Towards an Improved Thermal Model with Physically Consistent Heat Loss Coefficients

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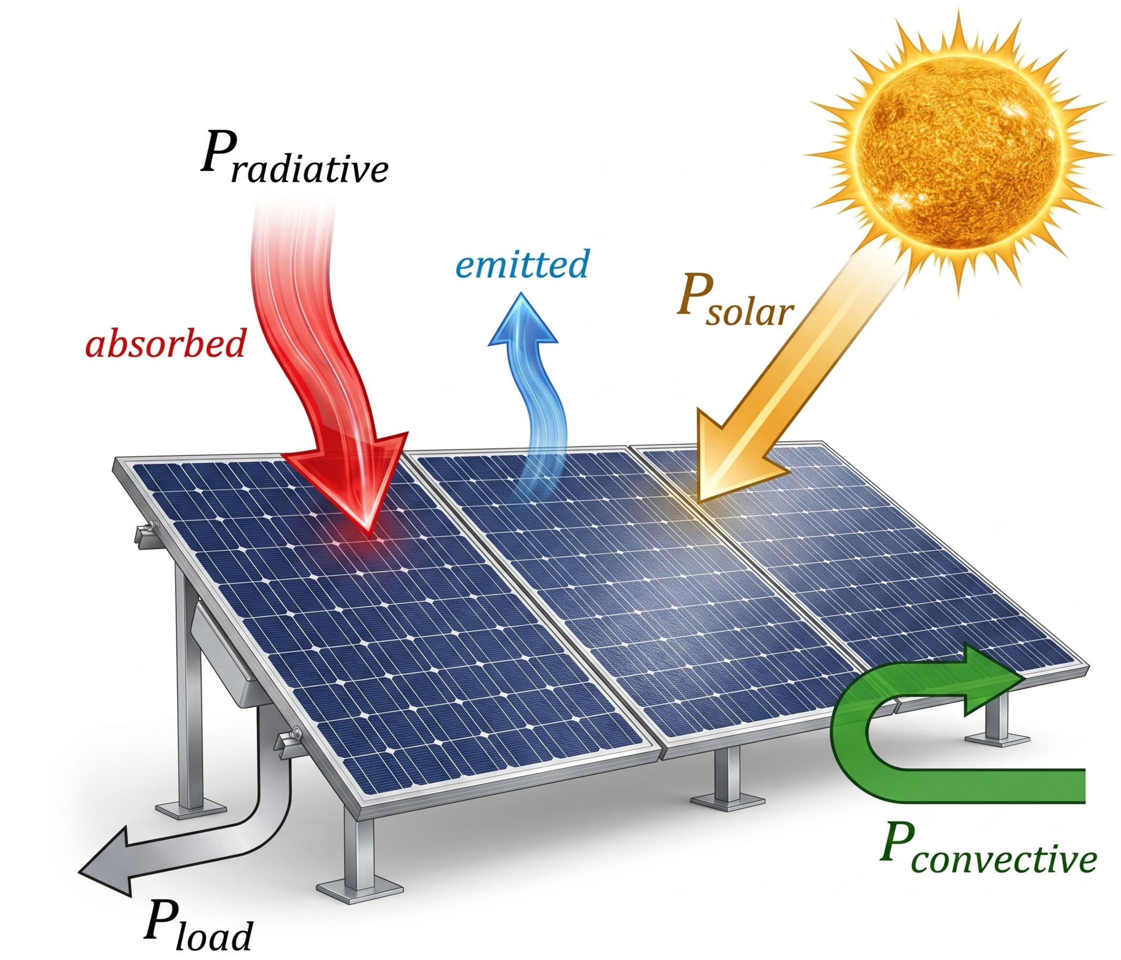
Study Background and Impact

- Accurate module temperature modelling is essential for predicting energy yield, performance, and degradation.
- Early-stage projects often rely on default thermal coefficients due to limited site-specific data.
- More physically accurate thermal models are required to improve prediction accuracy.
- Updated default thermal coefficients are therefore needed to support these models across different climates and mounting configurations.

