Major Comment 1: The paper would benefit from a conceptual schematic and stronger directory-style guidance, ideally integrated into Section 2.

While the manuscript does mention its rationale for selecting representative and newly developed models and those at the climatology-hydrology interface, it currently lacks an overarching conceptual framework that visually summarises the overall structure of the review. Including a schematic diagram early in Section 2, clearly illustrating how different urban processes (such as radiation, evapotranspiration, runoff, and soil moisture) relate to the various model classes reviewed (bulk, SL-UCM, ML-UCM, hydrology-focused models) and coupling strategies, would provide valuable directory-like guidance. Such a visual roadmap would help readers, especially those less familiar with the fxield, to better navigate and contextualise the rich and diverse content of subsequent sections.

We will incorporate this conceptual framework of the overall structure to provide readers with a clearer understanding of the connections and context of the models reviewed. We will incorporate the framework at the end of Section 1 while explaining the following structure and contents.

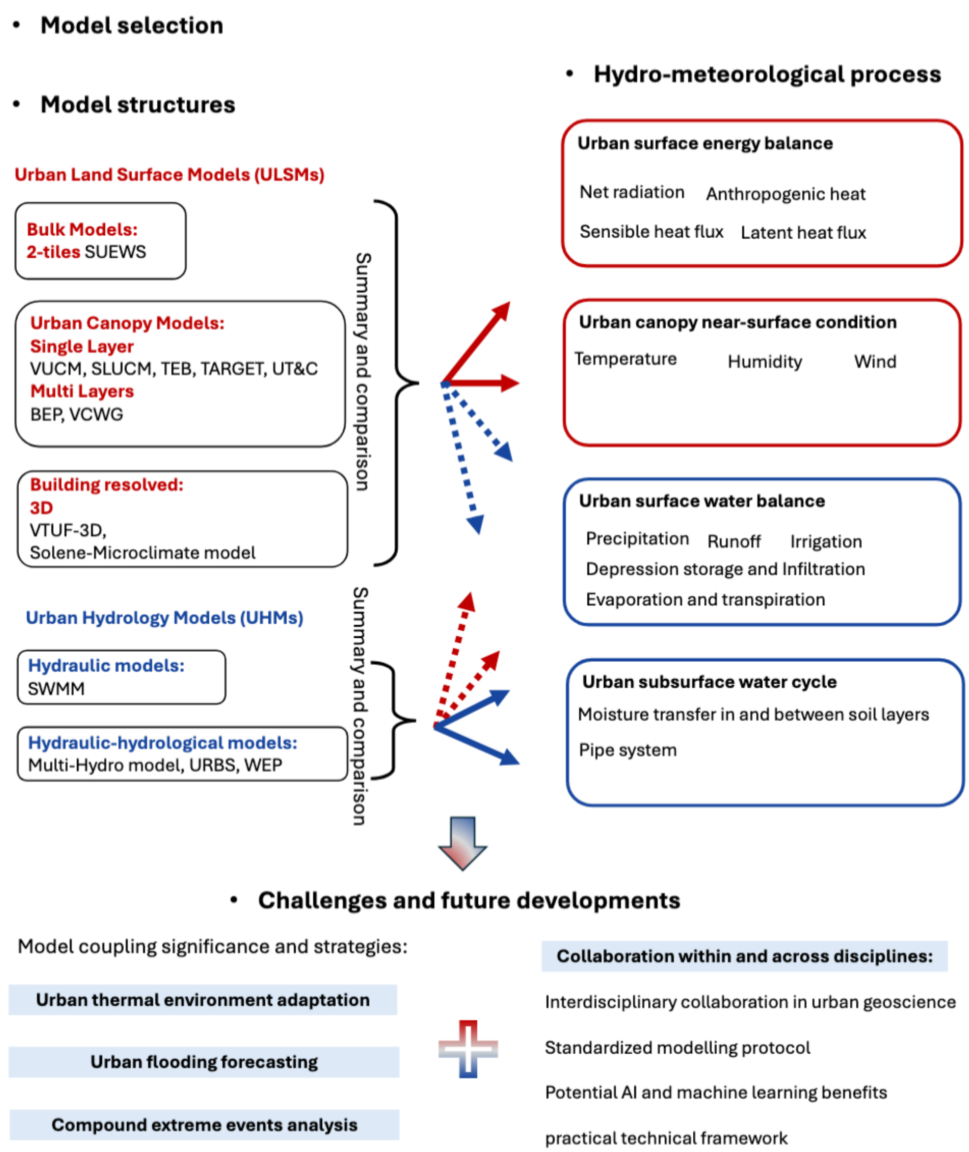


**Figure 1.** The overall schematic structure of the review.

Major Comment 2: The future directions section should be more closely tied to specific scientific tasks and supported by clear technical mechanisms.

