

Reviewer 1

General

This is a comprehensive and timely GMD style evaluation paper. It benchmarks short wave radiation in the microscale model PALM version 25.04 across different urban and vegetated settings in Prague Dejvice, and it does so over a meaningful ensemble of episodes from clear sky to cloudy conditions. The takeaway lands well that PALM can reproduce street scale shading and reflection patterns very convincingly when the incoming radiation is right, but it cannot fix errors coming from the mesoscale cloud and radiation forcing. The results and figures support that message clearly. I generally find the paper well prepared and would recommend a minor to moderate revision focused on reproducibility details and a slightly tighter interpretation at the most problematic site.

Specific comments

1. The paper would benefit from a compact run description inside the manuscript itself, not only in the archive. Right now a reader has to piece together key setup details. *I suggest to add a short block that states PALM horizontal and vertical grid, time step, episode length, spin up length, and output frequency, plus which modules were active and which radiation options were used.*

It would also help to explicitly describe how station values were sampled from the model, including the sampling height, whether it is nearest grid cell, and how reflected short wave from the model is matched to the up looking and down looking pyranometers.

Answer: In this study, the term 'spin-up' refers to the specific operational mode of the PALM model system used to perform the primary micro-scale simulations, rather than a separate pre-processing phase; for the purposes of this study, these 'spin-up' runs constitute the primary simulations. Hence, PALM simulations were performed with horizontal and vertical grid resolutions of 1 m, utilising a 5 s timestep during spin-up. Regarding the simulation duration (i.e., the spinup length), while the selected physical episodes covered 24 to 48 hours, the simulations for each day were initiated at 23:00 UTC (one hour prior to the target date) and lasted 23 or 46 hours, depending on the selected physical episode. A one-hour initialisation offset (starting at 23:00 UTC) was implemented to address technical constraints within the PALM/palm_meteo framework, with no loss of critical data, since short-wave radiation is zero at midnight. PALM output data were recorded at a frequency of 600 s (10 minutes).

The modelled irradiance values for the pyranometers were taken at the grid cell nearest to the sensors' actual locations. In the vertical direction, this translates to 1 m above ground for both the upward- and downward-facing sensors. The short-wave irradiance of the sensors was modelled identically to that of actual surfaces in the RTM module of the PALM model, utilising fully 3-D radiative interactions with multiple reflections and shading by the modelled terrain and buildings, and partial attenuation by the fully resolved vegetation. More details about RTM are

available in Krč et al. (2021). The identified limitation was the agreement between the modelled representation and reality, particularly regarding tree crown shapes in the input data (see Section 4.1 and Figure 8, which compares the photographed reality and the modelled representation).

As noted by the reviewer, the active modules (LSM, BSM, RTM, and MESO) are detailed in Section 2.1 Line 138). The complete section 2.1 has been rewritten, and an additional paragraph, 2.1.1 “Spin-up simulations,” has been added, in which the specific issues are elaborated in detail.

- 2. The spin up approach is described as not affecting short wave radiation, but the interpretation needs one more sentence of care. Reflected short wave depends on surface albedo and on surface and canopy state. Please clarify what can change during spin up for the land and vegetation state, especially soil moisture and grass or vegetation parameters, and what is fixed. This matters directly for your explanation of the reflected radiation behavior at the vegetated site.**

Answer: The reviewer makes a valid point regarding the potential influence of surface and canopy states on reflected short-wave radiation. In this study, however, the land and vegetation parameters—specifically albedo, leaf area density (LAD), and canopy height—are prescribed as static inputs via the static driver file and remain constant throughout the simulation. For a detailed specification of the static driver data included in this study (i.e., individual land-surface and plant-canopy input parameters), we refer to the validation study by Resler et al. (2020).