Improvements in the Thermal Model

Energy Balance of A PV module



Improvements in Thermal Models

Steady Model (Faiman):

$$T = T_a + \frac{G_{inc}\alpha(1-\eta)}{U_c + U_v \times W_s}$$

Steady Radiative Model:

$$T_{module} = T_a + \frac{G_{inc}\alpha(1-\eta) - F.\varepsilon(\sigma T^4 - q_{dr})}{U_c + U_v \times W_s}$$

q_{dr} → ERA5 / Swinbank

Transient Radiative Model

Prilliman

$$T_{module} = \frac{\sum_{i=2}^{t_i \le 660}(T_{ss.i} \times e^{-P \times t_i})}{\sum_{i=2}^{t_i \le 660}(e^{-P \times t_i})}$$

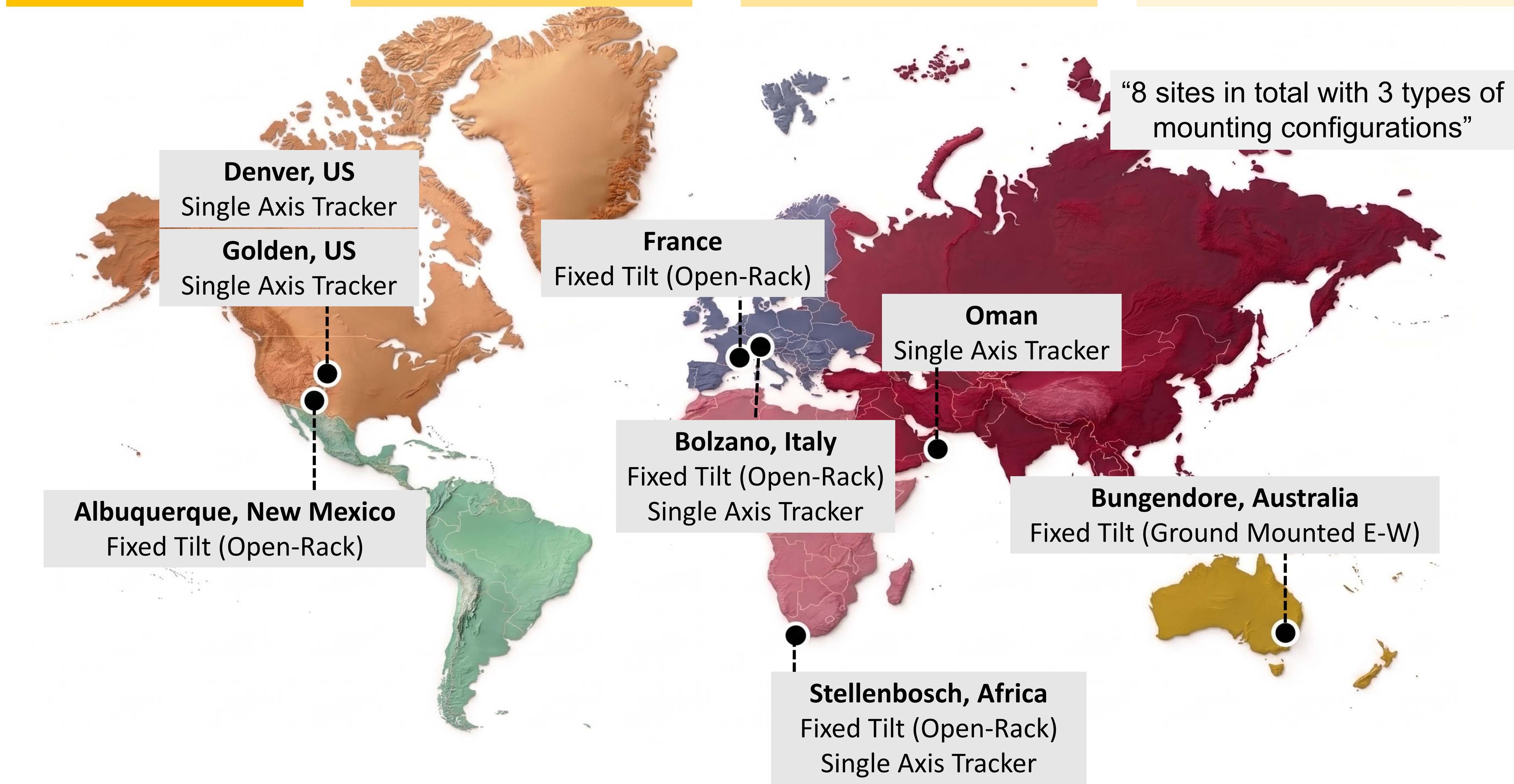
RK4

