Frost model in ERAPave (SSR model)

Karlis Rieksts
Postdoc

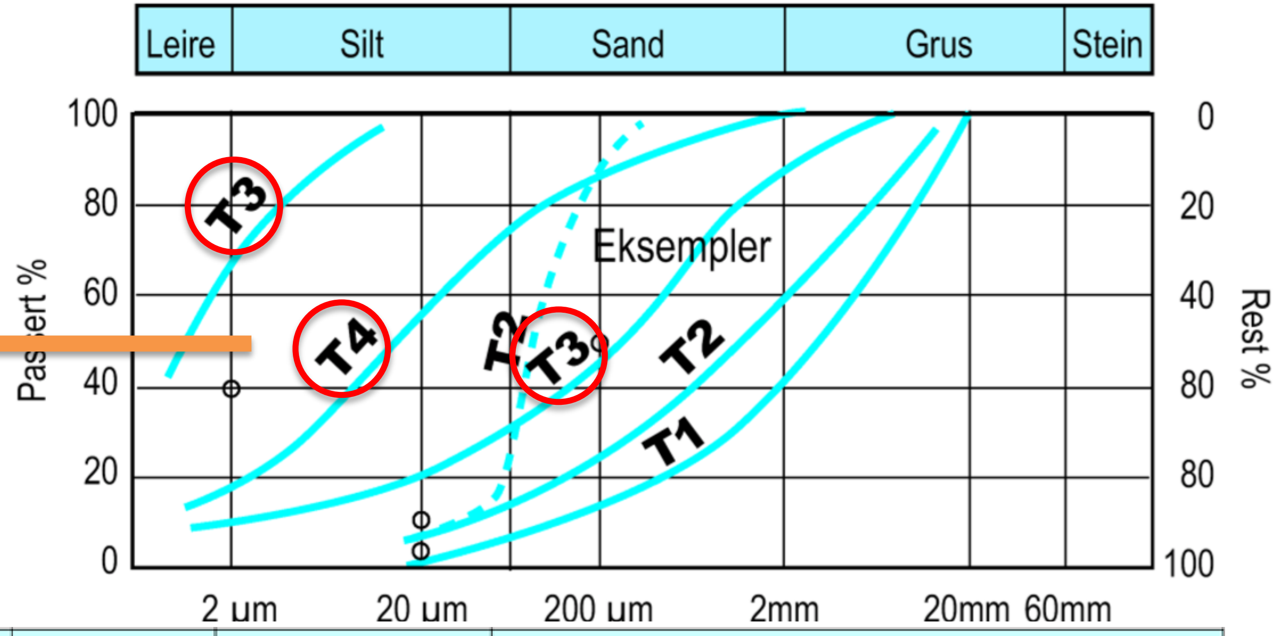
The current model

T3, T4

Frost protection required

Design choices:

