



Supplement of

Process-based upgrades to the WRF multi-layer green-roof scheme (WRF-MLGR v2.0) and evaluation against field observations

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S1 Soil thermal-conductivity comparison

To support the revised description of the soil thermal-conductivity and vegetation-modulated surface-conductivity treatments in Sect. 2.3.1 and Sect. 2.3.2 of the main manuscript, Fig. S1 compares the average soil thermal conductivity simulated by the original and modified WRF multi-layer green-roof schemes during summer 2014. The original scheme produces unrealistically large and highly variable conductivity values, including peaks above $49 \text{ W m}^{-1} \text{ K}^{-1}$, indicating excessive conductive heat transfer under wet conditions. The modified scheme strongly reduces these values and keeps the conductivity mainly within approximately 0.32 to $0.98 \text{ W m}^{-1} \text{ K}^{-1}$, a more physically reasonable range for engineered green-roof growing media (Barozzi et al., 2017; Shao et al., 2021). This result demonstrates the effect of replacing the original thermal treatment with the revised moisture-dependent soil thermal-conductivity formulation and vegetation-modulated effective surface conductivity.

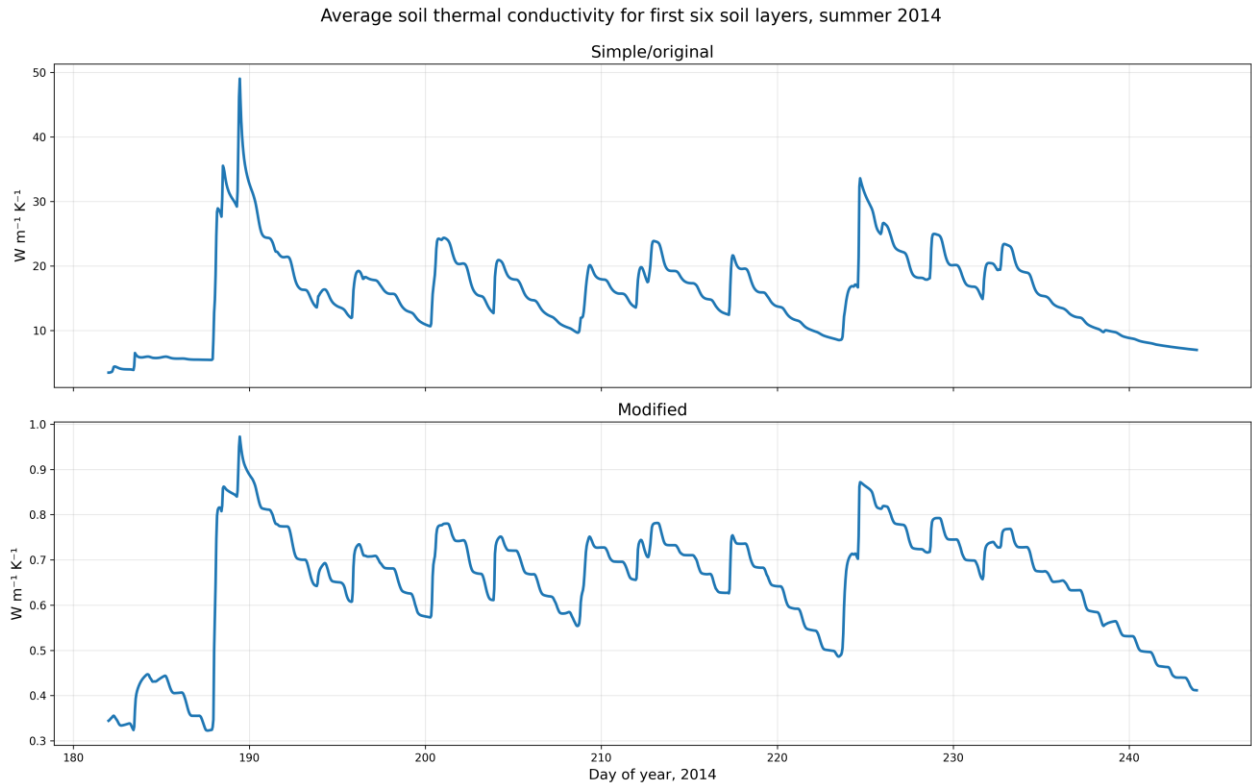


Figure S1. Comparison of soil thermal conductivity averaged across the first six soil layers between the original and modified WRF multi-layer green-roof schemes during summer 2014.

