THE SURFEX/TEB NEW ROAD MODEL WITH TRAFFIC EFFECTS:- VALIDATION AND OPERATIONAL PLANS

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Summary

The urban climate model SURFEX/TEB V9.0 has been adapted for road winter weather maintenance purposes. It aims to bridge the gap between road weather models and urban climate models for better modeling of artificial surface conditions and complex road environments. New components are added in TEB: a detailed snow model, an ice reservoir, and a traffic parameterization impact. TEB is being tested with the intent to replace Météo-France's current road weather forecast system. The preliminary results have shown significant improvements.

Introduction

At Météo-France, a dedicated road weather forecasting system is operationally used since the mid 2000s. This system is based on a heat-balance model named ISBA-ROUTE/Crocus forced by atmospheric variables from numerical weather forecasts and human expertise [14]. Since 2022, a new project attempt to completely reshape the system in use. The surface model ISBA-ROUTE/Crocus model [1] aims to be replaced by a modified version of the urban climate model TEB within the SURFEX V9.0 modeling platform [2] and it will be forced by AROME atmospheric forecasts [10]. TEB has been largely successful for representing urban heat island effects [4]. It benefits from a large user community, and has been tested in inter-comparison studies [3]. Thus, TEB is chosen for its performance and its ability to compute surface state variables while accounting for complex environments such as facing walls or roadside trees [5].

Thus, the aim of this study is to extend SURFEX/TEB V9.0 with new processes selected to address road condition issues (Multi-layer snow-model, ice content, traffic parameterizations). The new processes are tested in off-line at a number of sites to evaluate their contribution to surface modeling in winter and cold climates.

Modeling

The heat balance TEB model represents a simplified urban environment with a local canyon geometry with two facing walls separated by a road. Distinct heat equations for each surface (roof, walls, and road) are solved while accounting for radiative trapping, shadowing, and reflections. However, the current model version in the SURFEX V9.0 modeling platform lacks necessary processes specific for predicting road weather conditions.

A multi-layer snow model named Explicit Snow (ES) [6] has been added to the existing one layer (1-L) [7] snow model to improve modeling. ES simulates the snow pack evolution using several prognostic variables: snow density, heat content, thickness of each snow layer, and albedo. Implicit heat coupling of ES is performed with the road surface layer, and water exchange is implemented through the snow melt process as shown Fig. 1.