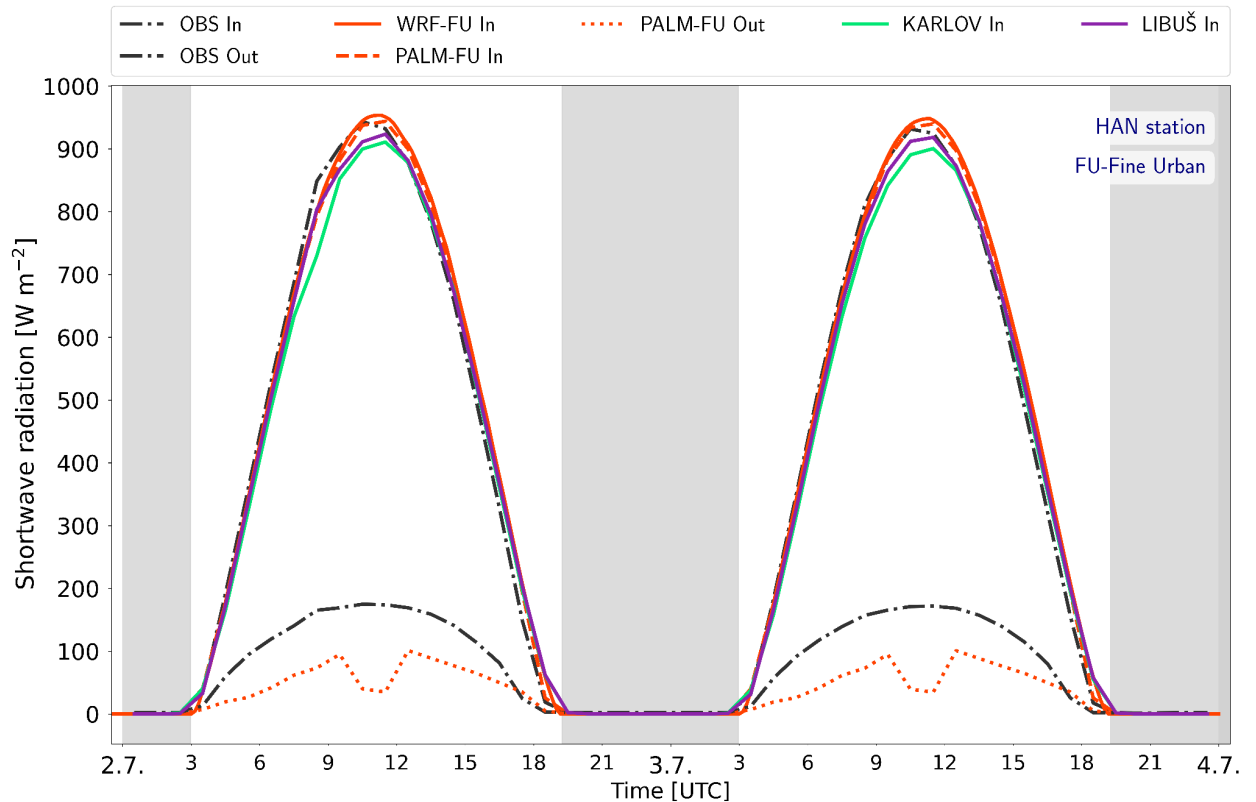
Parameters used in the Land Surface Model (LSM), i.e., **land_surface_parameters** such as “**root_fraction**”, “**soil_moisture**”, “**soil_temperature**”, and “**deep_soil_temperature**”, are fixed and prescribed in advance in the LSM model parameter list of the configuration p3d file. The same applies to the Plant Canopy Model (PCM) parameter list and “**plant_canopy_parameters**” in the p3d configuration file.

During the spinup phase for the original set of simulations, the option “**calc_soil_moisture_during_spinup**” was switched off, which means that the additional prognostic equation for the volumetric moisture content of the soil layer is not solved.

To assess the effect of this configuration parameter, we performed an additional simulation with this option set to True, which enabled the soil moisture prognostic equation to be solved. However, its activation did not affect the simulated short-wave radiation at the HAN station. The results indicate that for episode e5, radiative conditions were largely insensitive to the soil moisture settings. Furthermore, the absence of differences suggests that the modified soil moisture treatment did not substantially alter the surface thermal regime, with the soil moisture remaining similar between the simulations, or the atmospheric forcing dominated the surface energy balance during the episode.

In addition, for the revised manuscript and changes included we refer to Section 2.1.1 “Spin-up simulations”.

