Anonymous Referee #2

General comments

Snow and ice on winter roads is a serious hazard and a significant cause of human injury and economic damage. Overzealous use of de-icing agents contributes to environmental degradation in an already highly stresses urban ecosystem while inaction can lead to serious consequences. Contributing to better mitigation strategies for ice and snow on winter roads in cities has great influence on the quality of life for urban population and can contribute to more efficient use of resources.

The study "Accounting for anthropic energy flux of traffic in winter urban road surface temperature simulations with TEB model" describes and compares two model instantiations. This work is of interest, as may contribute to better forecasts of road conditions and the coordination of mitigation strategies. Of particular interest is the comparison of two different approaches to estimating road surface temperature and their validation against field experiments.

Some of the equations are quite vague and assumptions are not further explained or justified. This problem is apparent right at the start in equation (1). With the equation, as presented, I have two questions:

Question

- ΔZs is the first layer of the road cover thickness in meters. The authors set Zs = 0,001 to reflect only the road surface temperature. Since the authors relate the total heat flux across the road surface to the bulk heat capacity of the road, why do the authors minimize the road cover thickness? Is it to allow for an immediate response of the road surface temperature to heat flux changes without any thermal inertia? This choice should be explained in more detail.

Answer: Additional equations will be included to improve the understanding of the approach. The road cover thickness was minimized to indeed avoid thermal inertia. This is now specified into the text.

ΔZs is the thickness of the first layer of the road surface. ρroad.croad is the volumetric heat capacity of the road surface layer ($Jm^{-3}K^{-1}$), t is the time (s), G is the conductive heat flux across the bottom of the road surface layer (pavement heat flux, Wm^{-2}), Rn is the net radiation flux (Wm^{-2}), Sa is the sensible heat flux associated with natural wind (Wm^{-2}) and L is the latent heat flux associated with phase transition of water (liquid-vapor, and liquid-solid) (Wm^{-2}). We choose a very low thickness value (ΔZs equal to 0.001 m) so that its temperature reflects RST. It allows a quick response of the road surface temperature to heat flux changes without thermal inertia.

Parameterization of thermal fluxes generated by vehicles will be detailed. The following text and additional equations will be inserted in section 3.3, after the sentence " Khalifa et al (2014) have identified an impact factor for each traffic physical process to evaluate its contribution, as indicated in Figure 4b and Table 2.", and before the sentence "The parameters chosen for the description of the road and the impact zone of their associated physical processes is partial."

In the following study, we attempted to summarize the different approaches found in the literature and which have been analyzed in order to identify and to evaluate the different thermal traffic processes. Once the physical phenomena are identified, a choice was made on the equations used for their description, and their adaptation for their integration into the TEB model.

As so, and according to Fujimoto et al. (2006), the tire frictional heat flux S_t (W m^{-2}) due to tire friction can be evaluated with Newton's law of cooling as follows:

$$S_t = \alpha_{tp}\left(T_t - RST\right)$$

This equation is valid for an extended temperature range (Fujimoto, 2010). α_{tp} is the heat transfer coefficient between the tire and the road surface ($Wm^{-2}K^{-1}$), T_t is the tire temperature (K) and RST the road surface temperature (K) as mentioned above. In 2006, Fujimoto et al. (2006) have shown that the tire temperature depends on the ambient air temperature and the vehicle velocity. For a velocity lower than 70 km h^{-1}, the tire temperature is expressed by the following equation:

$$T_t = 0.9\left(T_{air} - 273.16\right) + 0.33V_{veh} + 273.16$$

T_{air} is the ambient air temperature (K) and Vveh is the vehicle velocity (km h^{-1}). The heat transfer coefficient α_{tp} between tire and road surface (W $m^{-2}K^{-1}$) is determined by Browne et al. (1980) and is defined by the following relationship:

$$\alpha_{\mathrm{tp}} = 5.9 + 3.7V_{veh}$$

Vehicle-induced turbulence can be also an important factor to modify the energy exchange between the air and the road surface in urban area, especially under conditions of low wind speeds which are typical for urban canyon. The turbulence generated by the passing vehicles promotes a forced convection between the road surface and the surrounding atmosphere. This physical process has been studied by several authors (Prusa, 2002; Sato, 2004; Fujimoto, 2012). In 2012, Fujimoto et al (Fujimoto, 2012) have defined an approach to assess the vehicle sensible heat flux S_{va} (Wm^{-2}) due to vehicle-induced turbulence. Their approach consisted in defining a heat transfer coefficient αs ($Wm^{-2}K^{-1}$) between the road surface and the surrounding atmosphere, depending to the vehicles velocity.

