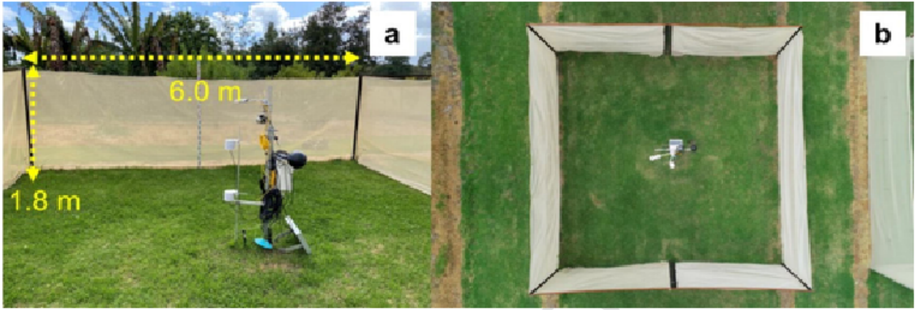
- Irrigation trials at University of Melbourne (Burnley)[1]. Looking for model capable of reproducing micro-scaled results.
- But most hydrology models are at a catchment scale.



[1] Cheung et al. [2024] (paper), 10.5281/zenodo.10140668, 10.5281/zenodo.10972538 (datasets)

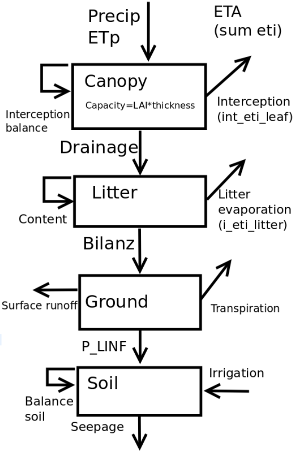
Motivation: Urban Plumber

- Meanwhile, Urban Plumber results: most urban models do a terrible job with hydrology [Jongen et al., 2024].
  - Most don't account for hydrology at all
  - If they do, water budgets are rarely closed
  - Or fully account for all types of indicators (runoff, infiltration, ET, storage)
  - Leading to less accurate modelling
- Urban Plumber and previous intercomparisions: Latent energy fluxes in urban areas poorly predicted by most models [Grimmond et al., 2011, Lipson et al., 2024]
- This is also true of my models, TARGET [Broadbent et al., 2019] and VTUF-3D [Nice et al., 2018]

The SIMPEL model

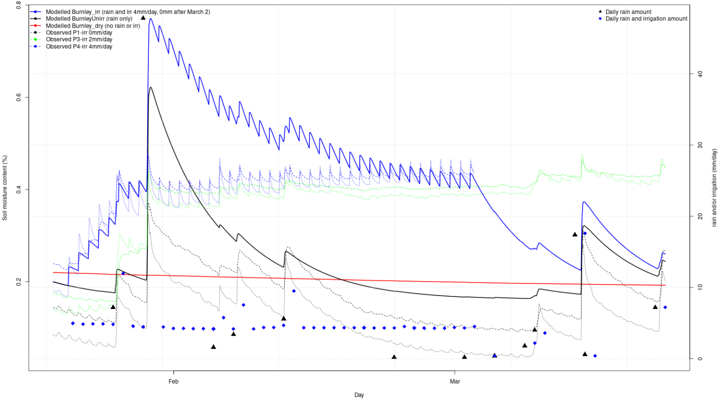
- Single bucket model
- Original Excel spreadsheet developed by Georg Hörmann
- Extended (snow, surface runoff) by Kristian Förster 2022
- Adapted by Kerry Nice 2023-5
- Added support for hourly timesteps, irrigation, additional site specific parameters

```
TreeMap<String,Double> Soil = (TreeMap<String, Double>) SimpelConstants.Soil.clone();
Soil.put("Timestep",1.);
Soil.put("Field Capacity %",20.);
Soil.put("Permanent Wilting Point %",5.0);
Soil.put("Start of Reduction %",12.);
Soil.put("Root Depth",25.);
Soil.put("Init-Value Soil %",20.);
Soil.put("Land use",SimpelConstants.landuse_spruce+0.0);
Soil.put("Minimum LAI",5.);
Soil.put("Maximum LAI",5.);
Soil.put("Vegetation Fraction",0.75);
Soil.put("Layer Thickness",0.35);
Soil.put("Drainage Coeff. b",3.7);
Soil.put("Max. Drainage Rate",2.88);
Soil.put("Cap. Litter",0.);
Soil.put("Init-Value Litter",0.);
Soil.put("Litter Reduction factor",3.);
Soil.put("Direct runoff factor",46.5);
Soil.put("Glugla coeff.",100.);
```



