

Detailed response to referees comments

We thank both reviewers for their comments on the study. The comments of both reviewers have induced changes in this new manuscript submission.

Thanks to the comment, we have made minor changes on the traffic impact parameterisations. First, we have modified the way we integrate the heat lost by the fuel consumption in the model. Rather than being considered as a ground fluxes, this flux is emitted directly as a component of the outgoing town sensible and latent heat flux. This calculation is more relevant for the tile approach in SURFEX. Second, for the analyses of the traffic impact on the road surface temperature, we consider its effect on the entire road lane width in Section 5.2. It allows a better understanding of the impact on average on the entire road surface. These changes modify marginally the results. However it does not changes the traffic impact interpretation.

Modifications have been made to clarify the methodology, the experimental set-up and the results. For the methodology, in the section 2 “Modelling strategy” new elements and clarifications have been made. For the experimental set-up, the paragraphs have been reordered and clarified. Finally, for the results the entire Section 5.2 named the “Analyses of the traffic impact parameterisations” has been completely rewritten.

In addition, on most graphics you will see changes, whether it is captions, label, or readability. One figure (Fig.8) has been completely changed in order to avoid misinterpretation and help the understanding for the reader.

We also have done a final sweep for grammar, spelling, and sentence clarity; thus you will see along the manuscript minor corrections.

We believe that thanks to these corrections, this work is now more understandable to the reader.

Best regards

Major changes for the first reviewer (R.C 1)

R.C 1 (Reviewer comments 1): 2nd paragraph: Two more previous studies may also be interesting to the authors and provide insights. Chen et al. (2021) studied the 3D vehicle heat impact on the urban thermal environment in Hong Kong by modifying the WRF-SLUMC model, and later studied the impact of electric vehicles. The vehicle heat includes both spatial and temporal information. And consider the components of different vehicle types. Their studies also pointed out the seasonal variation of the vehicle heat impact

1.Chen, X., Yang, J.*, Zhu, R., Wong, M. S., & Ren, C. (2021). Spatiotemporal impact of vehicle heat on urban thermal environment: A case study in Hong Kong. Building and Environment, 205, 108224. <https://doi.org/10.1016/j.buildenv.2021.108224>

2.Chen, X., & Yang, J.* (2022). Potential benefit of electric vehicles in counteracting future urban warming: a case study of Hong Kong. Sustainable Cities and Society, 104200. <https://doi.org/10.1016/j.scs.2022.104200>

A.C, (Author's comments 1): [We have added these citations to the 2nd paragraph and one sentence is added to be in agreement with these findings.](#)

Changes in the manuscript: I33-34 “However, the impact of traffic on the local climate is greater in winter, particularly at rush hours (Pigeon et al., 2007; Iamarino et al., 2011, Chen et al., 2021).”

I 31-32 “However, by adopting an electric-based vehicle fleet, the total anthropogenic heat released decreases proportionally Chen2022”

R.C 1: Modeling strategy, 1) How does the model consider different vehicle types providing different areas of shading? 2) And how does the model consider different vehicle types with different percentages of the total vehicle amount releasing different anthropogenic heat due to varied energy efficiency?

A.C: [In this study, trucks, buses, and 2-wheels are omitted in this study. Thus, only passenger cars that are considered to build an estimate of traffic impacts.](#)

[The different areas of shading from the different passenger cars are taken into account indirectly through only one average length and width value as the impact on the solar and infrared net heat fluxes.](#)

[The same method is used to calculate engine efficiencies. A single equation is calculated, corresponding to the average engine efficiency of all different types of passenger cars. If the modeler wants to divide the vehicle types into several subclasses, it could be possible through the estimation of several engine efficiencies and with a weighted calculation. Below is an example for two types of vehicle, passenger cars and buses:](#)

$$f_{traff} = (1 - f_{sn}) \left(p_{car} \frac{\overline{w}}{w_{rd}} \left(\frac{\overline{l}}{v} \Phi \right) + p_{bus} \frac{\overline{w}_{bus}}{w_{rd}} \left(\frac{\overline{l}_{bus}}{v} \Phi \right) \right)$$