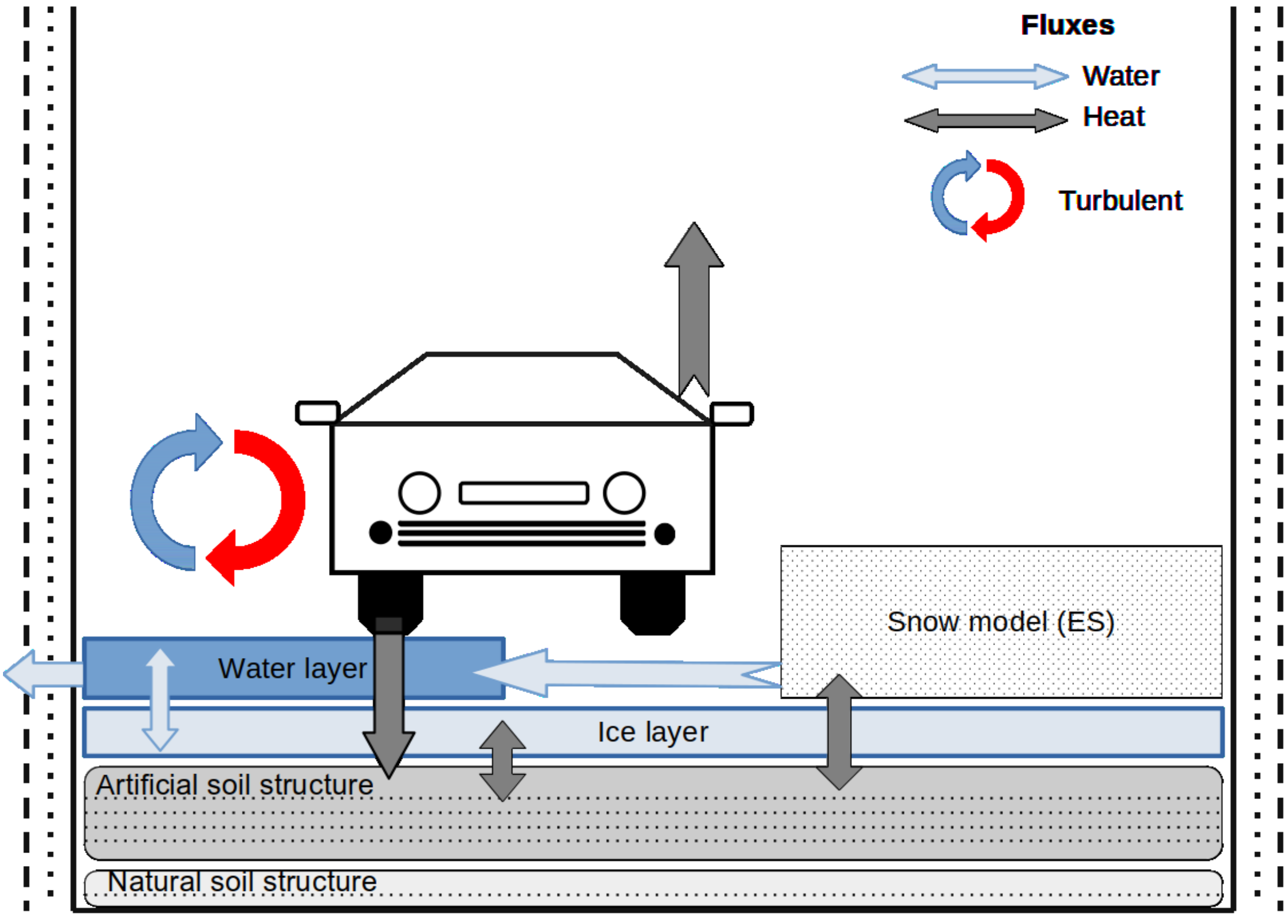

Fig. 1. TEB modified model with new components added as the ice layer, traffic parametrization and multi-layer snow model ES within the urban TEB canyon

For the needs of road weather, melting and freezing water processes following Boone et al. (2000) [11] formulation, has been added between the new solid water content and the liquid

water content (Fig 1). It impacts directly the surface heat balance and the latent flux with the atmosphere.
Roads and runways are man-made artificial environments that do not evolve freely with atmospheric conditions. They are monitored, and their state can be modified for safety reasons. In addition, their intensive use affects their surface conditions. Thus, traffic and snow removal parameterizations have been added to the model. Traffic is modeled as a tire friction process with the road, a source of sensible and latent heat from the car, and a modification of the turbulent exchange coefficient between the road and the atmosphere as inspired by Fujimoto et al. (2010) [8] and Khalifa et al. (2016) [13]. Explicit radiative effects in the urban canyon and a simple interaction modeling with snow cover fraction on the road surface is also taken into account.
Finally, snow removal operations are modeled in two ways: either as a one-off snow removal at a specific date, or as a removal of snow after a defined period of time from the first snow coverage on the surface.

Methods

The new processes included in the TEB model have been tested at several key locations. The SURFEX/TEB model has been compared with the modified SURFEX/TEB model (TEB-ES and TEB-ES-CAR named TEB-CAR) and the current Météo-France road weather model ISBA-ROUTE/CROCUS. Evaluation of snow and ice components have been conducted in France using the experimental results of the 1998/1999 GELCRO experiment [1] at the Col de Porte location in the Alps as well as using observations from the Finnish Salo Hajala road weather station [9].
A specific evaluation of the traffic parameterization has been performed at the Nupuri and Palojarvi Finnish road weather stations during winter 2017-2018 [9]. There, a large amount of deployed sensors provided atmospheric, road conditions and traffic observations in both directions on this busy Helsinki-Turku highway. The commuting traffic pattern in each direction allows separating the influence of weather from traffic in the observations, by assuming that the atmospheric conditions are the same on each lane. The road surface temperature differences measured between the two lanes are compared with two TEB-CAR simulations with different number of vehicles to validate the traffic parameterization.
In both evaluations, the models are run as a continuous simulation with similar initializations. The same physiographic and road parameters are considered for the different instances of TEB. Simulations are forced and validated by in-situ observations for all experiments except for Finnish road weather stations, ERA5 radiation data is used.

Results

The modified TEB model (TEB-ES) exhibits good performance in terms of road surface temperatures modeling (Tab. 1.). It outperforms both TEB and ISBA-ROUTE/CROCUS with better RMSE, MAE and R^2 values. Subject to frequent snowfalls, the Col de Porte experimental road is often snow-covered. Since the detailed snow model ES simulates snow height, density and temperature profiles more accurately, road surface temperature is better simulated.

	TEB	TEB-ES	ISBA-ROUTE/CROCUS
RMSE	2.82	2.05	2.53
MAE	2.10	1.33	1.40
R^2	0.82	0.89	0.83

Table 1. Scores comparison of the road surface temperature between TEB the modified TEB model (TEB-ES) at Col de Porte location during winter 1998-1999.