Currently, the call for integration and collaboration in Section 6 is valuable but somewhat general. To strengthen its practical impact, the authors could explicitly frame future development around specific urban hydroclimate challenges (e.g. urban flood forecasting, heat mitigation, compound event analysis), clarifying the necessary coupling strategies and modelling approaches.

Two concrete, actionable suggestions could help operationalise this vision:

Develop a common modelling protocol—similar to the NetCDF CF conventions widely used in climate sciences—which is currently missing for urban hydroclimate modelling. Such a protocol could standardise inputs, outputs, metadata, and resolution criteria to greatly facilitate interoperability and cross-model comparisons. Initial steps toward this goal have already been taken within the Urban-PLUMBER initiative, but these efforts should be expanded and formalised into more broadly accepted community practices.

Establish a practical technical framework to overcome barriers in collaborative model development. Leveraging open-source collaboration platforms like GitHub could foster transparency, modular development, and community engagement. Additionally, considering WRF's wide adoption and flexibility, it might serve effectively as a common base framework to host and test integrated urban hydroclimate components.

These steps would provide concrete pathways to improve the current fragmented landscape, enabling more coherent and coordinated model advancements.

We concur that focusing future development on specific urban hydroclimate challenges will significantly enhance the practical impact of our call for integration and collaboration.

We will revise our manuscript for Section 6, Challenges and future developments, to include a more detailed explanation of the necessary model coupling. The first three parts of the revised Section 6 explicitly frame future developments around specific urban hydroclimatic challenges, including urban thermal environment adaptation, urban flooding forecasting, and compound extreme events analysis. The necessity and significance of model coupling strategies and modelling approaches are addressed for each specific topic:

*6.1 Urban thermal environment adaptation*

*The thermal environment depends not only on temperature, but also on humidity. Thus, accurately estimating these two terms is essential to take into account. Two directions of efforts have been made in the last decades on ULSMs.*

*First, ULSMs are widely implemented in regional climate models, as mentioned in Section 3 and Figure 2. Coupling the atmospheric models with land surface models, including ULSMs, supports studies of land-atmosphere interactions, specifically the impact of urban* *land on this interaction. Recent studies have further employed physically realistic, coupled atmosphere-land surface-subsurface models (Wagner et al., 2016; Fersch et al., 2020; Kim et al., 2021). These coupling simulations aim to evaluate the intricate interplay between terrestrial and atmospheric processes, shedding light on their influence on hydro-meteorological phenomena. By coupling the WRF-SLUCM and a land surface-subsurface model (ParFlow), Talebpour et al. (2021) emphasized the critical need to account for terrestrial hydrology, particularly in urban areas where diverse development patterns introduce additional complexities to coupled atmosphere-groundwater interactions. The coupling between the WRF-SLUCM and ParFlow can overcome some of the limitations of representing the saturated soil layer and groundwater in the ULSMs found in the current study.*

*Second, the ULSMs are further developed, accounting for complex physical processes, notably hydrological processes and the representation of vegetation, to support studies on the interface of meteorology and hydrology. In general, the development of ULSMs initially focused on stand-alone models, which have subsequently been implemented in coupled versions with mesoscale climate models. Therefore, stand-alone versions are usually more advanced in physical complexity than their coupled versions. This is the case for, e.g., ASLUM (Wang et al., 2013) and WRF-SLUCM (Yang et al., 2015), as well as the SUEWS and WRF-SUEWS (Sun et al., 2023; Sun and Grimmond, 2019). However, the hydrological module of BEP was first implemented in a coupled version by Yu et al. (2022) (WRF-BEP) instead of as a stand-alone version. In the version of WRF-BEP, depression storage over impervious land, evaporation over urban green surfaces, and pipe system parameterizations based on Manning's formula are included (Yu et al., 2022).*

*However, urban land surface models (ULSMs) face challenges in simulating natural land surfaces, including water and vegetation, within urban areas. Current mesoscale land-atmosphere simulations focus on impervious urban areas, but urban regions also contain vegetation and lakes. These natural patches are crucial for simulating the urban thermal environment, affecting energy balance and humidity levels. Based on our study, stand-alone ULSMs have started incorporating natural land surfaces, including vegetated land and trees, but often exclude urban lakes and ponds. It is recommended to include urban water surfaces in ULSMs to address interactions between natural and built-up landscapes. Using large eddy simulation with mesoscale climate models can improve spatial resolution and capture small natural landscapes within urban areas. Adjustments are needed for simulating urban lakes due to differences from natural lakes. The Local Climate Zone scheme should also consider urban water landscapes in its classifications.*