$$S_{va} = \alpha_s\left(T_{air} - RST\right)$$

α_s is estimated from the natural wind velocity V_w (ms^{-1}) using the following equation:

$$\alpha_s = 10.4V_w^{0.7} + 2.2$$

The radiative heat flux R_v (Wm^{-2}) emitted downward from the bottom of a vehicle has been studied by several authors (Ishikawa, 1999; Prusa, 2002, Takahashi, 2005;

Fujimoto, 2007). These studies reported that radiant heat from the bottom of a vehicle significantly affects the heat balance on a road surface, and may be evaluated by the Stefan-Boltzmann law:

$$R_v = \varepsilon_{veh}\sigma T_v^4$$

ε_{veh} is the vehicle emissivity, σ the Stephan-Boltzmann constant, and T_v is the vehicle temperature. In order to ease calculation, the heterogeneity of materials constituting the vehicles bottom surface was neglected and an average value was therefore chosen (ε_{veh} = 0.95). In this study, the vehicle will be represented by two temperatures. One is representative of the lower part, T_{veh_inf} (K), and another one of the upper part, T_{veh_sup} (K). T_{veh_inf} can be evaluated with the frame of the study of Fujimoto et al. (Fujimoto, 2006).

$$T_{veh\_\inf} = [0.2(T_{air} + 44) + 0.2(T_{air} + 25.9) + 0.6(T_{air} + 20.3)]$$

It is assumed that the upper part of the circulating vehicle body is at a thermal equilibrium with air. Then, T_{veh_sup} is assumed equal to the ambient air temperature (K).

$$T_{veh\_sup} = T_{air}$$

The infrared radiative flux emitted by the lower ($F_{IR\_veh\_inf}$) and upper ($F_{IR\_veh\_sup}$) parts of the vehicle are thus evaluated in the following way:

$$F_{IR\_veh\_\inf} = \varepsilon_{veh}\sigma\left[0.2(T_{air} + 44)^4 + 0.2(T_{air} + 25.9)^4 + 0.6(T_{air} + 20.3)^4\right]$$

$$F_{IR\_veh\_\sup} = \varepsilon_{veh}\sigma T_{air}^4$$

Fuel consumed by the vehicle is transformed into different type of energy necessary to operate the vehicle. The major part is transformed into kinetic energy for vehicle circulating and electric energy to the battery and all electric components of the vehicle. The part left is transformed into heat flux will be generated by the engine and the exhaust system. Based on physical approaches and thermodynamic laws, Prusa et al. (Prusa, 2002) assessed heat flow generated by the engine S_m (Wm-^{2}) and exhaust system E_{ex} (Wm-^{2}), explained by the following equations:

$$E_{ex} = m_{ex}C_{ex}(T_{ex} - T_{air})$$

$$S_m = \alpha_{comb}m_{H_2O}m_{ex}\lambda_{fg}$$

The parameters of these equations depend on the traffic conditions. E_{ex} (Wm^{-2}) and S_m (Wm^{-2}) respectively are the exhaust and the engine sensible heats, T_{ex} the exhaust system

exit temperature (K) and the selected value is 350 K, m_{ex} is the combustion products mass flow rate considered as constant and equal to 0.0323 kgs^{-1}, C_{ex} is the specific heat of the combustion products (1.16 $kJkg^{-1}K^{-1}$). m_{H2O} is the water vapor mass fraction in the exhaust system considered constant and which chosen value is 0.089, α_{comb} is the fraction of water vapor that condenses, and λ_{fg} is the latent heat of condensation of water vapor (equal to 2.50 MJ kg^{-1}). Maximum effects are achieved with α_{comb}=1. All values indicated above were given in the article of Prusa et al. (Prusa, 2002).

Traffic also impacts the energy balance by an intermittent interruption of the radiative flux towards the surface of the road. This phenomenon is called vehicle shield and depends on the traffic parameters. Vehicle shield firstly prevents the incident solar radiation to reach the surface of the road. It consequently leads to a loss of energy on the surface energy balance, and secondly it blocks the radiation emitted by the road surface. This physical traffic process can be evaluated by a shield effect coefficient C_{shield} (dimensionless number). The vehicle shield effect on the road has been investigated by Khalifa et *al.* (2014) and can be defined by the following expression:

$$C_{shield} = \frac{T_{veh}}{t_{time}} D_{traffic}(t)$$

t_{time} is the modeling time step (s), $D_{traffic}$ represent the traffic density (dimensionless number) and T_{veh} is the shielding time caused by the passage of one vehicle (s), equal to the ratio between the length and the vehicle velocity.