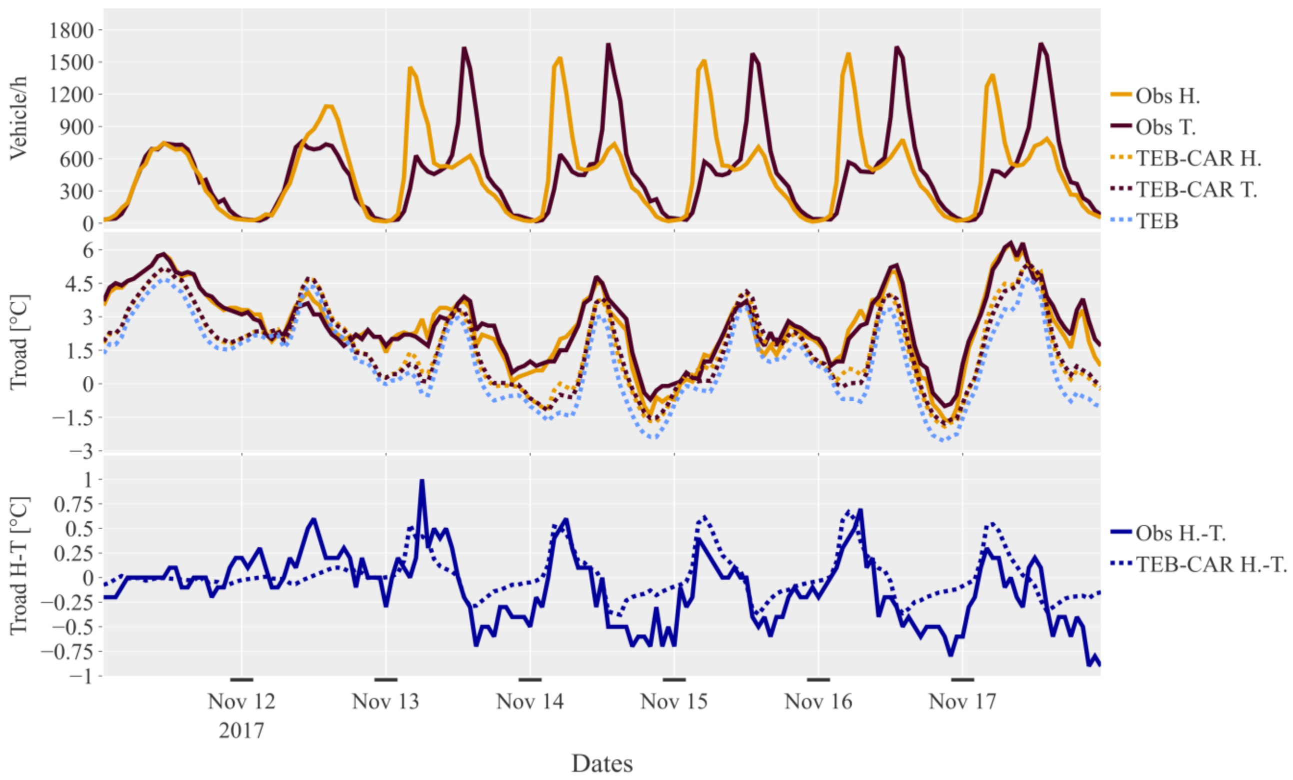

Fig. 2. Comparison of the road surface temperatures measurement with TEB and TEB-CAR simulations on lanes towards Turku (T.) and Helsinki (H.) at Nupuri location. On the bottom panel, H.-T. means the difference between the lanes towards Turku and Helsinki.

Figure 2 shows a consistent physical behavior of the traffic parametrisation, and in agreement with the observations. The observed surface temperature differences on the bottom panel are consistent with the differences between the two TEB-CAR simulations. In the morning, at peak traffic-flow in Helsinki direction, the increased relative road surface temperatures observed is well represented by TEB-CAR. In the afternoon as well, the peak traffic-flow in Turku direction lead to increased relative road surface temperatures in Turku direction. TEB-CAR represents correctly this situation but with a lower magnitude. Globally, in the middle panel (Fig. 2), upgraded winter processes lead to better performance at this location also shown (Tab. 2).

	TEB T.	TEB-CAR T.	TEB H.	TEB-CAR H.
RMSE	3.56	1.83	3.49	1.82
MAE	1.55	1.07	1.53	1.05
BIAS	-1.14	-0.66	-1.0	-0.51

Table 2. Comparison of the road surface temperature simulations of TEB and TEB-CAR at Nupuri location with the measurements on the lanes towards Turku (T.) and Helsinki (H.)

Conclusion and perspectives

The new processes included in TEB and necessary for road winter modeling have significantly improved the results of the published SURFEX/TEB V9.0 model and outperformed ISBA-ROUTE/CROCUS operational model predictions.

As the new physical model TEB has shown promising results in several controlled offline experiments, the next step is to implement road surface condition forecasts. Road surface conditions are subject to rapid changes and reach equilibrium with the atmosphere within a few hours. Accurate representation of the atmospheric conditions is a key component for precise road weather simulations. AROME state-of-the-art operational high resolutions forecasts at a 1.3km horizontal resolution on a domain centered over France will be used to force the model. AROME represents synoptic and local weather effects and will be traduced in terms of high-resolution patterns on road conditions. Since probabilistic road condition forecasts would strengthen decision making for road and airport operators during difficult snow or icing conditions [12], an ensemble forecast system will be developed using TEB forced by AROME ensemble forecasts.

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