Specific Responses

3rd paragraph: The Col de Porte experimental site received a measurement campaign from 1997 to 1999 with 6 experimental road segments constructed. It is an idealized road. on which sensors were specifically installed for the analysis of the behavior of the snowpack and road temperature on an artificial surface. There was no human activity on the site, no vehicles, no salting, except for manual snow removal by an operator during the two winters campaign We acnowledge that this experiment represents an idealized case. It is only the first step in representing real road state conditions. The model will therefore need to be improved regarding the representation of human activities.

4th paragraph: We thank the reviewer for this comment. In the edited paper, we will reduce the analysis of the Finnish site experiment by focusing on the improvement of road temperature simulation and the difficulties of the model in predicting road state. Indeed, the passage of vehicles and the systematic use of salt to melt slippery conditions strongly modifies the road contaminant. This experiment provides an important result: modeling the effects of human activities on the road is essential for predicting its state. We will add this result to the result section and the abstract.

5th paragraph: We acnowledge that the improvements shown are an significant step, yet further improvements are needed to simulate road states on a road with traffic and winter maintenance operations. We believe that informing the community about the advantages of using an urban model for simulating road conditions is important and will encourage the community to improve this tool.

Response to Specific Comments

Line 42: Thank you for this comment, we will modify this sentence and make it clearer. Indeed, the heat balance equation only modifies the temperatures and not the other variables.

Line 70: This argument is based on experiments conducted in the urban climate community. Physical models that take little or no account of urban morphology tend to have lower performance in simulating physical variables in cities than those that take it into account (2-tile model or canyon model) [Lipson et al. 2024]. By analogy, the behavior will be the same for road weather models that do not take into account the effect of building geometry on surface conditions.

Line 82: The direction of the canyon can indeed be specified since the version of TEB in Surface V9. We will mention this in the text.

Line 107: The parameters associated with equation 2 are presented in table 1. We will add to the text the link between this equation and the table.

Line 124: The albedo does not depend on the other variables. Indeed, as in Douville 95 (Douville et al. 1995a), it follows an exponential law that depends on the initial condition and a time constant, whose values are the same as in Lemonsu et al. 2010.

Line 137: The introduction of conduction between snow and ice, and ice and road surface would strongly modify the way mass reservoirs are taken into account in TEB and more broadly in SURFEX, the mass reservoirs being simulated in a similar way in ISBA.To be in agreement with the TEB modeling choices, the ice layer Wi energy, as the water reservoir Ws energy is not explicitly modeled. Their energy are considered indistinguishable from the road surface. Thus, the processes involved on the ice evolution, freezing , melting and sublimation, are parametrized by simple energy consumption methods that impact directly the road surface budget (Boone et al. 2000). This approximation remains reasonable and will not much infleunce the results.

Line 144: The TEB model does not explicitly simulate the amount of energy contained in the water layer. In the same spirit, we do not model the amount of energy in the ice layer. Their energy are considered indistinguishable from the road surface. Therefore, there is no conduction flux between the soil and the water, the ice and the water, the ice and the snow. We perform a simple parameterization that allows us to simulate the mass exchange between the ice layer and the water layer. The processes involved on th ice evolution, freezing , melting and sublimation, are parametrized by simple energy consumption methods that impact directly the road surface budget. The freezing rate, the melting rate and the solid-gas latent heat flux equations for the ice evolution on the the natural surface layer from Boone et al. (2000) are adapted for impermeable artificial surfaces. The insulating effects of the vegetation is removed (Ks=1) (Boone et al. (2000)) as well as the phase change coefficients for subgrid-scales effects (epsilon=1) (Boone et al. (2000)).

After further checking, thanks to the reviewer's comments, we have identified errors in both the text and the code on the modification of the ice that leads to minor modifications on the results. We will modify the manuscript in accordance with the following modifications:

Fixed equation:

$$F = \frac{1}{\tau}\min(W_s, \frac{\max(O, T_f - T_{road})}{C_l L_f})$$

$$M = \frac{1}{\tau}\min(W_i, \frac{\max(O, T_{road} - T_f)}{C_l L_f})$$

$$LE^* = \gamma_{ice}\rho_a \frac{1}{R_a L_s}[Q_{sati}(T) - Q_a]$$

The τ parameter is set to 25000s rather than the 3300/0.05 value in the paper to get consistent evolution for this study experiments. More experiment are needed to fix the correct τ, but 25000s is for now considered sufficient.

Line 149: After further analysis thanks to the reviewer's comments, we use the value of 25000 seconds, also used in SURFEX/ISBA when the model is forced by the ARPEGE atmospheric model. This value is the most consistent with observations (co-evolution of the ice and water reservoirs) particularly on the Finnish experiment. The value given in (Boone 2000.) of 3300 seconds turned out to be much too low. We recognize that further verification is necessary regarding this value. We will add a comment on this subject to the discussion.

