A 3D radiation model for urban ecophysiology modelling

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Introduction

- Urbanisation drives CO_2 emissions, urban heat islands, and affects climate, energy use, and public health.
- Urban climate mitigation and adaptation strategies require a thorough understanding of the mechanisms controlling microclimate in cities.
- Urban climate modelling allows scenario testing without having to rely on sparse in situ weather stations.
- We are developing a simple and lightweight *3D ecophysiological model* for urban climate analysis, representing buildings, terrain and tree canopies as voxels.
- Here we present the radiation component estimating irradiance in urban canyons.

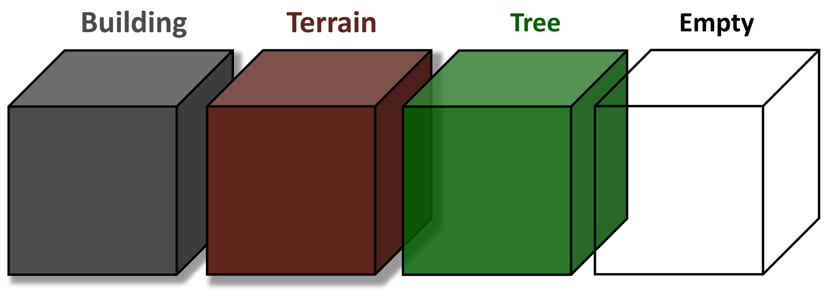


Fig. 1 – The four types of isometric cubic voxels present in our model.

Study Areas

We evaluated the model at two sites equipped with meteorological stations measuring atmospheric variables, including incoming and outgoing irradiance.