With $p_{car} + p_{bus} = 1$

Changes in the manuscript:

I351-354 “Finally, throughout the simulation period, the traffic counts show that more than 95% of the vehicles driven are passenger cars at both road weather stations (Colas, 2025). Therefore, to avoid complexity, only one vehicle type is considered for the estimation of the traffic parameters, with trucks, buses, and two-wheelers omitted. Estimates of the passenger cars engine efficiency and driver behaviors are made with the corresponding WLTC cycle and manufacturers’ data (Colas, 2025).”

I481-483 “It could be defined as a second vehicle type with its own set of estimated characteristics. The traffic impacts of the set of two average vehicle types could then be calculated as a simple arithmetic mean, weighted by a vehicle type ratio.”

R.C 1: 3) How does the model consider whether there is a vehicle on the street or not at different times throughout the study period?

A.C: Traffic intensity is observed at the road weather station as an average number of vehicles per hour. These observations are given to the model and then converted to vehicles per second. Thus, at each model time step the number of vehicles is constant. We add two sentences for the reader.

Changes in the manuscript: I93-95 “Traffic intensity is included in the model through average values of traffic counts and converted to vehicles per second. Therefore, traffic counts change at each atmospheric forcing time (each hour in this study).”

R.C 1: Methods: I suggest that authors list the surface energy balance before and after considering the traffic to demonstrate clearly how the traffic related process modify the surface energy balance and then further changes the estimation of the surface temperature.

A.C: It will indeed help the reader to have a quick glance of the changes we have made. We have added the town energy balance equation before and after the traffic impact parameterisation as well as a quick explanation on how the traffic impact modifies the town energy balance.

Changes in the manuscript: I113-127 “The urban energy balance without traffic impacts is written as:

$$Q^* + Q_f = Q_h + Q_e + \Delta Q_s + Q_m + \Delta Q_a$$

In the urban area, Q^* and Q_f are the net radiative heat flux and the anthropic heat flux (without traffic), respectively. On the right-hand side of the equation, there are two turbulent fluxes Q_h and Q_e sensible and latent heat fluxes, respectively, and ΔQ_s the heat flux by conduction through the urban surfaces. Q_m is the power exchanged by the melting and freezing of the water and finally ΔQ_m the horizontal advection, which is neglected in this study. All terms of the equation are expressed in watts per square metres.

Each traffic impact then modifies the energy balance within the canopy. First, three new source terms are added into this equation with the sensible $Q_{Hengine}$ and latent heat flux $Q_{Eengine}$ from the heat lost by the vehicle engine and the tyre-road friction heat flux Q_r . Secondly, the turbulent fluxes Q_h , Q_e of the urban area are modified by the wind induced by the traffic U_{traff} . Indeed, traffic modifies the fluxes from the soil-atmosphere interaction. Finally, the solar and infrared net heat fluxes are modified by the vehicle body as depicted in Fig.~\ref{fig:Scheme} and the resulting energy from the vehicle balance is released as sensible heat in the air. The other terms are not formally modified, but react according to the new energy exchanges driven by the new and modified terms. The updated urban energy balance, function of the different traffic impacts gives:

$$Q^*(traff) + Q_f + Q_{f_traff} = Q_h(U_{traff}) + Q_e(U_{traff}) + \Delta Q_s + Q_m + \Delta Q_a + Q_{Hengine} + Q_{Eengine} + Q_r + Q_{veh} \quad (2)$$

with Q_{f_traff} , the total source of energy coming from the vehicles distributed in the different right-hand terms of the equation.

R.C 1: Experimental set-up and model configurations: The estimation from ICCT needs more clarification; it is not clear to me with the current information.