Line 150: The sublimation of ice is negligible. Indeed, this quantity is very small in all atmospheric conditions, particularly when compared to the melting process.

Line 163: The impact of road traffic on the snowpack has been little studied. However, the compaction of snow by vehicles is likely to have a very important effect on the physical variables of the snowpack. Indeed, according to T. Kobayashi et al. 2006, just a few dozen vehicle passages cause the snow density to be multiplied by 4, which probably explains the very low values observed of water quantity by the sensors in Finland.

For the rest, some processes modeled in the multi-layer snow model remain essential which are not modeled in the previous model. For example, the use of a temperature profile allows us to model the real temperature of the snow and in particular represent the isothermal episodes that a single-layer model cannot handle correctly. The new model also allows us to take into account the effect of rain on the evolution of the liquid water content of the snowpack and a part of the incoming radiation go through the snowpack and is absorbed by the road.

Moreover, the use of TEB is not limited to artificial surfaces with vehicles. It is used for all urban surfaces, sidewalks, parking lots, pedestrian paths, bike paths.

The studies on the effect of road traffic on the snowpack are modest. This subject is under-studied and many questions are unanswered. In our case, in the future, it would be interesting to model correctly the traffic effect in both, the one-layer snow model and the explicit snow model, then to evaluate the relevance of a multi-layer snow model on busy roads. We shown that the use of a multi-layer snowpack improves the results of road temperatures and road state conditions without traffic. Without extended studies on this subject, we can therefore use this fairly robust result to argue that it is important to use a multi-layer snow model. We will add some comments in the discussion to stimulate research and potential studies.

Line 230: The operational version of ISBA-Route/CROCUS in Météo France is the same but the forcings are diffferents compared to the one described in the 2006 study (Bouilloud and Martin 2006). We will remove this word that does not make sense here.
ISBA-Route/CROCUS model does not include human activities.

Line 298: In agreement with the comment, we will reduce the synoptic weather descriptions on this subection and those of the Finnish experiments.

Line 330: The road surface temperature is at 0°C as the sensor are buried in the road. We model the road surface temperature, so in contact with the snow mantle bottom layer.

Line 364 : We agree with this comment and will change the section accordingly.

Line 376 : At 6h UTC in the models, the snow mantle is removed. It is a simple parameterization to take into account the snow ploughing on the Finnish site.

References :

– **Douville H, Royer JF, Mahfouf JF :**A new snow parameterization for the Météo-France climate model, Part I : Validation in stand-alone experiments. Climate Dyn 12:21-35, 1995a

- **Boone, A., Masson, V., Meyers, T., and Noilhan, J**.: The Influence of the Inclusion of Soil Freezing on Simulations by a Soil–Vegetation–Atmosphere Transfer Scheme, J Appl Meteorol Clim, 39, 1544–1569, https://doi.org/10.1175/1520 0450(2000)039<1544:TIOTIO>2.0.CO;2, 2000.

- **Bouilloud, L. and Martin,** E.: A Coupled Model to Simulate Snow Behavior on Roads, J Appl Meteorol Clim, 45, 500 – 516, https://doi.org/10.1175/JAM2350.1, 2006

- **Lipson, M. J., Grimmond, S., Best, M., Abramowitz, G., Coutts, A., Tapper, N., Baik, J.-J., Beyers, M., Blunn, L., Boussetta, S., Bou-Zeid,E., De Kauwe, M. G., de Munck, C., Demuzere, M., Fatichi, S., Fortuniak, K., Han, B.-S., Hendry, M. A., Kikegawa, Y., Kondo, H.,Lee, D.-I., Lee, S.-H., Lemonsu, A., Machado, T., Manoli, G., Martilli, A., Masson, V., McNorton, J., Meili, N., Meyer, D., Nice, K. A.,Oleson, K. W., Park, S.-B., Roth, M., Schoetter, R., Simón-Moral, A., Steeneveld, G.-J., Sun, T., Takane, Y., Thatcher, M., Tsiringakis, A.,Varentsov, M., Wang, C., Wang, Z.-H., and Pitman, A. J**.: Evaluation of 30 urban land surface models in the Urban-PLUMBER project: Phase 1 results, Quarterly Journal of the Royal Meteorological Society, 150, 126–169, https://doi.org/10.1002/qj.4589, 2024

- **T. Kobayashi, T. Sato, K. Kosugi, S. Mochizuki and A. Sato** : Consolidation, Melting and Refreezing Process of Snow on Roads by Vehicles, SIRWEC, 2006