S2 Soil-layer configuration and internal states

The offline WRF-MLGR setup used in this study has 10 thermal layers in total. The lower four layers represent the underlying roof construction, while the upper six layers represent the 0.15 m green-roof soil. Temperature is calculated for all thermal layers, while volumetric water content is calculated for the six soil layers. To illustrate the vertical variation within the soil profile, Fig. S2 shows the mean diurnal temperature cycle of the six soil layers during summer 2014, while Fig. S3 shows the daily mean volumetric water content of the six soil layers over the same period. For clarity, the six soil layers in Figs. S2 and S3 are numbered from the soil surface downward, with Soil layer 1 representing the uppermost soil layer and Soil layer 6 the deepest soil layer.

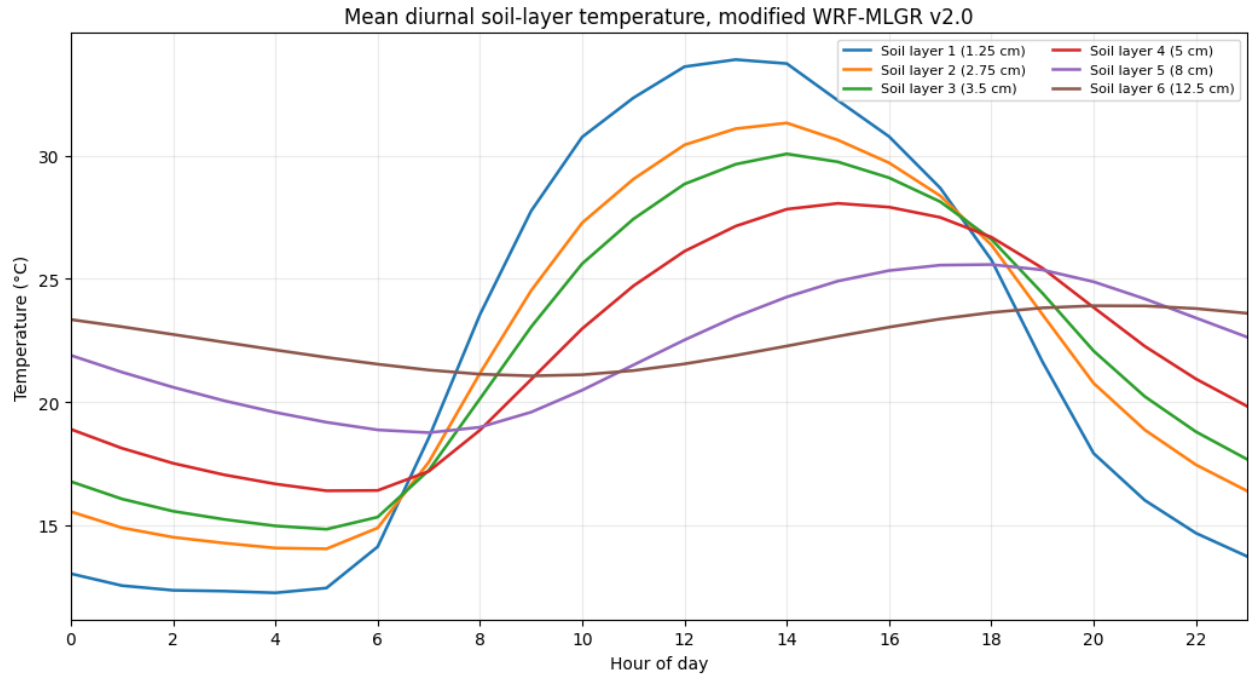


Figure S2. Mean diurnal cycle of temperature for the six green-roof soil layers in the modified WRF-MLGR v2.0 simulation during summer 2014. Soil layers are numbered from the soil surface downward (Soil layer 1 = uppermost soil layer), and labels also give the center depth below the soil surface.