$$T_{module.i} = T_{i-1} + \frac{\Delta t}{6}(\dot{T}_1 + 2\dot{T}_2 + 2\dot{T}_3 + \dot{T}_4)$$

Methodology

The sites used for the thermal modelling and their configurations

1. Multi-site thermal modelling with different configurations
2. Model fitting using measured PV module temperature data
3. Model comparison based on error metrics and accuracy assessment
4. Proposed default values for U_c and U_v in radiative-aware and transient models



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References

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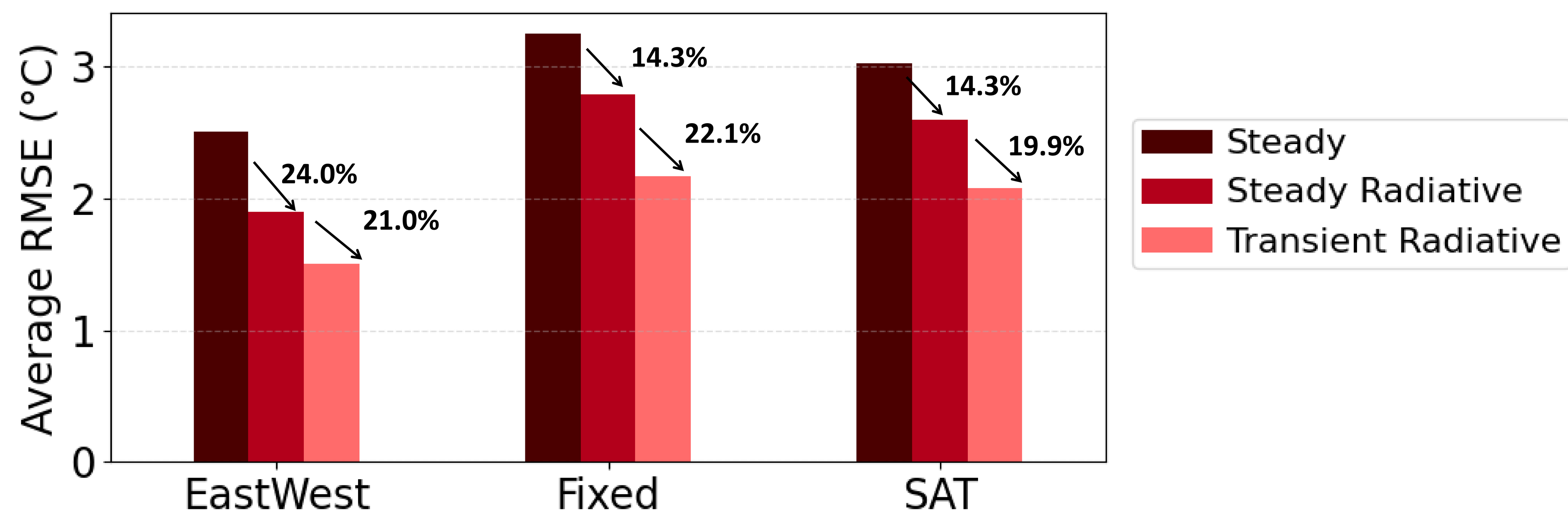
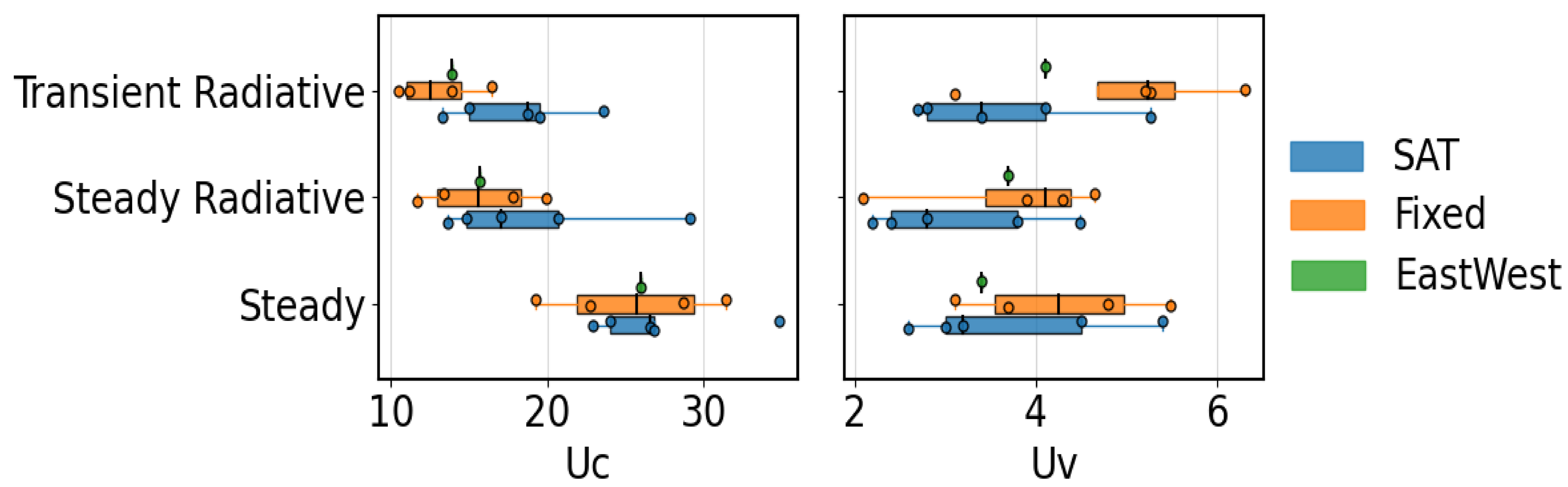
Results