Traffic influences the heat transfer coefficient between the road surface and the surrounding atmosphere by increasing the air aerodynamic resistance. This process has been studied by several authors and different approaches were used to its evaluation (Chapman 2001; Prusa, 2002; Jacobs 2006, Denby and Sandvor 2012). We will use here the one of Denby and Sandvor (2012) illustrated by the following equation:

$$AC^{*}_{road} = AC_{road} + C_{shield} AC_{traffic}$$

$$AC^{*}_{road-watt} = AC_{road-watt} + C_{shield} AC_{traffic}$$

AC^{*}_{road} and $AC^{*}_{road\_watt}$ respectively are the aerodynamic conductance of a dry and a wet circulated road. They are computed with the ones of a non circulated road, AC_{road} and $AC_{road\text{-}watt}$, and the aerodynamic conductance specific to traffic $AC_{traffic}=10^{-3}$ experimentally determined by Denby and Sundvor (Denby, 2012), and validated with the model NORTRIP.

The incidence of traffic on solar radiation will be performed as follows:

$$\boldsymbol{R^{*}_{ns} = R^{*}_{sd} + R^{*}_{su}}$$

$$\boldsymbol{R^{*}_{sd} = (1 - C_{sheild})\, R_{sd} + C_{sheild} a_{road\_veh} R_{su}}$$

$$R_{su}^{*} = (1 - C_{sheild})\, R_{su} + C_{sheild} a_{veh\_inf} R_{su}$$

a_{veh_inf} is the albedo of the lower part of vehicles, and is consedered as esqual to the road albedo. a_{road} is the road albedo, a_{veh} the one of vehicles, and a_{road_veh} an albedo including the one of the road and the one of vehicles for a circulated zone, calculated with the following equation.

$$a_{road\_veh} = (1 - C_{sheild}) a_{road} + C_{masque} a_{veh}$$

The application to another urban site will be possible if traffic data is available, or considering a generic traffic density profile representative of the site. In the case of an entire city, considering the canyon hypothesis, an average traffic density could be selected, and the chosen parameterization applied, though partition of local climate zone necessary.

Question

The equation only accounts for the latent heat of evaporation, not for the latent heat of fusion of ice to water. Surely this is a factor when considering iced road conditions? The reasoning for this choice needs to be explained as this equation is fundamental to the models proposed.

Answer: **L covers phase transition of water (liquid-vapor, and liquid-solid). The text will be explicit about this term.**

Question

Both modeling approaches are validated against experimental data in the field. The authors were able to demonstrate that traffic does have a significant shielding effect but neither of the two models can accurately reproduce it. In the data presented, marked differences occur in the early hours of the day, a time most critical to the motivation of their research to improve mitigation of road hazards by iced roads. The experiments themselves were not conducted under relevant weather and road conditions. According to the data, all measurements took place at temperatures above freezing.

When the model results are compared to experimental results, both models underestimate road surface temperatures. In practice, this would lead to false alerts with respect to ice on roads.

Answer: **Some text will be added to take into account the remarks of Referee #1, indicating RST is still underestimated, and might lead to false alerts with respect to ice occurrence, which could be critical in the early commuting hours of the day, and that some work is still needed to improve the mitigation of road hazards by ice on roads.**

Analysis of the RST_TEB_A2 shows that RST forecast is improved by 2°C to 3 °C with respect to RST_TEB_IC. This improvement primarily reflects the impacts of traffic on the RST and also that the configuration with which the traffic was introduced into the TEB model seems more appropriate for the case of winter season. Although experiments were conducted above freezing, RST is still underestimated, and might lead to false alerts with respect to ice occurrence. This could be critical in the early commuting hours of the day, and some work is still needed to improve the mitigation of road hazards by iced roads.

Question

In their conclusions, the authors should be clearer about the performance of their models. They do demonstrate the relevance of including traffic in a TEB but the models do not perform well in critical situations.

Answer: Some text will be added to the conclusion to clear the performance of the model as follows "(…) The presence or the absence of buildings also influenced the modeling of RST. A validation was also successfully obtained with the air temperature. These results were obtained in the winter situations not considered as critical. RST is still slightly underestimated in this second approach, and could therefore trigger false alerts of ice occurrence on pavement. To obtain a better forecast of the RST with the TEB model it is necessary to properly define the configuration of the urban environment. It should be noted that the integration of traffic in the TEB model according to this second approach significantly improved the RST forecast in the winter season. However, there is still a difference of 0.5°C to 1 °C between the measurements and the TEB simulated RST. (…)"

"(…) Within the same context of this study, another work will be undertaken to analyze the sensitivity of the TEB model to these different physical processes of traffic, and on the basis of some additional field data currently available. The objective is to assess the contribution of each traffic process in improving the RST modeling according to the traffic parameters and the variation of the atmospheric stability. These thermal impacts of traffic should also be coupled with the road surface water balance of the TEB model to identify and further to quantify the influence of the presence of water in its various forms (liquid, solid (ice and snow)) on the RST modeling. (…)"