- crushed rock
- foam glass / expanded (
- xps

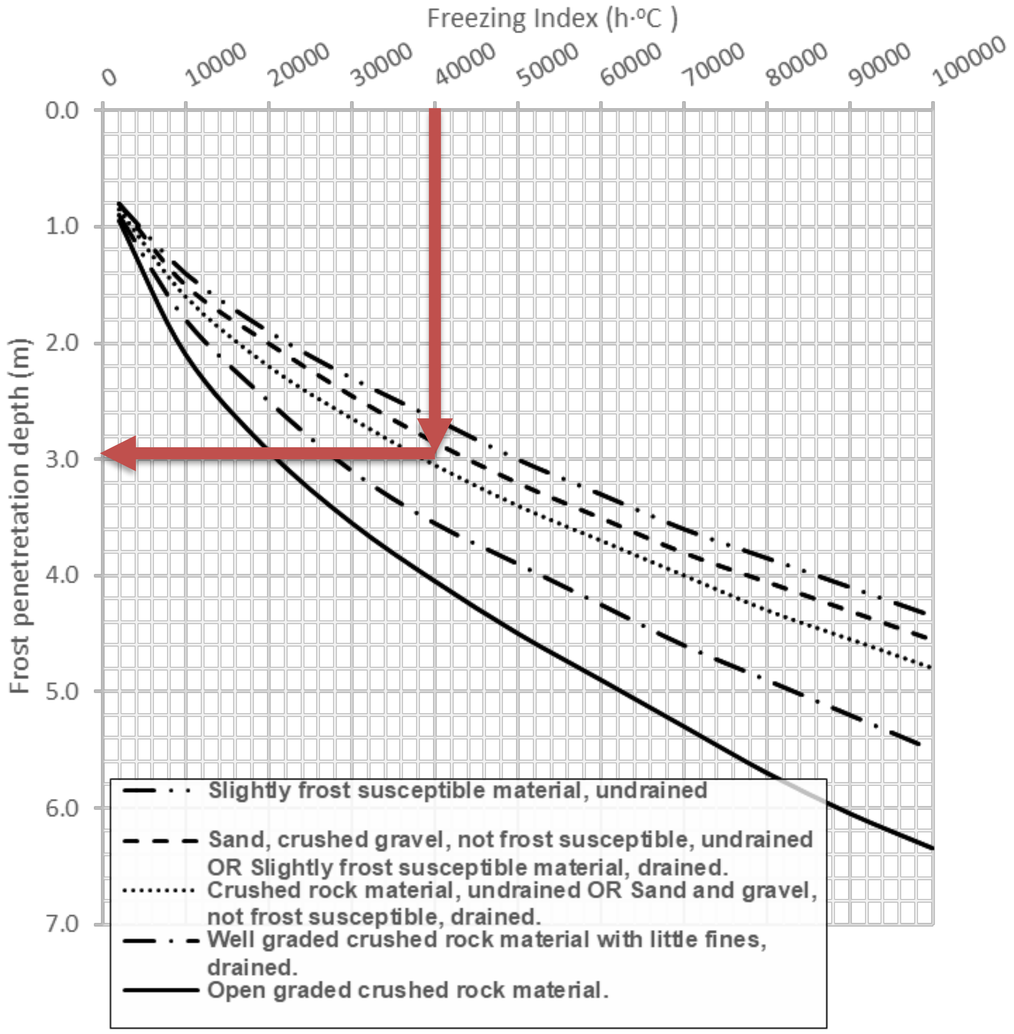


AADT	Number of traffic lanes	Frost susceptibility group	Frost protection	
			Design frost quantity	Max.[1] pavement thickness
> 8000	4 or more	T3, T4	F_{100}	2,4 m
> 8000	< 4	T3, T4	F_{10}	2,4 m
1501 - 8 000		T3, T4	F_{10}	1,8 m
≤ 1500		T3, T4	Actions to prevent uneven frost heave should be considered [2]	1,8 m

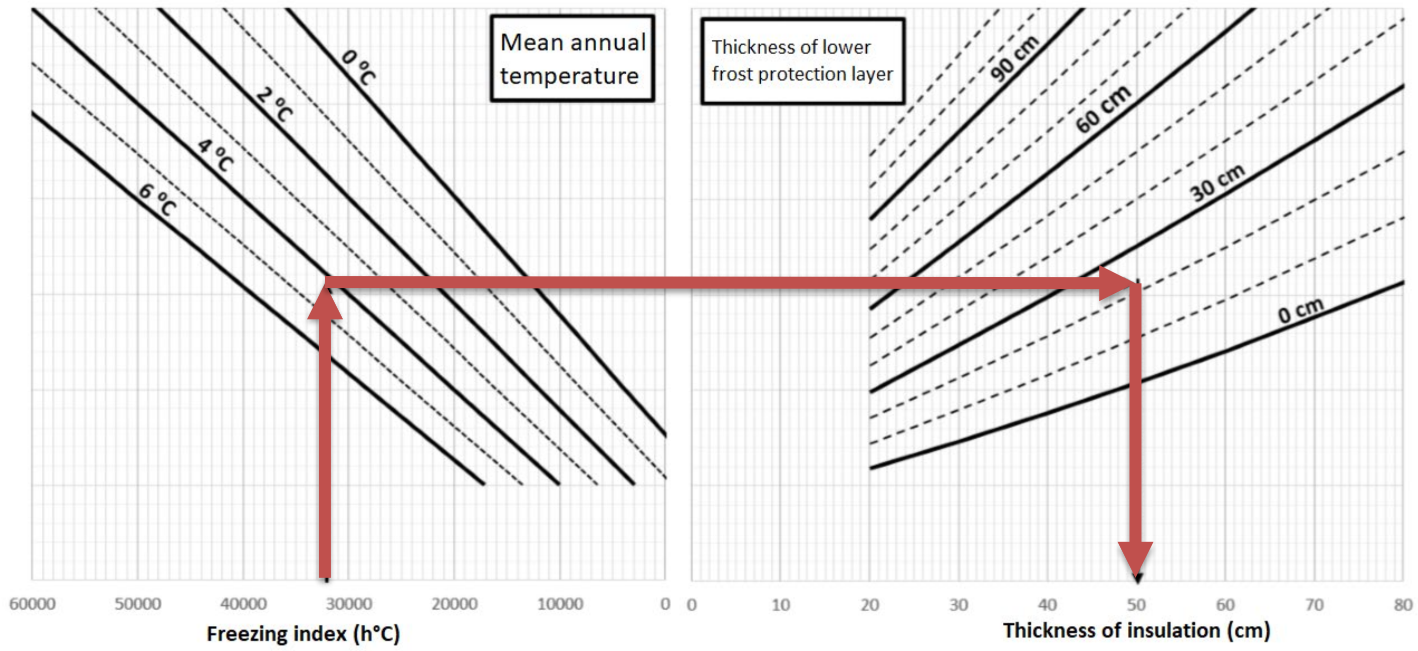
1) The notion «max.» means that the given thickness is normally considered adequate to prevent unacceptable frost heave even if the frost depth is bigger
2) Measures to prevent uneven frost heave should be based on frost quantity F10