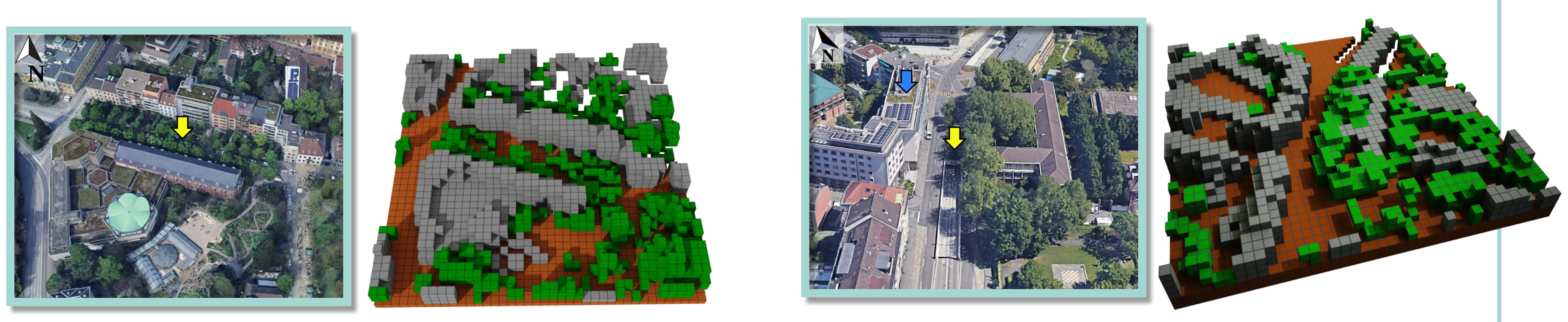
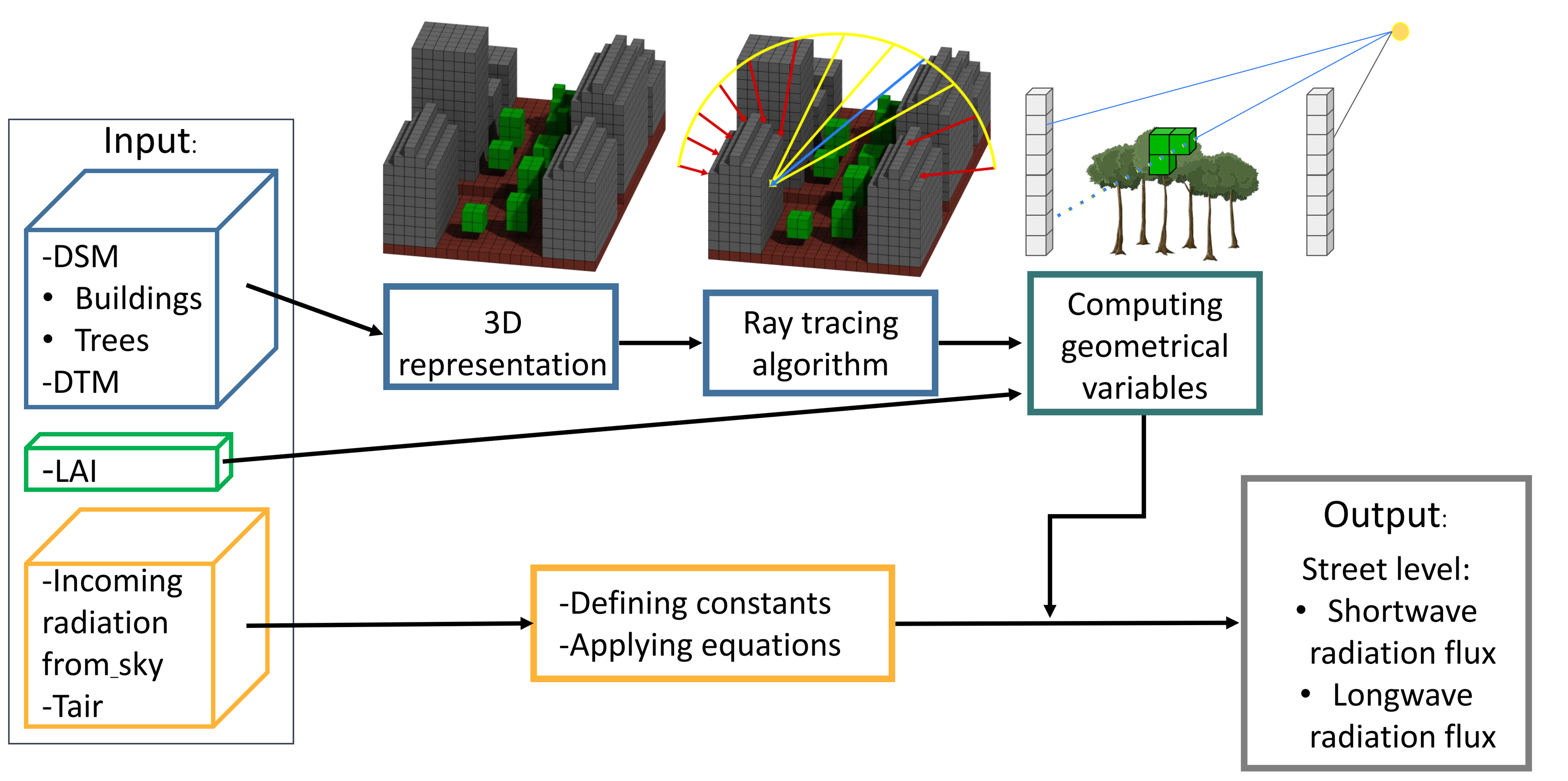


Fig. 2 – Aerial view (Google) of the study neighborhoods and their 3D voxel representation with 5m isotropic voxels. Arrows indicate station locations: the street-level station used for evaluation (yellow) and the tower providing meteorological forcing data (blue).

Radiation Model



- Geospatial data are used to develop a 3D representation of the study area. A ray tracing algorithm then identifies blocked directions and canopy interception, allowing us to compute geometrical variables such as Sky View Factor (SVF), voxel shadowing, and reflection paths for shortwave (SW) and longwave (LW) contributions.
- The radiation intercepted by trees according to their Leaf Area Index (LAI) is also determined by the same algorithm.
- This information is stored and used in the relevant radiation equations avoiding repeated geometrical computations.