Adapted from Hörmann et al. [2007]

Validations against Burnley irrigation observations

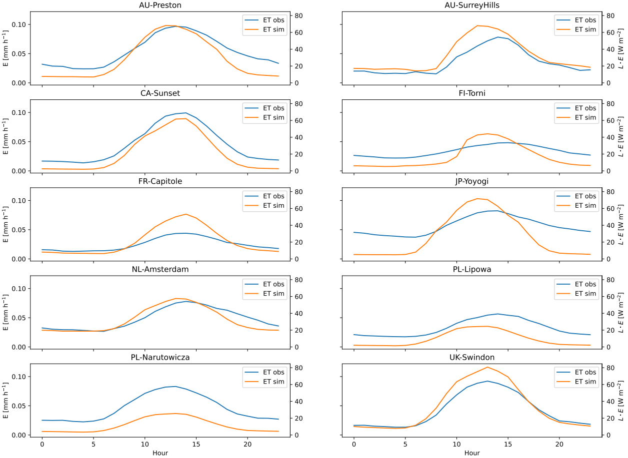


Initial testing of SIMPEL model with Burnley observations[1] were promising. Reproducing soil moisture of different irrigation amounts (0, 2, 4mm/day).

[1]Cheung et al. [2024], 10.5281/zenodo.10140668, 10.5281/zenodo.10972538

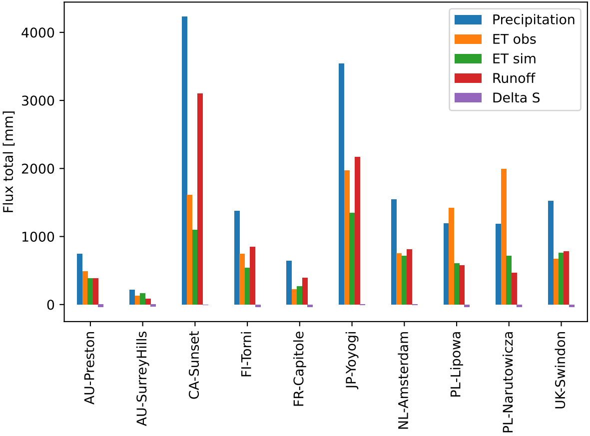
The SIMPEL evaporotranspiration comparisons with Urban Plumber sites

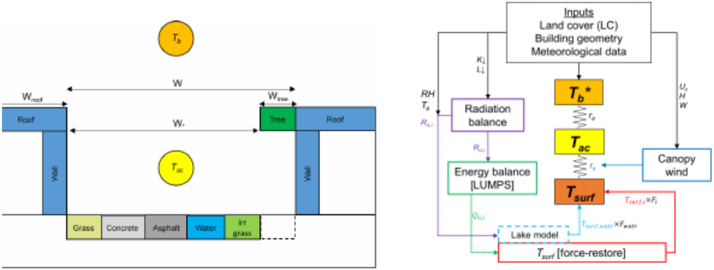
And broad agreement across many Urban Plumber sites of evaporotranspiration levels



The SIMPEL water balance comparisons with Urban Plumber sites

And includes necessary components for water balance closure





The Air-temperature Response to Green/blue-infrastructure Evaluation Tool (TARGET) is a computationally efficient model designed to evaluate blue/green infrastructure, based on an urban canyon and aggregations of different land cover types [Broadbent et al., 2019].

Integration into TARGET

Table 1. Parameter set-up for all TARGET simulations in this article.