The current model

Crushed rock or sand



Foam glass or expanded clay



SSR model: Seppo Saarelainen (1992) (Seppo Saarelainen Routanousu)

heat balance equation

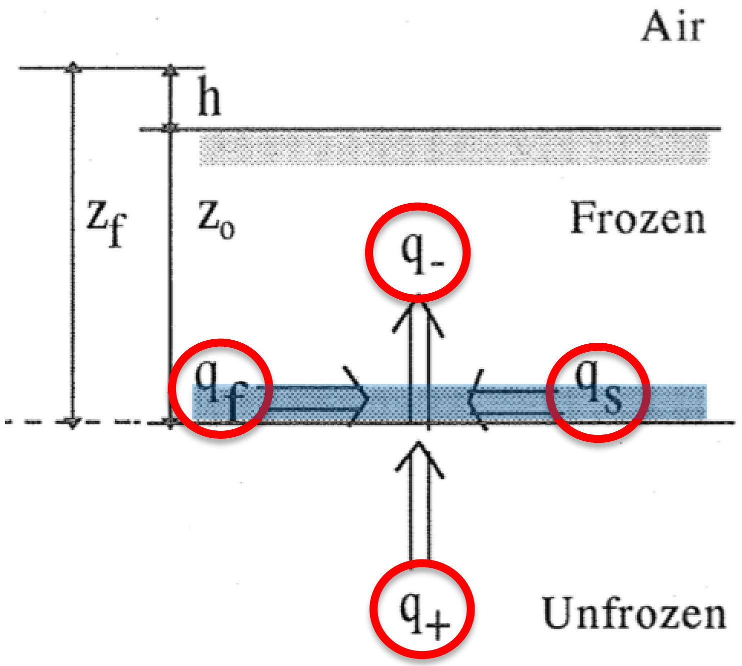
$$q_- = q_f + q_+ + q_s$$

$$k_f \nabla T_- = L \frac{\Delta z_0}{\Delta t} + k_t \nabla T_+ + L_w SP\, \nabla T_-$$

Stefan (1889)

Skaven-Haug (1971)

Konrad & Morgenstern (1981)