A.C: [We have refined the description of the traffic parameters extracted from ICCT and used in this study.](#)

Changes in the manuscript: I354-357 “In addition, missing input traffic parameters for the TEB-CAR simulations (average mass, length and height of the vehicles), are derived from the yearly passenger car statistics ICCT2023). In this study, the average vehicle body characteristics of the passenger cars sold in 2018 for the EU-28 are taken as input values and displayed in Table 1.”

R.C 1: Results: I would suggest that authors list all simulation cases, including those with different physical processes again, to remind the reader.

A.C: To help the reader, several changes are made at the beginning of this section and on the experimental set-up section.

Changes in the manuscript: I344-350 “In Sect. 5.2, an ablation setup is implemented. It means that for each road direction, 3 more simulations are launched, each with a traffic impact removed from the model. They are called rolling friction, radiative, and wind-induced. The heat released by combustion is not considered for this part because this flux is released on the upper vertical domain of the grid and so have no impact on the road surface temperature. By removing a traffic impact for each simulation, it is possible to investigate the relative impact of each traffic parameterisation on the simulated variables when compared with the reference simulation of TEB-CAR. To evaluate the impact of the traffic on the full road lane width, in this section the vehicle to road width ratio w/w_{rd} is set to 0.5 in the traffic fraction occupation f_{traff} .”

“The cumulative effect of the new set of traffic parameterisations in TEB (named TEB-CAR) results in marked impacts on the physical variables of the road. Each traffic parameterisation may have opposite or cumulative effects on the physical variables. In addition, each impact may change depending on atmospheric conditions, seasonality, and traffic intensity. Thus, in this section, the individual effect of each traffic impact in the model is studied using the Nupuri experiment throughout the entire simulation period. A total of eight more simulations at Nupuri are analysed here. Each simulation has a traffic impact removed from the model and is launched in both road directions.”

R.C 1: Please maintain a consistent unit of temperature throughout the entire manuscript. *And also consider using different line styles*

A.C: All the °C units have been modified into Kelvin.

R.C 1: Results: Fig. 5a and b, are they Delta T or T, or the values subtracted from the observation values? Please make it clear.

A.C: In the article and in all the figures, we have modified the symbols for the road surface temperature. We now have 3 different symbols related to the road surface temperature. First: RST (K) for the road surface temperature. Second: ΔRST_{dir} for the road surface temperature difference between the two road directions (it can be an observed value or a

simulated value). Third: ΔRST_{mod} use only for the last Fig. 8. It represents the difference of temperature between TEB-CAR and TEB with (TEB-CAR minus TEB)
In addition, we modified the captions for both figures.

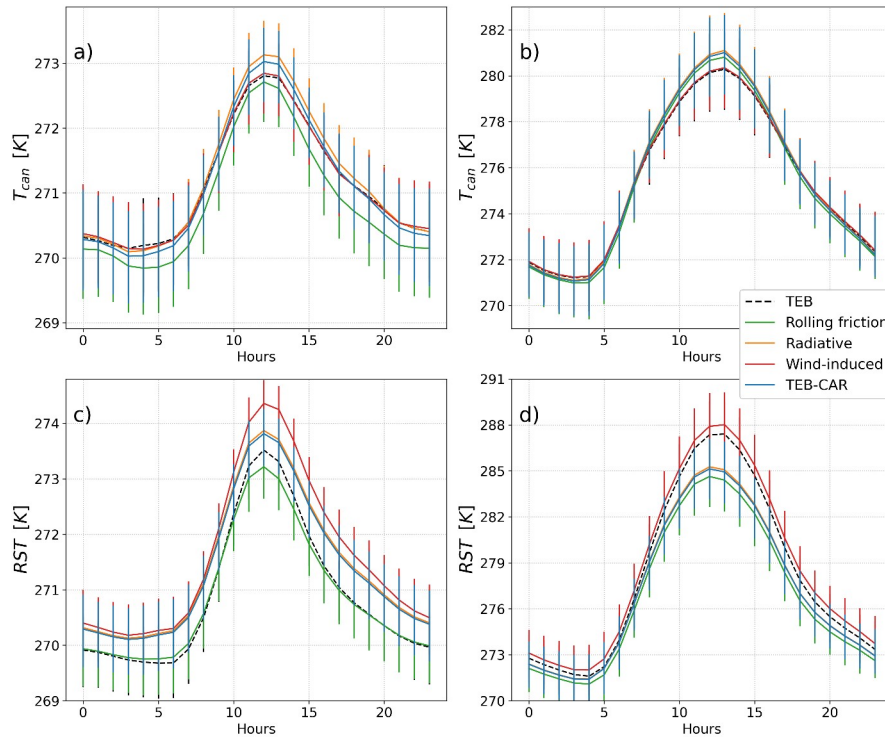
Changes in the manuscript: Fig.5 “Comparison between the observed and simulated RST on a eight days subset period beginning a monday at Nupuri location. The subscripts "h" and "t" are for values on Helsinki and Turku directions respectively. From top to bottom panel: (a) observed and modelled road surface temperature difference between the two road directions ΔRST_{dir} (Helsinki minus Turku), (b) road surface temperature, (c) number of vehicles per hour”