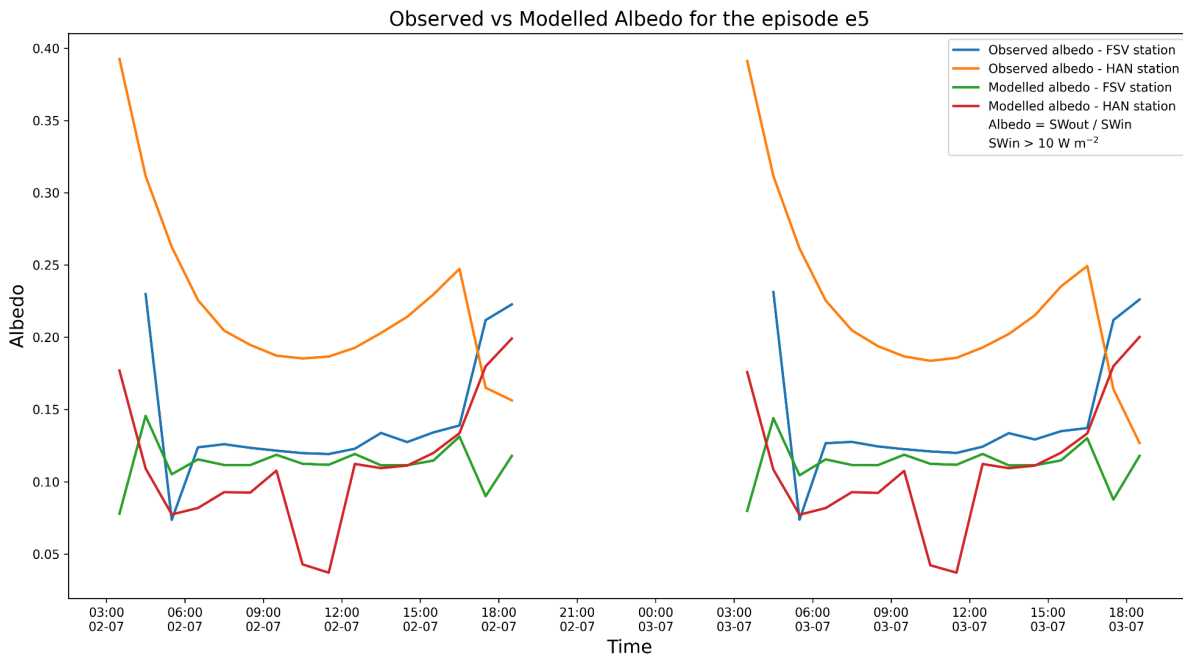
Figure: The comparison of observed hourly averages of incoming (In) and outgoing (Out) short-wave radiation for the e5 episode at the HAN station, with PALM model output for WRF Fine Urban (WRF-FU) configuration with the soil moisture parameter switched ON. Additional lines represent the raw WRF output, Fine Urban (WRF-FU), and measurements from professional meteorological stations in Karlov and Libuš.



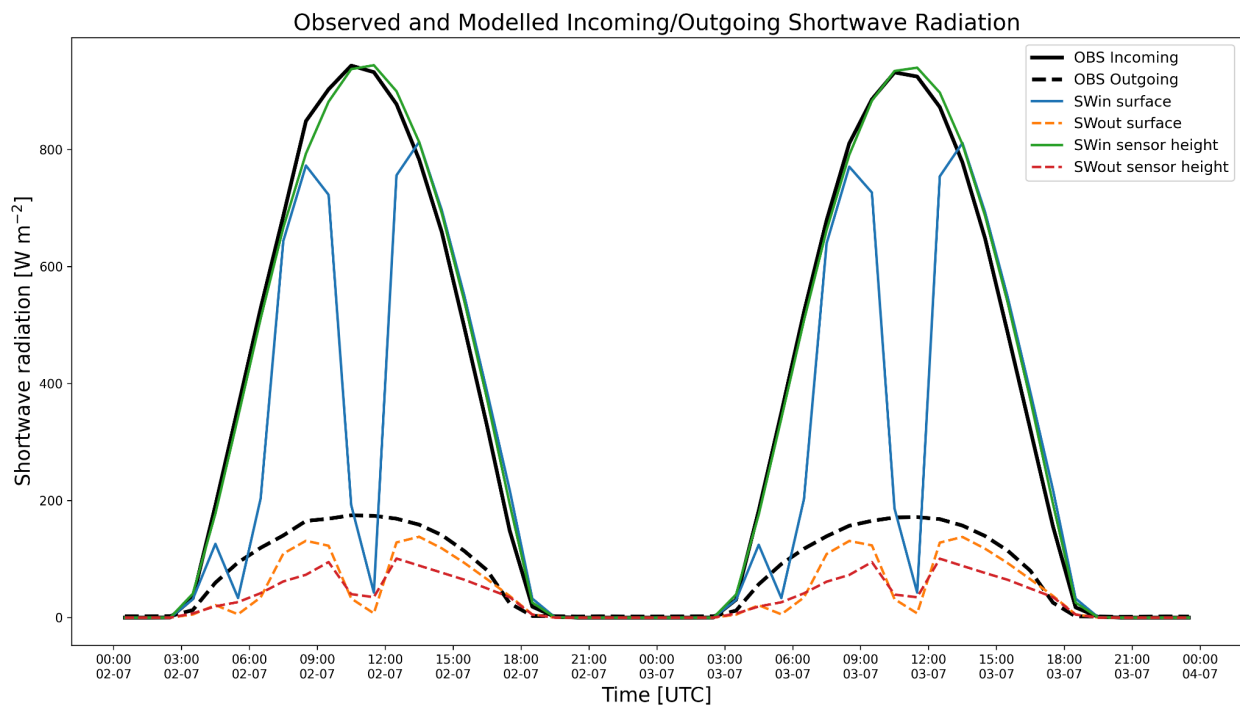
3. The persistent reflected short wave bias at the HAN location is an important result and it is already well highlighted in the tables and discussion, but it still reads a bit like a likely story rather than a demonstrated diagnosis. Since this site drives several conclusions about static driver limitations, I suggest strengthening it with one concrete extra analysis. I guess the simplest option is to show a time series of observed albedo, reflected divided by incoming, and the modeled equivalent for HAN and one well behaving site. Another option is a small sensitivity test with plausible albedo changes, for example plus or minus 0.05 to 0.10, or an alternative grass parameter set, to show how much of the bias is realistically explainable. One of these would turn the HAN section into a clean quantitative lesson for the community. However, I raise it here as an optional extra analysis which, if doable, will enhance the analysis.