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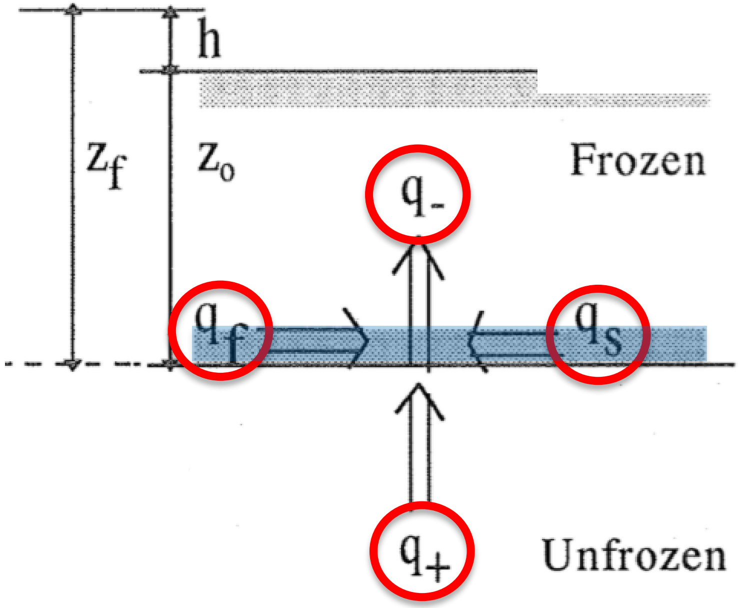
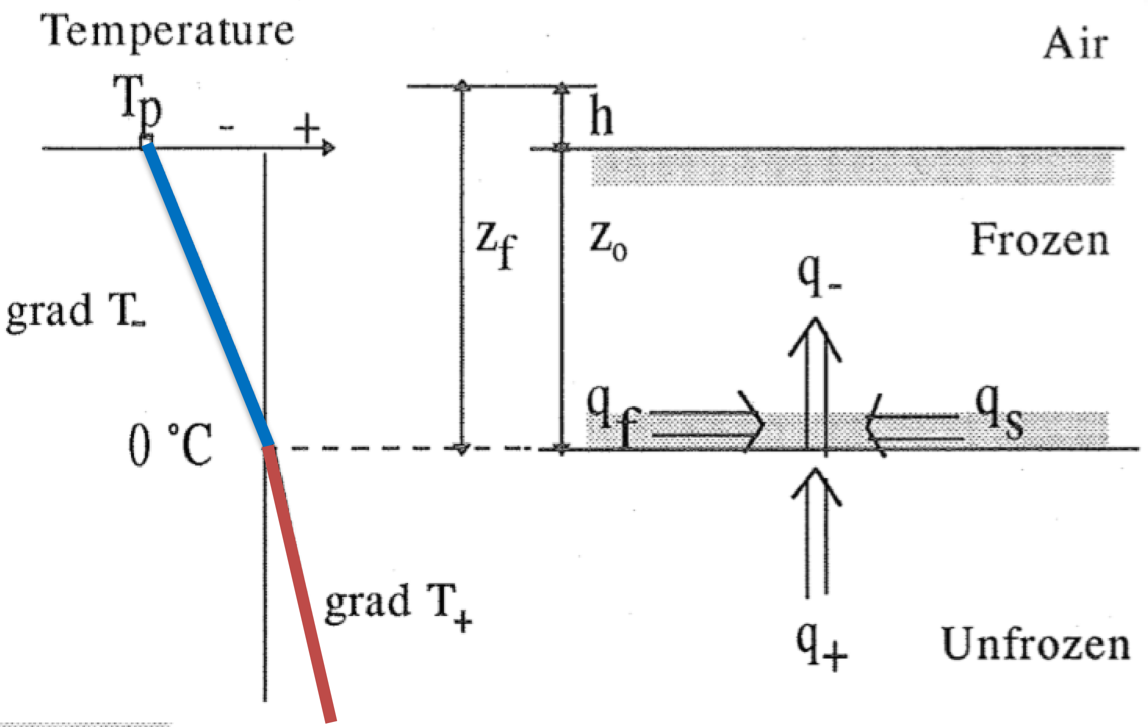




Current model equation

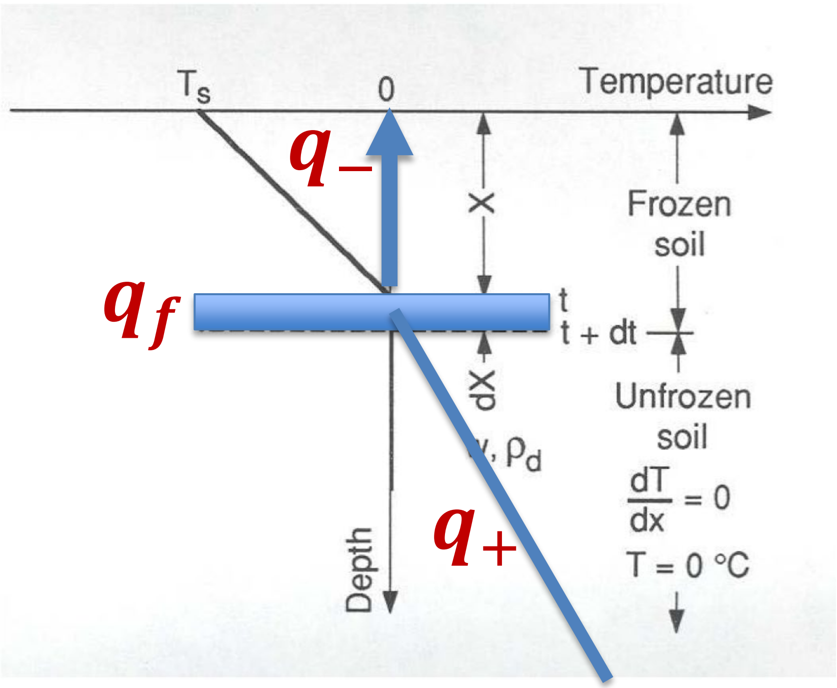
Stefan's equation: *" ..describes the dependence of ice-cover thickness on the temperature history.. "*

heat balance equation

energy conducted = energy from phase change

$$k_f \frac{dT}{dx} \approx k_f \frac{T_S}{X} = L \frac{dX}{dt}$$

$$X = \sqrt{\frac{2 k_f I_{sf}}{L}} \rightarrow X = \sqrt{\frac{2 k_f I_{sf}}{L + C\,\theta_m}}$$