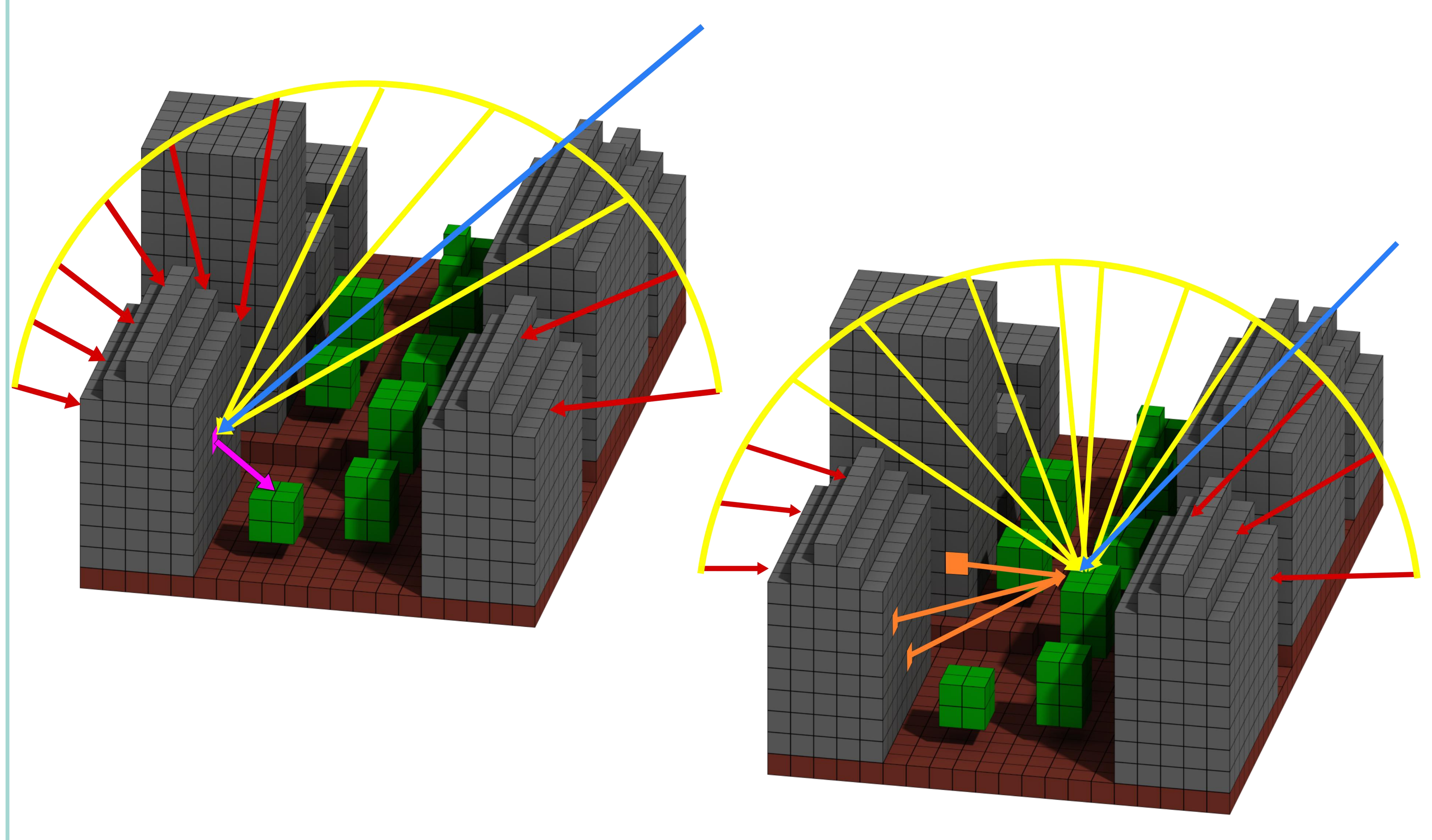


Fig. 3 – A 3D visualisation of the algorithm functions for a tree voxel in an urban canyon. The colours of the arrows indicate: blue, the direct shortwave from the sun direction; orange, the thermal emission of solid voxels; yellow, directions free to the horizon; red, blocked directions. The pink arrow shows one of the voxels seen by the tree voxel and the reflection path connecting them.

