

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 2)

R.C 2: The current study focuses exclusively on winter. Could the authors elaborate on why summer was not included in the simulations? What differences in traffic-induced impacts would be expected between winter and summer conditions, particularly in terms of radiative processes, boundary layer development, and surface–atmosphere interactions?

A.C: We did not work on the summer, because the focus is on winter conditions and the key variable associated, the road surface temperature. In addition the road weather station data that has been given for this study correspond to the same period given by the open-access data on the Zenodo from the FMI here. It runs from 19 October 2017 to 1 May 2018.

The spring conditions, subjected to more and more direct downward solar radiation as we approach the 1 May in the simulation, gives an idea of the impact for summer. The traffic-induced impacts would be relatively similar to the spring but at an higher extent. First, the heat lost from the combustion and the rolling friction are not weather dependent in this work, thus their extents will not change as their impact on the air and road surface temperature in summer. Second, the radiative impact of the vehicles is small compared to the other impacts. Thus, this impact is expected to stay small but to grow slightly. Finally, it will be interesting to see the effect on the wind-induced impact. This impact depends heavily on the difference between air and road surface temperatures. It leads to increased turbulence and heat exchange between air and road surface temperature. This impact is expected to grow as the temperature difference is would increase as well. In conclusion, the cumulative of these impacts may increase the overall cooling impact on the RST and the overall heating effect on the air temperature.

Changes in the manuscript: I484-I487 “Future work should evaluate the model subject to higher traffic intensities and summer conditions to assess the reliability of the traffic impacts parameterisation. The simulation period studied was relatively short, on winter and spring conditions only and only two road weather stations have been used to assess TEB-CAR improvements.”

R.C 2: In the comparison with observations from the two road weather stations in southern Finland (Nupuri and Palojärvi), how were the atmospheric driving conditions specified in the model simulations? Were they based on in-situ measurements, reanalysis products, or another source? This information is important for assessing the reliability of the comparison.

A.C: The road weather stations measure the atmospheric variables needed to force the model (Specific humidity, air temperature and wind force and direction). In addition reanalysis of downward solar and infrared radiation from ERA5 are used to force the model.

We have modified the section 4 to increase the clarity of the experimental set-up. (1) The overall model configuration is now exclusively on the first paragraph. (2) Comments on why we choose Nupuri and Turku station are gathered in the second paragraph. (3) Everything related to the atmospheric forcings and the road weather stations specifications are gathered in paragraph four and five. We also have fixed the height symbol “h” in the Table 1.

Changes in the manuscript:

I400-I449« This model improvement study is based on the version of the TEB model described in Colas et al. 2025, which models cold conditions using explicit modelling of snow and ice with processes of water melting and freezing. This version of TEB is used as a reference, and compared with the modified version named TEB-CAR, which includes the anthropic processes described in the previous sections. Both models are configured as the TEB-ES version in Colas et al. 2025 except for some changes to the snow removal parameterisation: the total snow cover is removed whenever the snow has been continuously present on the ground for 6 hours, except at night between 0 am and 5 am. Six levels are taken for the surface boundary layer option (Masson 2009) for both models with Tcan (K) the lower air temperature simulated at 0.5 m.

Measurements of long data series on busy road lanes of paired traffic, weather and surface physical variables are essential for this study. Thus, road weather stations from Southern Finland are chosen because they collect in-situ measurements of these variables as shown in Fig.4. Among the road weather stations deployed on the Turkü-Helsinki highway, Nupuri (60.22805N, 24.59641E) and Palojärvi (60.29328N, 24.31916E) road weather stations are chosen because a strong vehicle commuting pattern is observed at these stations. Indeed, the majority of the commuters go to Helsinki in the morning, then drive back home in the afternoon. This pattern creates clear differences on the road surface physical variables between both directions. It allows to isolate the traffic impact from the other effects since both directions are subject to the same atmospheric conditions. This study takes advantage of this commuting pattern to evaluate the TEB-CAR capacity to model the marginal effects of traffic impacts at these road weather stations.

