Responses to Editor's comments:

Thank you for your thorough revision of manuscript egusphere-2025-3397. You have addressed all reviewer concerns comprehensively, and I am pleased to recommend acceptance for publication in GMD.

Before final publication, I have one optional but strongly encouraged suggestion to enhance the paper's value as a self-contained evaluation study. While your revision appropriately condensed the general urban canopy model literature discussion in response to Reviewer #1's feedback, I believe the paper would benefit from a focused technical summary of the specific model being evaluated. I recommend considering an Appendix that provides a concise technical summary of HRRR's slab urban parameterisation scheme, particularly focusing on how the scheme calculates near-surface temperature, specific humidity, and wind diagnostics, along with the key parameterisations for surface energy balance, roughness lengths, and thermal properties, and the physical assumptions and known limitations relevant to urban environments.

This enhancement would help readers interpret your findings without needing to consult HRRR technical documentation, which is particularly valuable since your evaluation reveals systematic biases that likely stem from the slab scheme's physical limitations. I suggest approximately one to two pages drawing from NOAA's HRRR technical documentation or relevant WRF physics papers, which would make the paper more useful as a standalone reference for the growing community evaluating operational urban forecasts.

This addition is not required for acceptance, and if you prefer to proceed without it, the manuscript is acceptable as-is for immediate publication. Please just reply to me in your next response. However, if you choose to add this enhancement, please submit within two weeks. Either way, congratulations on this excellent contribution to urban NWP evaluation.

Thank you for this great suggestion! We have now added a new Appendix A to explain "how the scheme calculates near-surface temperature, specific humidity, and wind diagnostics, along with the key parameterizations for surface energy balance, roughness lengths, and thermal properties, and the physical assumptions and known limitations relevant to urban environments". The new appendix is included below for your reference:

Appendix A: Technical summary of the urban parameterization used by the land surface model in HRRRv4

This appendix summarizes the slab urban parameterization implemented in the Rapid Update Cycle Land Surface Model (RUC LSM) within HRRRv4. Technical details are primarily based on Dowell et al. (2022) for HRRRv4, Smirnova et al. (2016) for the MODIS-based RUC LSM, and Benjamin et al. (2021) for the diagnostic fields.

(1) Surface representation and physical properties

Operational HRRRv4 couples the atmosphere model to the RUC LSM, which includes nine soil layers extending to a depth of 3 m. Urban areas are represented through the "urban and built-up" land-use category in the MODIS classification. The RUC LSM treats each urban grid cell as a slab surface (i.e., without explicit building geometry), rather than more advanced urban canopy models such as the single-layer urban canopy model.

RUC LSM in HRRRv4 uses a mosaic approach to account for sub-grid land-use heterogeneity. For each grid cell, surface parameters such as emissivity, leaf area index, and plant coefficient for transpiration function are computed as fractional-area weighted averages of all land-use types present. These aggregated values govern the grid-mean properties. However, the effective roughness length is not a simple area-weighted mean. It is computed based on a blending-height formulation following Mason (1988).

Sub-grid soil heterogeneity is similarly represented using the area-weighted mosaic method. Soil hydraulic and thermal properties, including heat capacity, Clapp–Hornberger parameterization exponent, available water capacity, saturated hydraulic conductivity, saturated soil matric potential, residual soil moisture, field capacity, wilting point, and quartz fraction, are averaged over soil types within the grid. The resulting effective parameters are used in the soil heat conduction and moisture transport equations.

In HRRRv4, the greenness fraction has been updated from climatological values to a real-time VIIRS-based green vegetation fraction product, allowing dynamic seasonal evolution of vegetation cover.

(2) Surface energy balance:

The RUC LSM solves coupled heat and moisture transfer equations for soil and canopy layers together with a surface energy balance at the interface between the surface and the atmosphere. The net radiation flux at the surface is decomposed into sensible heat flux, latent heat flux, ground (soil) heat flux in the top layer, heat storage, and energy flux of snow phase change. The model solves for surface/skin temperature and specific humidity to close this balance using a root-finding algorithm. Surface exchange coefficients for heat and moisture are from the MYNN surface layer scheme, which provides stability-dependent turbulent transfer coefficients.

(3) Near-surface temperature, humidity, and wind

The 2-m air temperature is diagnosed using surface/skin temperature, sensible heat flux, air density, heat transfer coefficient, and potential temperature at the lowest prognostic model level (0.999-sigma or ~8 m above ground level). The 2-m specific humidity is diagnosed from surface and lowest-level specific humidities, latent heat flux, air density, and moisture transfer coefficient. The 2-m dew point temperature is calculated directly from temperature, specific humidity, and pressure at the lowest prognostic model level.

The 10-m winds are estimated by logarithmic interpolation between model levels using Monin–Obukhov similarity, typically between the first and second model levels (0.999-sigma and 0.996-sigma or ~8 m and ~30 m above ground level). The derived 10-m wind represents a grid-cell mean wind, consistent with the grid-mean roughness length.

(4) Known limitations of the HRRRv4 urban parameterization

Although HRRRv4 benefits from frequent data assimilation and high spatial resolution (3 km), the representation of urban processes remains simplified. Major limitations include:

Lack of explicit urban geometry: Buildings and streets are represented as a uniform slab, with no street-canyon radiative trapping and shading. As a result, nocturnal longwave trapping and diurnal shadowing effects are not captured.

Prescribed and static urban parameters: Thermal and radiative properties (e.g., emissivity, roughness, and heat capacity) are fixed for the urban land-use category and do not vary with geographic location, morphology, or building material.

Simplified surface heterogeneity: The sub-grid mosaic approach represents fractional contributions to parameters from multiple land use types but cannot resolve within-grid variations and interactions.

Diagnostic height inconsistency in urban canopy layers: The 2-m and 10-m output variables essentially assume horizontally homogeneous, aerodynamically smooth surfaces and therefore do not accurately represent conditions within urban canopy layer, where the mean building height often exceeds the first or even second atmospheric model levels.

Simplified hydrology: Urban surfaces are not treated as fully impervious; infiltration and evaporation can still occur through soil properties. The model lacks stormwater routing or runoff storage, which limits its direct applications for hydrological or flood studies.

Omission of anthropogenic fluxes and urban vegetation management: Anthropogenic heat emissions, building energy use, or irrigation of green spaces, which can modify local energy and moisture balances, are not considered.