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Individual contributions of anthropogenic physical processes associated to urban traffic in improving the road surface temperature forecast using TEB model

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ABSTRACT

For years, some work has been undertaken on the traffic heat issue input in the Town Energy Balance (TEB). It has been the subject of many studies related to the summer period and urban heat islands topic. However, during winter conditions, the traffic energy input was marginally integrated into the modeling of the road surface parameters. This deficiency, may explain the differences between forecast and observations for road surface status (RSS) during winter season. Over the past decade, identification and quantification of traffic effects were undertaken. However, they have been studied independently, and non-numerical model integrates the energy contribution of traffic into the RSS. Based on the (TEB) model (v7.2), recent research provided a detailed integration of the traffic thermal contribution in the TEB. This study showed traffic increases the road surface temperature (***R S T***) by 2–3 °C, and its heat inputs improve significantly the ***R S T*** modeling. This study consists in evaluating the thermal contribution of each traffic process to improve the ***R S T*** modeling based on field experiments. Secondly, the most significant physical processes of traffic responsible for ***R S T*** changes have been identified and their contributions discussed. Finally, we analyzed the effects of weather conditions onto the thermal contribution of traffic processes.

1. Introduction

The costs of winter road maintenance are elevated (Petty and Mahoney, 2008), but the losses due to road closures are much higher, so accurate ice occurrence forecasts are needed (Chapman et al., 2001; Shao and Jones, 2012). Furthermore, in the specific case of urban areas, one have to consider associated costs to the large number of streets to be treated against ice, the sidewalks and bicycles dedicated zones, bus lanes, and the economical impact for all urban commercial zones customers are unable to reach. Currently, these forecasts of road status primarily come from numerical road prediction models. They take weather forecasts and road condition data as inputs using a surface energy-balance equation. It describes the fluxes of energy between the atmosphere and the road (Saas, 1992). Numerical road weather prediction models were first developed during the late 1970s and used a one-dimensional

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heat conduction model or a neural network approach. Since then, many have been developed around the world (Bouilloud and Martin, 2006; Bradley et al., 2002; Crevier and Delage, 2001; Jacobs and Raatz, 1996; Marchetti et al., 2014; Saas, 1992; Shao, 1990; Shao and Lister, 1996; Thornes, 1984). All have the same aim of forecasting Road Surface Temperature (***R S T***) and road conditions from a basic forecast of meteorological parameters (Thornes, 1991), of environment geography and topography (such as the difference between urban and rural areas) and of road ones. Some improvements have been continuously implemented to better meet the needs of road users and managers in term of safety and of mobility, and to obtain the best forecast of the road surface state (RSS), directly related to both ***R S T*** and the amount of water located on its surface. Thus, a spatial component has now been included to incorporate the influence of both meteorological and geographical parameters. This is even more specific for a urban configuration, with a the occurrence of urban heat island, where a significant radiative contrast does exist with respect to a rural zone. A urban area is tridimensional, with a specific density and orientation of shapes (Giguère, 2009; Nunez and Oke, 1977). This contributes to a local climate change through a heating process (Bärring et al., 1985; Eliasson, 1996, 2000; Gustavsson et al., 2001). The impact on climate varies as a function of many parameters such as the land cover, the sky view factor, thermal characteristics of constituting materials, and urban roughness. A urban does not have as many natural means (water, vegetation) to cool the atmosphere though evaporation and evapotranspiration (Oke, 1988). This urban heat is the sum of all heat production from vehicles, industries, buildings, urban equipments and human metabolism (Giguère, 2009). These sources are more numerous in a urban area because of the concentration of inhabitations and activities. This anthropogenic heat depends on seasons, of mobility modes, of population density, of the industry level of the city and of its topography (Colombert, 2008). Indeed, human activity can significantly modify ambient temperature as it is a source of energy as important as global radiative inputs (Taha, 1997). However, traffic, which is representative part of a urban configuration, has so far been a challenging parameter to be integrated in ***R S T*** forecast.