Results

- Errors in LW simulations are mainly linked to simplified process representation (e.g. thermal storage) which produces an offset in the hourly comparison in Fig. 4 (top).
- The underestimation of LW emission during night and overestimation during day cancel out in the daily comparisons in Fig. 4 (middle and bottom).
- Converting continuous space into a voxel grid introduces discretization errors. The simulated direct irradiance can be obstructed at a shifted time relative to reality, producing the offset visible in the hourly averages in Fig. 5 (top).
- In urban canyons with buildings on both sides, the displacement of shadows usually happens twice a day in opposite directions, therefore daily means average out that error as visible in Fig. 5 (middle and bottom).

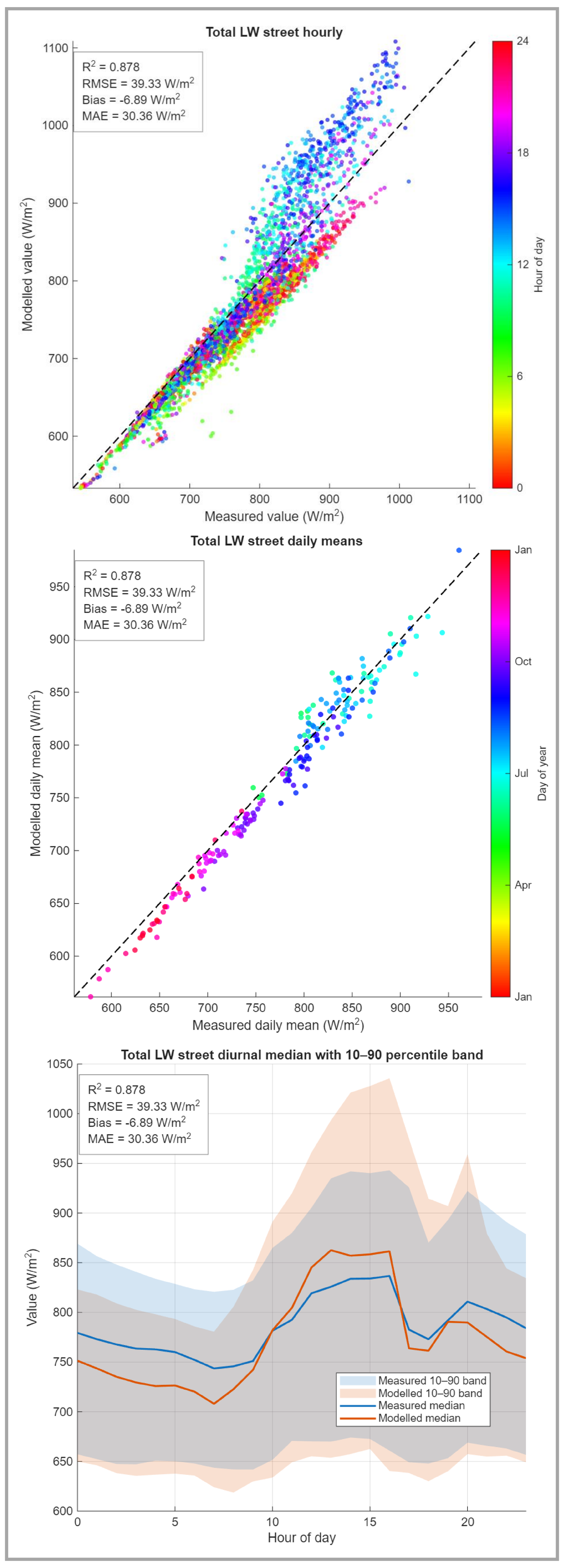


Fig. 4 – Comparison of street-level modelled LW radiation (total: incoming + outgoing) against measured data for the second half of 2025 at BBER location. Top: hourly average colour-coded according to the hour of the day (UTC +1). Middle: daily average colour-coded according to the day of the year. Bottom: hourly diurnal statistics across the 6 months.