Fig.6 “Road surface temperature differences ΔRST_{dir} of both measured and simulated values between Helsinki and Turku directions (Helsinki minus Turku). Robust linear regression lines (RLM) are drawn between $\Delta Traff$ and ΔRST_{dir} for both observations and simulations. Panels (a) and (b) show the differences at the Palojärvi site on weekdays (a) and weekends (b). Panels (c) and (d) show the same information at the Nupuri site.”

R.C 1: The lines in Fig. 7 are not very clear; consider increasing the height-to-width ratio of each sub-figure.

A.C: Thanks to this observation we have made the appropriate change for this figure by increasing the height of each subplot. We have also increased the readability of the new Fig. 8.

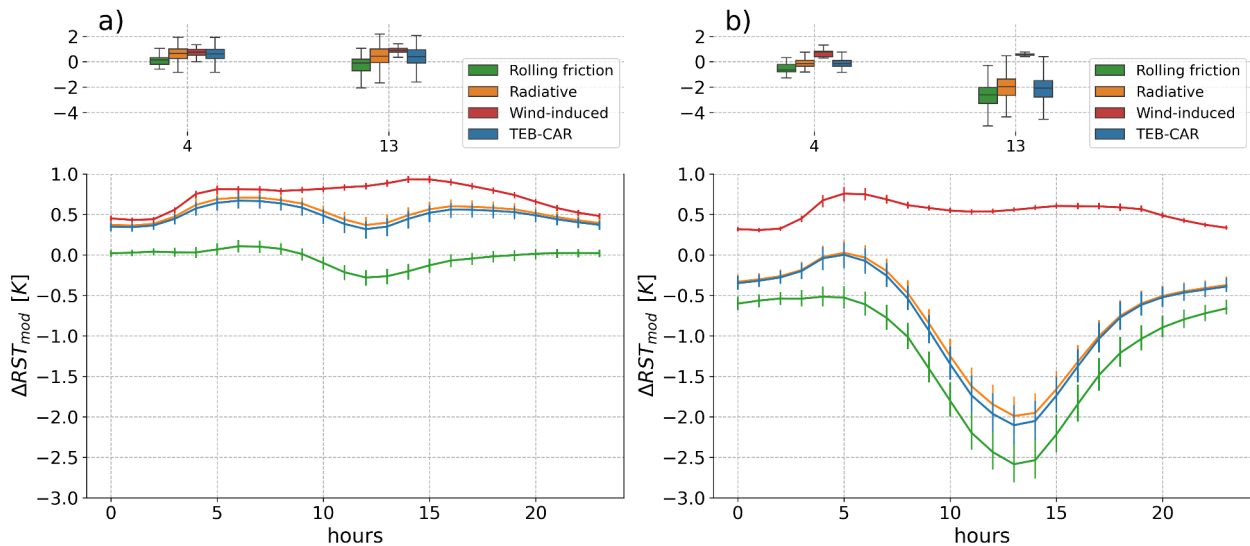
Changes in the manuscript:



R.C 1: Besides, for the same text in the two figures, do they indicate the same case? Please also clarify how to calculate the temperature difference (ΔT s). I suggest that the present values directly represent the impact, negative for cooling and positive for warming.