Average RMSE Across Models and Configurations



"Adding the radiative and transient terms reduces errors across all sites and improves model accuracy"

Distribution of Fitted U_c and U_v Across Models and Configurations



"The spread reflects variation between sites"

Proposed Default Coefficient

Thermal Models	SAT		FT		EastWest	
	(Uc, Uv)	Average RMSE	(Uc, Uv)	Average RMSE	(Uc, Uv)	Average RMSE
Steady	(26.8, 3.9)	3.2	(24.4,4.5)	3.1	(26.0, 3.4)	2.5
Steady Radiative (Era5)	(17.9, 3.4)	3.1	(15.0, 3.9)	2.9	(15.7, 3.7)	1.9
Steady Radiative (Swinbank)	(23.5, 2.4)	3.5	(15.8, 4.2)	3.0	(17.7, 3.1)	2.3
Transient Radiative (Era5)	(17.6, 3.8)	2.6	(13.1, 4.7)	2.7	(13.9,4.1)	1.5
Transient Radiative (Swinbank)	(21.7, 2.8)	2.9	(13.5, 5.7)	3.0	(16.3, 3.43)	2.7

Notes:
ERA5 Improve Accuracy
Swinbank Simpler Approach
Best >>>>> Worst

Steady Best fit for >15min interval
Transient Best fit for 1 – 5 min interval

Conclusion

- Thermal models used in PVsyst, and similar tools can be improved by including heat loss to the sky (radiation) and transient effects.
- Defining good default values for this improved model is important in modelling because they allow accurate predictions even when detailed site data is not available.

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