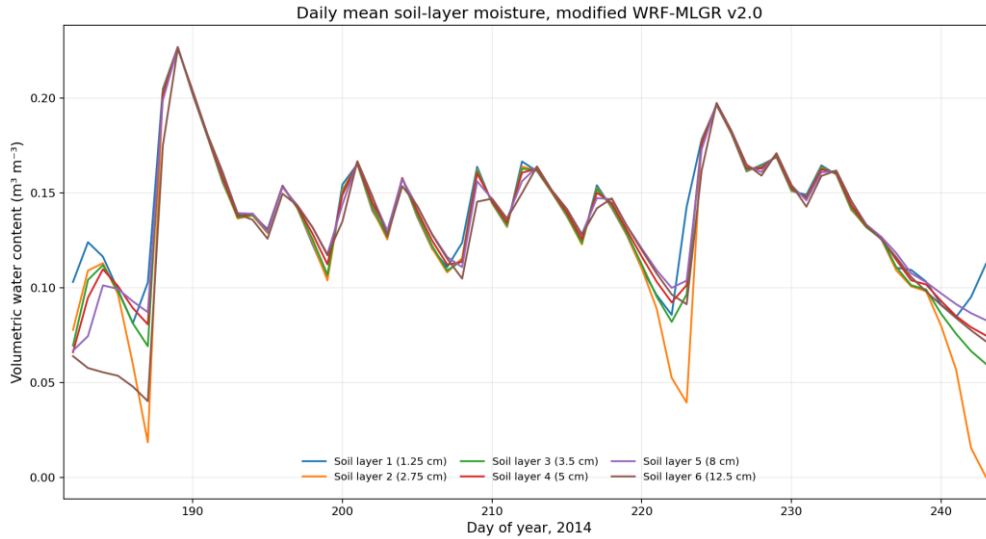


Figure S3. Daily mean volumetric water content of the six green-roof soil layers in the modified WRF-MLGR v2.0 simulation during summer 2014. Soil layers are numbered from the soil surface downward (Soil layer 1 = uppermost soil layer), and labels also give the approximate center depth below the soil surface.

S3 Seasonal water mass balance

To quantify water mass conservation in both the original and modified WRF-MLGR schemes, the seasonal water balance was diagnosed for the summer (DOY 182–243) and fall (DOY 244–304) 2014 evaluation periods. The residual was calculated as

$$R = P + I - Q_{E_{\text{net}}} - D - \Delta S, \quad (\text{S1})$$

where P is precipitation, I is irrigation, $Q_{E_{\text{net}}}$ is the net evaporative water loss from the modeled green-roof system represented by the latent water flux, D is drainage, and ΔS is the change in total modeled water storage. No irrigation was applied during either evaluation period ($I = 0$). For the original scheme, ΔS represents the change in soil water storage. For the modified scheme, ΔS includes changes in both soil water storage and canopy interception storage. A residual R close to zero indicates closure of the modeled water balance.

The original model produced seasonal residuals of -3.352 mm in summer and -2.749 mm in fall, corresponding to closure error magnitudes of 1.95 % and 1.31 % of seasonal precipitation, respectively. The modified model produced much smaller residuals of -0.225 mm in summer and -0.326 mm in fall, equivalent to 0.13 % and 0.16 % of seasonal precipitation, respectively (Table S1). Thus, both configurations show near-closure of the seasonal water budget, while the modified WRF-MLGR v2.0 closes to within 0.2 % of precipitation during both evaluation periods.

Table S1. Seasonal water mass balance diagnostic for the original and modified WRF-MLGR schemes during summer and fall 2014. Symbols follow Eq. (S1). Closure error is reported as $|R|/P \times 100$, calculated from the values shown.

Model	Period	P (mm)	$Q_{E_{\text{net}}}$ (mm)	D (mm)	ΔS (mm)	R (mm)	$ R /P$ (%)
Modified	Summer 2014	171.717	136.335	32.539	+3.068	−0.225	0.13
Modified	Fall 2014	210.206	68.849	125.096	+16.587	−0.326	0.16
Original	Summer 2014	171.717	129.323	43.306	+2.440	−3.352	1.95
Original	Fall 2014	210.206	63.584	131.206	+18.165	−2.749	1.31

Note: $Q_{E_{\text{net}}}$ is expressed as an equivalent water depth. Positive values denote net evaporative water loss from the modeled green-roof system, including evaporation and transpiration, while dew formation in the modified scheme is treated with the opposite sign as a water input to the system.

S4 Direct comparison of original and modified time series

Figure S4 provides the summer 2014 time series with observations, the original model, and the modified model plotted together in the same panels. The combined plot is included here to allow direct visual comparison of the two model configurations.