A.C: In agreement with this comment, to prevent misunderstanding and to emphasise on the traffic induced impacts, we have completely modified the figure. The new figure shows the road surface temperature differences between TEB-CAR and TEB (TEB-CAR minus TEB) and between the ablation experiment simulations and TEB on the Helsinki road direction. As suggested by the reviewer, a positive value shows a warming impact of the simulation without the wind-induced effect (in red). Thus, when compared to TEB-CAR, the wind-induced impact has an overall cooling effect.

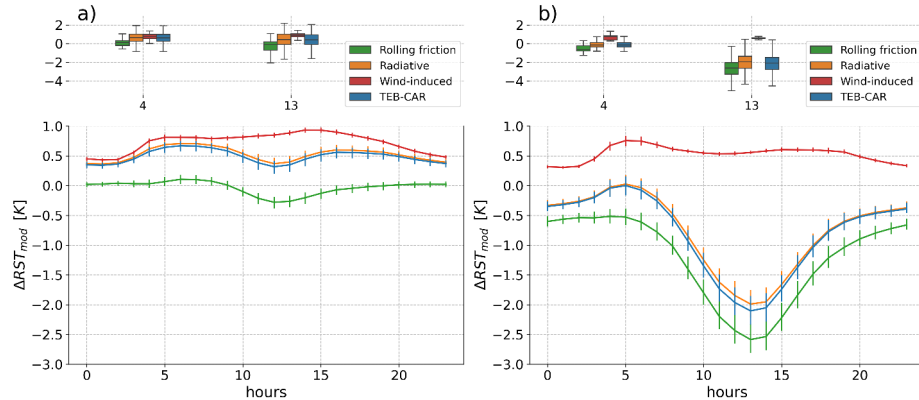
Changes in the manuscript:



R.C 1: The figure legends in Figs. 7 and 8 are different; the same text is assigned a different color, which is confusing.

A.C: Indeed, it was supposed to be the same color for both figures, there is a mistake on the figure integrated in the manuscript. Thank you for pointing out this. The new Fig. 8 has the same color corresponding to the Fig.7 as you can see in the figure below and above.

Changes in the manuscript:



R.C 1: The results shown by Figures 7 and 8 are very interesting and important. However, the current description and discussion are not clear and comprehensive. I would encourage a more straightforward description and discussion of the mechanisms, for instance, including more discussion on the seasonal and diurnal variation.

The explanation and discussion of Fig. 7 are also not clear and robust enough. For example, the explanation of the less impact from the heat release is not robust and persuasive.

The whole description and discussion for Fig. 9 are missing.

A.C: It is true that this section is not detailed enough. We added some explanations. We have modified the entire section regarding the “Analyses of the traffic impacts parameterisations”