1.1. *Thermal effects associated to traffic on* ***R S T***

Different physical processes have been identified by many authors, for example Prusa et al. (2002) and Hendel et al. (2014), with which traffic impacts ***R S T***. This generated heat will be added to the road surface via sensible heat and moisture fluxes from the engine and the exhaust system as well as frictional heat dissipation from the tires and braking phases. The passing vehicles on the road do also block long wave radiation exchange and do prevent shortwave radiation from reaching the road surface during the day. Traffic flow will also generate additional mixing of air above the road surface promoting increased turbulent flow. Farmer and Tonkinson (1989) have shown that the energy input of these different traffic effects process causes an increase in ***R S T***, especially in traffic jam conditions. Other studies have also shown that ***R S T*** in the areas affected by passing vehicles is greater than in other ones not circulated. This increase can reach 2 °C to 3 °C depending on the traffic parameters (Chapman and Thornes, 2005; Gustavsson and Bogren, 1991; Hendel and Royon, 2015; Parmenter and Thornes, 1986; Shao, 1990). One of the main difficulty is to at least identify the sole contribution of traffic in the energy balance, as indicated by Chapman and Thornes (2005). The results of the study conducted by Gustavsson et al. (2001) showed that the traffic impacts are most important during peak hours. Chapman and Thornes (2005) also managed to point out the effect of atmosphere stability focusing on a multiple lane road considering all other parameters were constant, though topographic and geographic subtle differences could still induce differences between observed and calculated RST values. Furthermore, another research carried out on an urban road by Fujimoto et al. (2010) and Schrijvers et al. (2016) completed the one of Chapman and Thornes (2005) study, with a traffic signal, reported that the ***R S T*** under vehicles stopped at traffic signals was 3 °C to 4 °C higher than ***R S T*** nearby. These observations indicate that the thermal effects of vehicles are not negligible, especially in an urban configuration when the traffic density is high. They must then be taken into account in the modeling of the town and the road surface energy balances.

1.2. *Integration of traffic in the* ***R S T*** *modeling*

Many studies were dedicated to the forecast of ***R S T*** (Bouilloud and Martin, 2006; Chapman and Thornes, 2005; Chapman et al., 2001; Crevier and Delage, 2001; Marchetti et al., 2014; Raatz and Niebrügge, 2002; Sass, 1997; Shao and Lister, 1995). However, the challenge of traffic integration into ***R S T*** modeling (Prusa et al., 2002) arises from the diversity of the physical processes associated to the traffic and indicated before. Because of the variations in the traffic density, models from the literature have either used a simple parameterization to describe it effects, or have neglected them in the ***R S T*** modeling (Paumier and Arnal, 1998; Rayer, 1987). As an example, Shao and Lister (1996) modified the turbulent exchange coefficients and the net infrared radiation between the road surface and the surrounding atmosphere, according to the traffic density. Chapman et al. (2001) took into account three physical processes of traffic to improve the IceMister model (Thornes, 1984). Changes consisted in arbitrarily increasing the temperature with a correction factor on the ***R S T***, in changing the radiative heat flux received by the road surface with a second correction on the radiative heat flux emitted by the bottom of the vehicle, and in the amplification of the turbulent exchange with 2 m s^{-1} increase of the wind speed. Jacobs and Raatz (1996) integrated the traffic in the ***R S T*** modeling by increasing turbulent exchanges. The minimum wind speed was of 5.14 m s^{-1} during the day and of 2.57 m s^{-1} during the night and holiday periods. Crevier and Delage (2001) have observed a constant heat flux of 15 W m^{-2}, with a correction based on the bias on the mean ***R S T*** of the previous nights. Sass (1997) also based his study on the same approach to take into account the topography and the traffic impact to improve ***R S T*** forecast. Chapman and Thornes (2005) studied the effect of traffic in a multiple lanes road considering each lane has a different volume of vehicles, the other parameters such as topography and climatology processes, construction materials and rules of the road being constant. The analysis indicated the importance of atmosphere stability but did not accurately separated the different physical phenomena associated to traffic. This brief literature review shows that the traffic was marginally integrated in the modeling of the ***R S T***. However, as