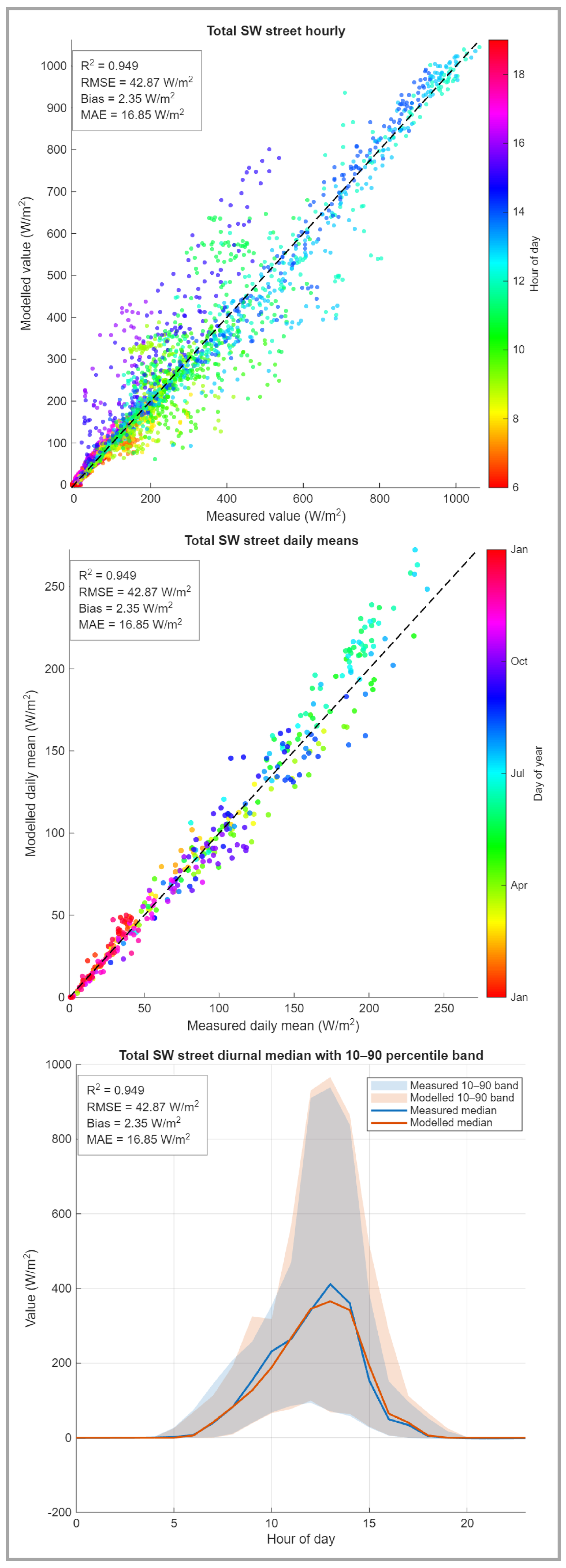


Fig. 5 – Comparison of street-level modelled SW radiation (total: incoming + outgoing) against measured data for 2023 at BKLI location. Top: hourly average colour-coded according to the daylight hour of the day (UTC +1). Middle: daily average colour-coded according to the day of the year. Bottom: hourly diurnal statistics across the whole year.

Conclusions and future work

- In Basel's urban canyons, our computationally efficient approach predicts shortwave and longwave irradiances well.
- The results show errors caused by modelling effects such as discretization and process simplification, but these errors are comparable to those reported for other models in the literature.
- Radiation fluxes are simulated at very high horizontal and vertical resolutions and this should allow us to simulate leaf-level processes more precisely than 2D models.
- The next steps of the model development are to include leaf-level photosynthesis and transpiration processes and derive canopy scale CO_2 and water vapour fluxes.

References:

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