Answer: Thank you for highlighting this important issue and for your valuable suggestion. We have conducted the analysis and included the relevant information in the revised manuscript on lines 491-499. Additionally, we have provided an extended analysis in the figures presented below.

1. EVALUATION #1 TIME SERIES OF OBSERVED ALBEDO: The figure below compares observed and PALM modelled albedo at the FSV (well-behaving) station and the problematic HAN station during episode e5. Albedo was calculated as the ratio between reflected and incoming short-wave radiation, and only periods with $SW_{in} > 10 \text{ W m}^{-2}$ were considered to avoid unrealistically large values associated with low incoming short-wave radiation. The observations indicate differences between the two observation stations. The HAN station exhibits substantially higher albedo than FSV throughout most of the daytime period, with albedo ranging from approximately 0.16 to 0.39, whereas at FSV it remains lower, generally between 0.11 and 0.23. Both stations show a pronounced diurnal cycle, with larger albedo values during the early morning and late afternoon and lower values around midday, consistent with the influence of solar zenith angle on surface reflectivity. The PALM model reproduces the magnitude and temporal evolution of albedo at FSV reasonably well, although it systematically underestimates the albedo calculated from observations by approximately 0.01–0.05. On the other hand, PALM underestimates albedo at the HAN station, with simulated values remaining near 0.08–0.20, whereas albedo calculated from observed values frequently exceeds 0.20 and reaches nearly 0.40 during the morning hours. Overall, the results suggest that PALM captures the albedo characteristics at the FSV station more successfully than at the HAN station. The systematic low bias at HAN may indicate deficiencies in the representation of surface properties and land-cover characteristics that control surface albedo during the episode.



2. EVALUATION #2 VALUES AT THE SURFACE VERSUS SENSOR HEIGHT VALUES: An additional analysis was performed to show the differences between outputs at the surface and the sensor sampling height. The figure below compares observed and modelled incoming and outgoing short-wave radiation at the HAN station during episode e5. In addition to the observational data, the modelled radiation fields are shown at the surface and at the sensor height corresponding to the measurement location. The incoming short-wave radiation simulated at sensor height reproduces the observations very well. The model captures both the timing and magnitude of the diurnal cycle, including sunrise, sunset, and the daytime maximum. In contrast, the incoming short-wave radiation at the surface shows pronounced reductions. These decreases are attributed to potential shadowing effects caused by varying plant canopy densities, which affect the radiation reaching individual surface elements. The lower plant canopy does not affect the radiation field at the measurement height above the surface; grass is typically lower, at a maximum of 1 m. The outgoing short-wave radiation also differs substantially between the two model levels. The surface level one produces larger outgoing short-wave fluxes than at the sensor height, but both modelled fluxes remain below the observed values throughout most of the daytime period. This comparison suggests the importance of diagnostic height within the urban canopy, as surface radiation fields are strongly influenced by local shading effects that are not apparent at sensor height.