*6.2 Urban flooding forecasting*

*Accurate precipitation data and coupling of hydrological models with hydraulic models contribute to accurately forecasting urban flooding and inundation. Atmospheric models have been coupled one-way with urban hydraulic models. Coupling enables more precise monitoring and control of hydraulic systems, thereby enhancing the accuracy of flood predictions and responses. Traditionally, hydraulic models utilize single-grid precipitation data as input; however, understanding the urban impact on precipitation events reveals significant spatial variability within a catchment (Cristiano et al., 2017). Consequently, higher-resolution input data from atmospheric models can improve hydraulic system performance. Furthermore, coupling allows to more effectively manage inundation by providing real-time data on soil saturation and atmospheric conditions, leading to improved predictions and responses to inundation events. For example, recently Gu et al. (2022) coupled the WRF with SWMM to provide precipitation input for their hydrologic-hydraulic simulation.*

*Urban land modifies both atmospheric and terrestrial hydrological processes. By leveraging the two-way coupling between land and atmospheric models, researchers can explore the effects of urbanization on atmospheric and terrestrial hydrological processes, respectively. For instance, an emerging study area involves investigating urban-induced convective precipitation events (Wang et al., 2021b; Yang et al., 2024). Accurately simulating high-resolution rainfall is challenging due to its spatial variability and randomness. There is another group of existing studies using hydrological models to investigate the impact of urbanization on terrestrial-hydrological processes, such as runoff and infiltration (Oudin et al., 2018; Locatelli et al., 2017; Yoo et al., 2021). However, these investigations often overlook atmospheric interactions, concentrating solely on land surface and subsurface hydrological processes. This alignment with the findings in the current analysis underscores the complexity of terrestrial-hydrological processes, which exhibit strong coupling with atmospheric dynamics.*

*To enhance urban flooding forecasts, it is crucial to integrate atmospheric, hydrological, and hydraulic models effectively. Accurate precipitation forecasts require a well-represented land surface in a two-way coupled land-atmospheric simulation. At the same time, the hydrological model WRF-Hydro shows potential for coupling with a land-surface model and an atmospheric model (Gochis et al., 2018). This can provide an opportunity to study urban impacts on terrestrial-hydrological processes and their subsequent effects on atmospheric-hydrological interactions simultaneously. In the end, hydraulic models take both outputs from the atmospheric and hydrological models to better simulate urban flooding and inundation.*

### *6.3 Compound extreme events analysis*

*Extreme weather events like heavy rainfall, floods, droughts, and heatwaves can lead to compound disasters. Urban water bodies and temporary water accumulations from rainfall, along with drought conditions, significantly impact the urban thermal environment by altering energy and humidity levels (Hao et al., 2023). Furthermore, urban heat islands can affect convective rainfall amount and distribution, and influence land hydrological processes. Understanding the interconnections of these events is crucial for assessing climate disaster risks. This involves studying land-atmosphere interactions and coupling thermal and hydro-hydraulic processes to improve urban micro-climate simulations, optimize drainage, and mitigate adverse effects on ecosystems.*

*Coupling and integration are mainly applied to land surface and atmospheric models. One key challenge in fully implementing hydraulic and terrestrial-hydrological processes with thermal processes is the need for interaction between simulation units, such as grid cells in ULSMs like Multi-Hydro and WEP, and sub-catchments in SWMM and UHE in URBS. WRF-Hydro, coupled with a land surface model, includes terrain routing modules for 2D overland flow and soil moisture links (Gochis et al., 2018). It also features channel and reservoir routing modules and can be two-way coupled with the atmospheric model. WRF-Hydro can be coupled with SMWW for urban hydrology and drainage (Son et al., 2023). However, its development and application in urban areas and the interface between urban thermal and hydrological environments are limited (Fersch et al., 2020).*

*Advancements in computing systems have led to the use of CFD models, traditionally for urban wind analysis, in simulating urban thermal environments. Despite limitations in 3D ULSMs for hydrological cycles, they show potential for urban hydro-thermal environments when integrated with distributed hydrological models (Robineau et al., 2022). Both 3D ULSMs and URBS hydrological models need high-resolution input data, such as urban morphology, topography, and sewer systems, limiting URBS compared to SWMM. Improved data collection methods may enable high-resolution simulations of urban microclimates and hydrological processes at the neighborhood scale, allowing comprehensive thermal and hydro-hydraulic interactions. CFD models are advantageous at neighborhood and microscale levels for studying climate-hydrological mitigation measures. Further development is needed to integrate physical processes with high-resolution hydraulic-hydrological models, considering data availability and computational resources.*

In the last part of Section 6, we discuss the actionable suggestions to enhance the collaboration within and across disciplines:

*6.4 Collaboration within and across disciplines*

*Our discussion on model comparison and future numerical model development highlighted the potential and challenges of inter- and intra-disciplinary cooperation. Collaboration between atmospheric science, hydrology, and hydraulics is essential for both regional-scale research and micro-scale applications. Detailed terrain data, urban building information, and other model inputs can advance research on urban hydrological and climate processes. This collaboration extends to geology, civil engineering, and architecture. The concept of urban geoscience emphasizes the need for communication across geoscience fields to address climate and natural disasters (Bricker et al., 2024). Urban geoscience, which applies geology and earth sciences to urban management, includes disciplines like engineering geology, hydrogeology, geological modelling, geochemistry, and environmental geology. It focuses on interactions between urban environmental systems and human activities, aligning with our findings (Bricker et al., 2024; Pescatore et al., 2024).*

*To promote collaboration, establishing common modeling protocols is practical. Standardization in numerical simulation offers benefits like consistency, quality control, efficiency, enhanced collaboration, interoperability, predictability, and innovation. The NetCDF Climate and Forecast (CF) Metadata Conventions facilitate sharing and processing climate and forecast data in NetCDF files (Hassell et al., 2017; Eaton et al.). These conventions ensure interoperability between datasets from different sources. A common framework ensures consistent processes and outputs, reducing variability and enhancing quality, saving time and resources. Standardized protocols improve collaboration among researchers, enabling different models and systems to work together for comprehensive cross-model comparisons. The Urban-PLUMBER initiative benchmarks and evaluates land surface models used in urban hydroclimate simulations, outlining key components like data formats, experiments, and expected outputs (Lipson et al., 2024). These initiatives should be expanded and formalized into widely accepted practices for urban hydro-meteorological simulations.*

*Building on the importance of interdisciplinary collaboration highlighted in our discussion, artificial intelligence (AI) and machine learning offer transformative potential for urban climate and environment modeling. These technologies can enhance predictive accuracy, identify complex patterns, and optimize model parameters, thereby complementing the* *collaborative efforts in atmospheric science, hydrology, and hydraulics. It has been shown that machine learning models and statistical models can work together with the physics-based models while being applied to different urban adaptation strategies under climate change (Li et al., 2022; Aliabadi et al., 2023). To study the urban heat, machine learning is applied for downscaling by generating high-resolution data from lower-resolution results from physics-based simulations, reducing temperature errors, and lowering computational costs (Wu et al., 2021b). Forecasting can benefit from AI and machine learning by working with numerical simulations and measurement data to enhance data accuracy and model performance for climate disasters (Luo et al., 2022). He et al. (2023) introduce a hybrid data assimilation and machine learning framework integrated into the WRF, which optimizes surface soil and vegetation conditions to improve regional climate simulations. To fully leverage these advancements, urban climatologists and hydrologists should also engage in discussions with scientists who specialize in AI applications. These interdisciplinary dialogues are crucial for integrating AI-driven insights into urban geoscience, aligning with our findings and recommendations on the necessity of interdisciplinary cooperation to address climate and natural disasters effectively.*

*To overcome barriers in collaborative model development, establishing a practical technical framework is essential. Open-source platforms like GitHub enhance transparency, modular development, and community engagement by allowing real-time collaboration. The Weather Research and Forecasting (WRF) model, widely adopted and flexible, can serve as a common base for hosting and testing integrated urban hydroclimate components. Most bulk and 2D ULSMs can be two-way coupled with WRF, though 3D ULSMs are less coupled. Emerging multi-physics urban large-eddy simulation models, such as PALM-4U (Gehrke et al., 2021; Resler et al., 2017), uDALES (Owens et al., 2024), and City-LES (Kusaka et al., 2024), benefit from increased computer resources and show potential to work with WRF outputs, e.g., WRF-PALM (Lin et al., 2021). WRF links atmospheric, land surface, hydrological, and hydraulic models and can work with machine learning models (He et al., 2023). WRF's robust capabilities make it ideal for integrating various urban climate models, facilitating comprehensive simulations. Utilizing such frameworks and platforms can drive innovation and improve urban hydro-meteorological research quality at multiple scales.*

L213: The authors state that “Wang et al. (2016) added an irrigation scheme to the model” (referring to SUEWS). This attribution is incorrect. The irrigation functionality was first introduced in Järvi et al. (2011), which documented the initial release of the Surface Urban Energy and Water Balance Scheme (SUEWS). The cited Wang et al. (2016) paper does not pertain to SUEWS development and focuses instead on vegetation cooling in desert cities. I suggest correcting this reference to reflect the accurate model development history.

Reply to comment on L213:

We will revise this part of the manuscript.