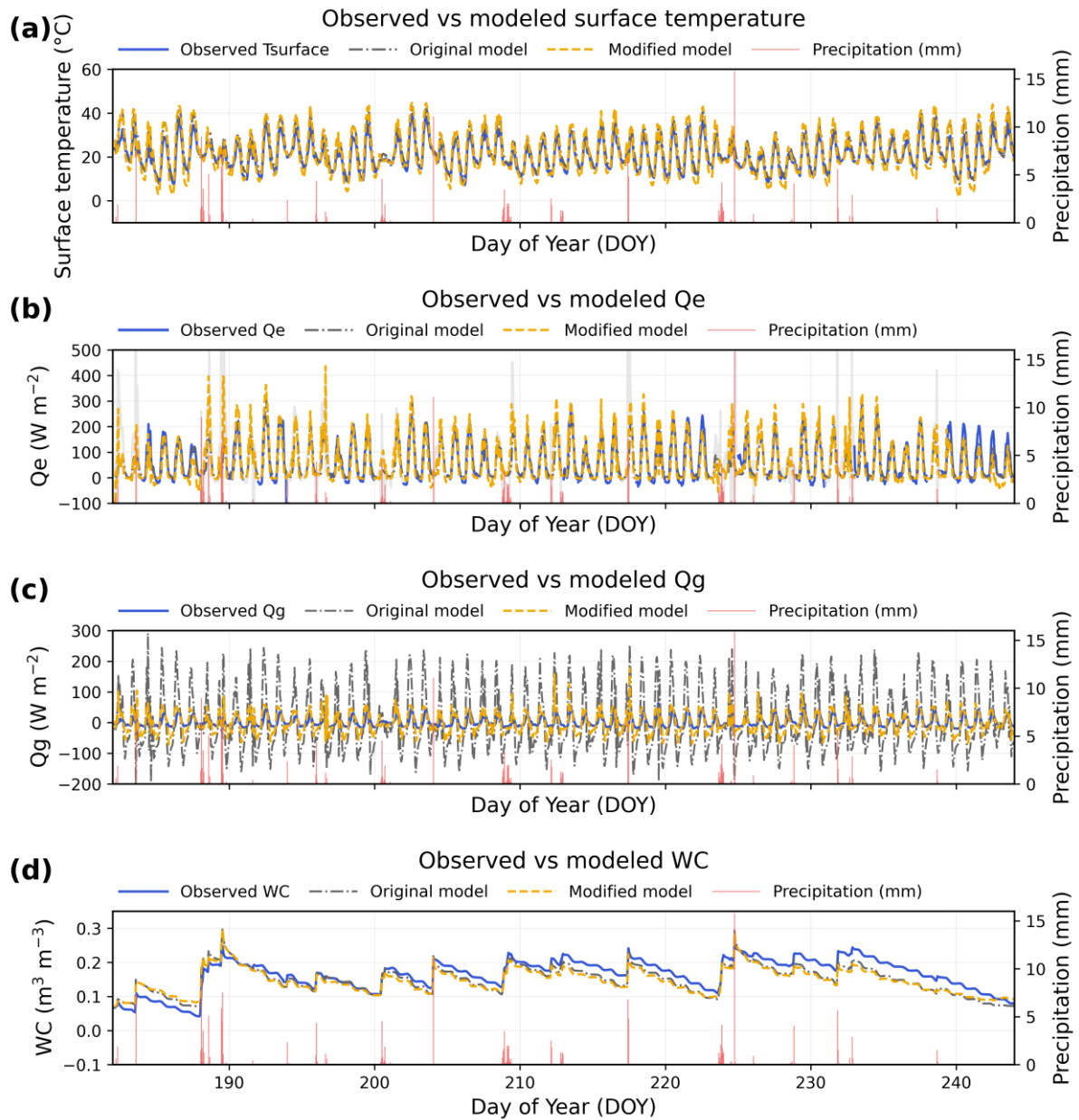


Figure S4. Combined summer 2014 time series of observations, the original WRF multi-layer green roof model, and the modified WRF-MLGR v2.0 model for (a) surface temperature (T_s), (b) latent heat flux (Q_E), (c) ground heat flux (Q_G), and (d) volumetric soil water content (θ). Precipitation is shown on the right axis. This figure presents the same model configurations and observational period as Figs. 3 and 4 of the main manuscript, but with both model versions overlaid in the same panels to facilitate direct comparison.

References

Barozzi, B., Bellazzi, A., Maffè, C., and Pollastro, M. C.: Measurement of thermal properties of growing media for green roofs: assessment of a laboratory procedure and experimental results, *Buildings*, 7, 99, <https://doi.org/10.3390/buildings7040099>, 2017.

Shao, B., Valeo, C., Mukhopadhyaya, P., and He, J.: Influence of temperature and moisture content on thermal performance of green roof media, *Energies*, 14, 2421, <https://doi.org/10.3390/en14092421>, 2021.