These road weather stations manufactured by Vaisala measure common atmospheric variables from roadside towers such as air temperature, wind direction and speed, humidity, precipitation, and also road surface conditions. Water, ice and snow on the road are measured by optical sensors and road surface temperature is measured with asphalt embedded sensors. These physical variables are directly influenced by the effects of traffic

and winter maintenance operations with large impacts on the road surface conditions. Road temperature sensors are buried under one high-speed lane for each direction. In addition, Fintraffic installed a vehicle counting system several kilometres ahead in each lane. These in-situ measurements are transformed and used to force both model versions in this study. They are available in the Zenodo dataset attached to this study (Colas 2025)

The road weather stations measure the atmospheric and surface variables every 6 minutes. They are transformed into hourly measurements to force the TEB and TEB-CAR models. To calculate hourly values, the value closest to the full hour is extracted. The 6-minutes accumulated precipitation measurements are aggregated every full hour. Snow and rain are discriminated using the following criterion: If the air temperature is > 274.15 K, the precipitation is deemed to be liquid, otherwise it is classified as snow as in Colas et al. (2025). The ERA5 reanalysis of the shortwave and longwave data at ground level is also used to force the model by selecting the grid point closest from the Nupuri and Palojärvi locations. Hourly traffic data, composed of vehicle counts and speed, are extracted from the Fintraffic API at the same location. TEB-CAR simulations are run on each direction of the road, with their associated vehicle counts every hour. The traffic counts from the slow lanes, for each direction of the road, are used to force the models because the probe embedded in the asphalt is located in the slow lanes of the pavement. Thus, in this study, it is assumed that traffic on the faster lanes has no effect on the conditions of the slower lanes.

Simulations are done at both Nupuri and Palojärvi location when atmospheric, surface and traffic observations are available. At Palojärvi location, a simulation of two-month and a half is done between 19 October 2017 and 30 December 2017. A longer simulation is performed at Nupuri location from 19 October 2017 to 1 May 2018. The joint two-month and a half observation period available at both the Palojärvi and Nupuri are used to validate the model at these both locations in Sect 5.1. Because the surface temperature probe is embedded close to the track lane, the vehicle to road width ratio w/w_{rd} is set to 1 in the traffic fraction occupation f_{traff} in this subsection in order to have a road surface temperature modelled that represents the surface covered by the cars and corresponding to the observed one.

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} .

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 Colas2025b. In addition, the missing input traffic parameters for the TEB-CAR simulations (average mass, length, and height of the vehicles) are derived from the ICCT yearly passenger car statistics ICCT2023. In this study, the average vehicle body characteristics of passenger cars sold in 2018 for the EU-28 are taken as input values and are shown in Table 1. »

R.C 2: According to Figure 5, the traffic-induced temperature difference appears to be lower in the afternoon than in the morning. Could the authors provide a physical explanation for this asymmetry? Is it due to differences in traffic volume, boundary layer stability, or background meteorological conditions?

A.C: The traffic-induced temperature difference asymmetry depends on the location and if it is modeled or observed. As shown in Fig.6, for Palojarvi, there is a traffic asymmetry with higher traffic intensity differences in the morning than in the afternoon. It leads on average to higher RST differences for both modeled and observed values.

For Nupuri, as shown in Fig.6, there is also an higher traffic intensity differences in the morning. It leads on the simulations to higher RST differences in the morning. In opposite, on the observed values, the RST differences are higher in the afternoon. On average the RST in the Turku direction is lower than on the Helsinki direction. This is true even when the traffic intensity differences are 0. The intercept of the regression equation on the observations gives -0.1846. These differences could be due to impacts from the surrounding elements or from sensor biases.

Changes in the manuscript: I376-I377 “The traffic intensity differences are lower in the afternoon than in the morning, leading to a lower observed ΔRST_{dir} . These amplitudes are well reproduced by TEB-CAR.”

I391-I394 “At Nupuri location, the observed and simulated ΔRST_{dir} distributions are shifted, the intercept of the regression equation for observed ΔRST_{dir} is negative, and the observed ΔRST_{dir} have a negative intercept. These features suggest that there is elements that produce this cold bias at Nupuri location that are not taken into account into TEB-CAR. It can also suggests that there is a sensor bias at this location since this effect is not found at Palojarvi location.”

R.C 2: The phrase “During working days wekdays” appears to contain a typographical error. Please clarify or correct this expression.

A.C: This comment is relevant for the section “Analyses of the traffic impacts parameterisations”. We have completely the section 5.2