4. The clear sky versus cloudy episode grouping is a good idea, but it needs an objective definition so others can reuse the protocol. A short criterion based on observed incoming short wave smoothness, or a threshold in modeled cloud fraction, would be enough.

Answer: Thank you for this suggestion. We agree that a more explicit description improves clarity. We have now added a detailed explanation of the protocol and criteria used to select and classify clear-sky versus non-clear-sky episodes. Please see the updated text in the revised manuscript in the 2.5 “Simulation episodes and meteorological conditions” section and Lines 273-177.

5. The paper is right to emphasize PALM superiority in resolving geometry driven shading and reflections, but please keep the wording careful so it does not sound like PALM is resolving cloud processes. The results show excellent redistribution and timing under clear sky and limited ability to correct wrong downwelling radiation when cloud timing is off in the driving model. That nuance is important for a GMD audience.

Answer: We thank the reviewer for this observation. We agree that the manuscript should more clearly distinguish between the simulation of urban radiative processes and the representation of cloud effects. In the PALM configuration used in this study, clouds are not explicitly simulated. Instead, the incoming radiative forcing, including the effects of cloudiness, is prescribed through the external dynamic driver. To avoid this potential misunderstanding, we have revised the manuscript to explicitly state this limitation. (Please see L139 in the 2.1 PALM configuration section).

6. There seems to be a small inconsistency between the station year labeling in the table and the narrative description of which sites were active in which year. Please double check that so readers do not get confused about the measurement periods.

Answer: The measurement periods and station nomenclature have been harmonised for consistency. Please refer to the revised text in section 2.4 and to Table 2 for these changes.

7. Please state clearly the model sampling height and how it relates to the pyranometer installation height, and confirm whether reflected radiation is taken directly from the surface flux or from a level that matches the sensor exposure.

Answer: Thank you for this comment. We agree that the relationship between the model sampling height and the pyranometer installation height was not described clearly in the original manuscript. We have revised the text to explicitly state the requested. This clarification has been added to the description of the PALM simulation setup, and we kindly refer the reviewer to our detailed response to Comment #1 and in the manuscript, Lines 170-174.

8. The pyranometer specification values in the sensor table look inconsistent in places, especially typical accuracy versus resolution. Please double check the units and the transcription from the original sensor documentation.

Answer: We have checked the pyranometer specifications with the original technical documentation and calibration lists. We have corrected these values and verified all units in the sensor table to ensure complete consistency with the official sensor data sheets. Please see the updated Table 3.

9. (Optional) A simple schematic showing the chain from WRF to PALM meteo to dynamic driver to PALM RTM, including how direct and diffuse short wave are handled, would improve readability. The text explains this, but a diagram would make it much easier to follow at a glance.

Answer: We thank the reviewer for this nice suggestion. We agree that a visual representation of the modelling chain enhances clarity. Following the reviewer's recommendation, we have added a new schematic diagram as Appendix B at Line 735. Furthermore, we offer a brief explanation to enhance the answer provided:

Essentially, this diagram illustrates the sequential data flow from the meso-scale WRF forcing through the PALM-meteo pre-processor, the dynamic driver, and PALM/RTM. In essence, direct and diffuse short-wave radiation components are taken from the WRF model, processed by the PALM-meteo into the dynamic driver file, transferred through the PALM dynamic driver into the PALM simulation, and subsequently modified by the PALM radiative transfer model (RTM) through interactions with urban geometry and vegetation.

***Direct Radiation:** Handled using a ray-tracing algorithm. The solar position from ray-tracing, which determines shading by terrain, buildings or trees, is discretised to the nearest pre-calculated position (resolution 4.5°), but the angle of incidence to the target surface is exact at each time-step.*

***Diffuse Radiation:** Handled using Sky View Factors (SVFs). Diffuse radiation scatters across the entire sky hemisphere. Instead of tracking individual rays, PALM uses the SVF to calculate the percentage of the open sky visible to any given surface (walls, roofs, or ground), adjusting the overall diffuse downwelling flux.*

***Reflected Radiation:** Handled using a radiosity algorithm using view factors towards other surface elements (pre-calculated by ray-tracing) and their short-wave radiosity.*

Diagram: Schematic representation of the WRF-to-PALM modelling workflow applied in this study. The figure illustrates how meteorological and radiation fields are passed from the WRF model through the PALM-meteo processor and the dynamic driver file into PALM and its radiation transfer module (RTM).