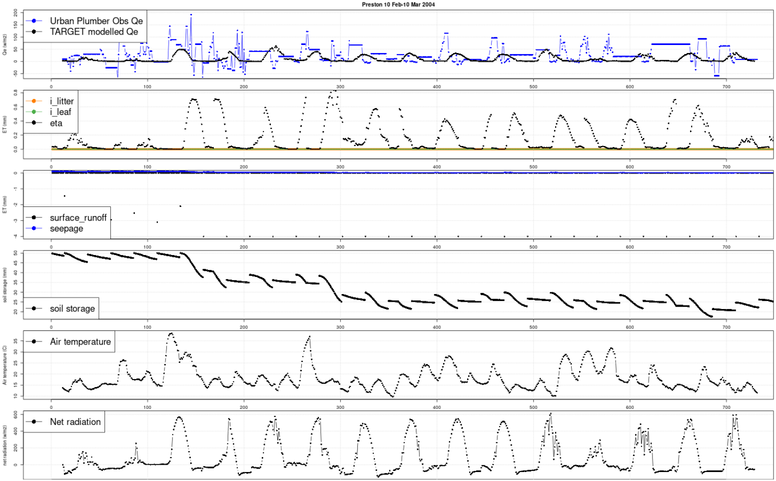
	Roof and wall[c]	Asphalt	Water	Soil (water)[a]	Concrete	Dry grass	Irrigated grass	Tree
α	0.15[1]	0.08[1]	0.10[1]	n/a	0.20[1]	0.19[3]	0.19[3]	0.10[1]
ϵ	0.90[1]	0.95[1]	0.97[1]	n/a	0.94[1]	0.98[2]	0.98[2]	0.98[1]
C ($\times 10^6$)	1.25[2]	1.94[1]	4.18[1]	3.03[1]	2.11[1]	1.35[3]	2.19[3]	n/a
κ ($\times 10^{-6}$)	0.05[b]	0.38[1]	0.14[1]	0.63[1]	0.72[1]	0.21[3]	0.42[3]	n/a
T_m	25.0 (28.2)	26.0 (29.0)	25.0 (24.5)	25.0 (24.5)	26.0 (27.9)	20.0 (22.4)	20.0 (21.5)	n/a
OHM $[a_1, a_2, a_3]$	[0.12,0.24,−4.5][3]	[0.36,0.23,−19.3][4,5]	n/a	n/a	[0.67,0.31,−31.45][4,5]	[0.21,0.11,−16.10][6]	[0.27,0.33,−21.75][6,7]	n/a
s	0.0	0.0	n/a	n/a	0.0	0.2	1.0	n/a
β	3	3	3	3	3	3	3	n/a

[1] Oke (1987). [2] Stewart et al. (2014). [3] Järvi et al. (2014). [4] Narita et al. (1984). [5] Asaeda and Ca (1993). [6] Grimmond et al. (1993). [7] Doll et al. (1985).
α is the surface albedo, ϵ is the surface emissivity, C is the volumetric heat capacity ($\mathrm{J\,m^{-3}\,K^{-1}}$) ($\times 10^6$), κ is the thermal diffusivity ($\mathrm{m^2\,s^{-1}}$) ($\times 10^{-6}$), T_m is the average soil (ground) temperature (°C), α_{pm} is the LUMPS empirical parameter (alpha parameter), relating to surface moisture, β is the LUMPS empirical parameter (beta parameter), and T_m bracketed values are used in Mawson Lakes suburb simulations, derived from 1-month spin-up.
[a] Soil layer beneath water layer. [b] The traditional force–restore method is not well suited to urban surfaces (e.g. roof and walls) — we use an artificially low thermal diffusivity to represent a thin layer. This is discussed further in Sect. 2.5. [c] Roof and wall layers are represented by the same model parameters. n/a: not applicable.

- Hydrology was not previously included
- Latent energy was indirectly calculated from ground flux heat storage calculations for different surface types using the α coefficient of the OHM model
- SIMPEL allows replacement with hydrologically-based evaporotranspiration and latent energy calculations requiring very minor additional computational costs.
- Provides additional capability to account for irrigation, drought and other hydrological impacts

TARGET evaluation against Preston observations

At this early stage of development, TARGET provides reasonable agreement with observed latent energy (top panel) of Urban Plumber Preston site [Coutts et al., 2007].



Future plans

- Integration into TARGET as a single surface type (irrigated grass) is nearly complete
- Integration into VTUF-3D as gridded individual patches of pervious/vegetated surfaces and underlying soil is in progress
- Improvement of ET using stomatal models to incorporate additional vegetation types
- Tuning and testing the model across a range of climate zones and city types
- SIMPEL model could also be integrated into other urban models, providing micro-scaled hydrology for a variety of vegetated and pervious surface types
- Or more accurate runoff for impervious surfaces
- Integration with UMEP plugin version of TARGET (come to the UMEP workshop on Thursday afternoon)

https://github.com/mothlight/Target-Java.v2
https://github.com/mothlight/VTUF-3D-Java.v2/
https://github.com/mothlight/Simpel
https://umep-docs.readthedocs.io/en/latest/processor/Urban%20Heat%20Island%20TARGET.html

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Thank you

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