Changes in the manuscript: Modified from I406 to I449

« To evaluate the relative contribution of each process on the physical variables, one must compare each simulation launched with a process removed, with the TEB-CAR simulation. Each process has a different marginal impact on the RST and the lower air temperature simulated at 0.5 m Tcan (K) as shown by Fig.7 and Fig.8. The figures show that the RST simulated without the wind-induced parameterisation is warmer than the one with the entire set of traffic impact (TEB-CAR simulation). Thus, it has a cooling effect on the RST because of the stronger heat exchange between the air temperature and the RST. The same trend is observed on the simulated RST with the radiative process removed. However, the cooling effect of the ablated wind-induced simulation is much stronger than for the ablated radiative simulation, in both seasons. This strong impact from the wind-induced parameterisation can be explained by the analysis of the processes Fig.9: the wind induced by the vehicles accounts for 75% on average of the total wind simulated by the model in the daytime. At night, this proportion falls between 15% and 45% on average due to much lower traffic and leads to a lower cooling effect. In spring, the cooling effect of the wind-induced impact is greater than in winter with up to around 2.5 K on average during peak traffic (13 h UTC), as shown in Fig.8. In addition, the Fig.8 shows that the standard deviation of the road surface temperature differences with the reference simulation ΔRST_{mod} is the lowest with the wind-induced parameterisation removed. In fact, the cooling effect of the wind-induced process is more pronounced when the temperature difference between the road surface and the air is the highest. This effect is highly dependent on meteorological conditions and then explains most of the traffic impact variability.

The radiative and the wind-induced processes have an opposite effect on the air temperature simulated at the lowest level Tcan. As shown in Fig.7, wind-induced leads to a slight warming effect whereas radiative impact leads to a slight cooling effect in both seasons. On average, these effects are greater in the daytime. Since the RST is almost always warmer than the air temperature, more energy is transferred when the differences in soil-air temperature are higher, especially in the daytime. In addition, the radiative impact leads to a slight cooling effect on Tcan like for the RST.

Furthermore, the RST simulated with the rolling friction is cooler than the RST simulated by TEB-CAR. Thus, this parameterisation has a warming effect on the RST. The warming effect of the heat lost by vehicles is low, even during peak traffic (4 h UTC and 13 h UTC) throughout the period, as shown in Fig.8. Indeed, the analysis of the processes in Fig.9 shows the power produced by rolling friction and transferred to the road surface is approximately 30 W m^{-2} on average during peak traffic for both road directions. This leads to a strong impact on the RST as shown by the significant shifts in descriptive statistics

from the TEB-CAR simulation on the boxplot diagrams in Fig.8 The source of energy from the rolling friction leads to an increased air temperature simulated at the lowest level Tcan as shown in Fig.7. This behaviour is consistent throughout the day and throughout both seasons.

To summarize, the processes added in TEB-CAR each have a different marginal impact on the RST: rolling friction has a strong marginal heating effect, increased turbulence a strong marginal cooling effect and radiative effect a small marginal cooling effect. In addition, depending on the meteorological conditions, the impact of traffic can change significantly due to the temperature dependency of the wind-induced parameterisation. The cumulative effect of the new set of traffic parameterisations in TEB (named TEB-CAR) results in marked differences compared to the model without the traffic parameterisation. In both seasons, the overall impact on the RST is driven by the competition between the wind-induced impact and rolling friction. Competition between these factors eventually leads to an overall warming effect on the RST in winter and a cooling effect in spring in both direction as shown on Fig.7 and Fig.8. The simulated TEB-CAR RST is 0.5 K warmer during the winter period and is 0.9 K cooler in spring than the RST of TEB. For air temperature Tcan}, in both directions, TEB-CAR compared to TEB simulations lead to equal air temperature in winter and and 0.14 K higher on average in spring.

Even if there is no direct impact of the heat released by the fuel combustion on the road surface temperature, it is interesting to look at the values. The total heat loss by the vehicle inefficiencies modelled in this study is comparable to the heat loss modelled in other studies. Pigeon et al. (2007) calculate 18.3 W m^{-2} released in the atmosphere for $1400 \text{ vehicles h}^{-1}$ from the inventory approach in Toulouse city. In Fig.10, the heat released by traffic is calculated considering the same traffic intensity ($1400 \text{ vehicles h}^{-1}$) spread over the same area $100\text{m} \times 100\text{m}$. Depending on the average speed of road traffic in cities, this study simulates an average heat released from 16 W m^{-2} for 4 m s^{-1} to 6.3 W m^{-2} for 15 m s^{-1} .»