Skaven-Haug (1971)

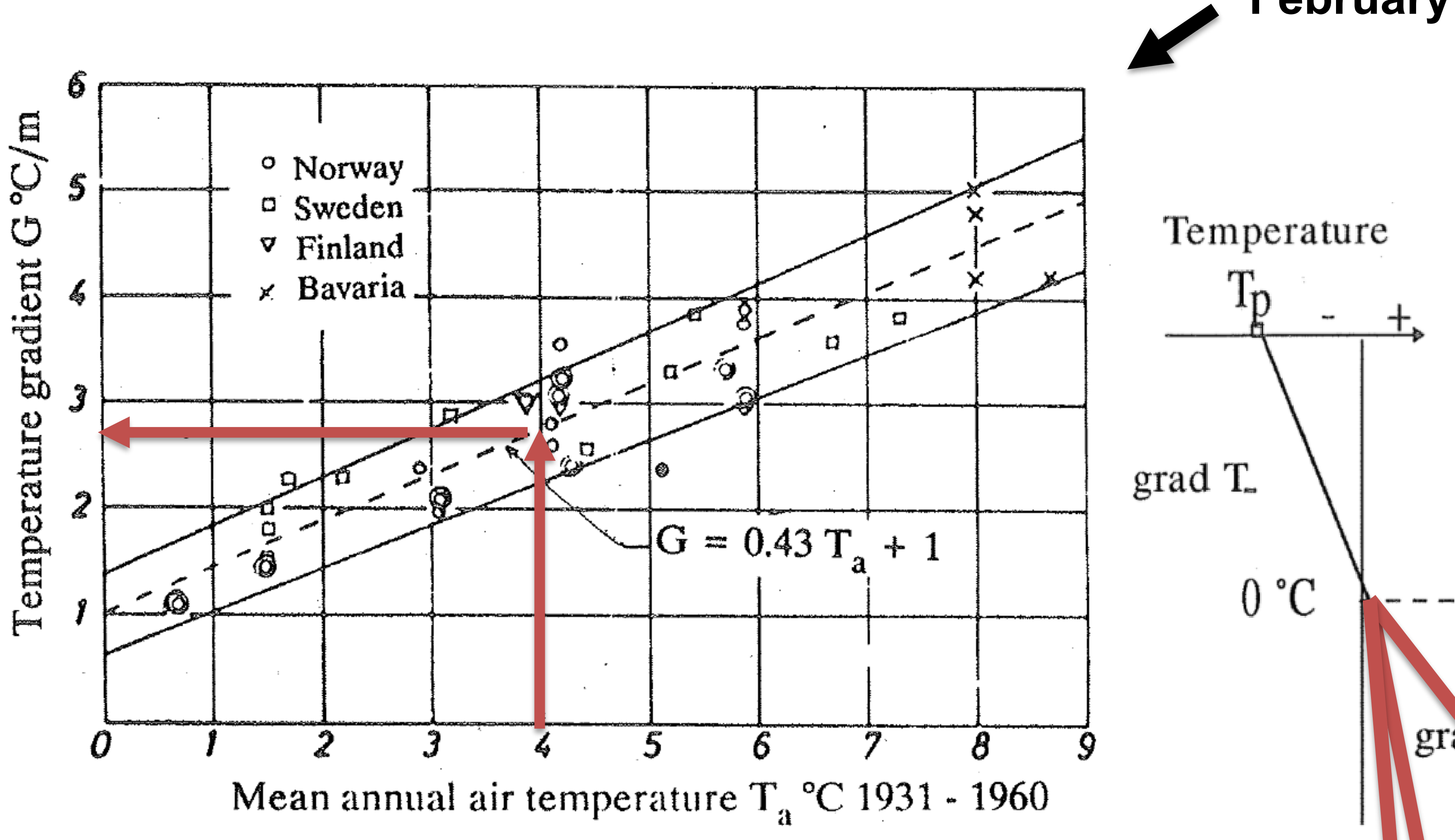
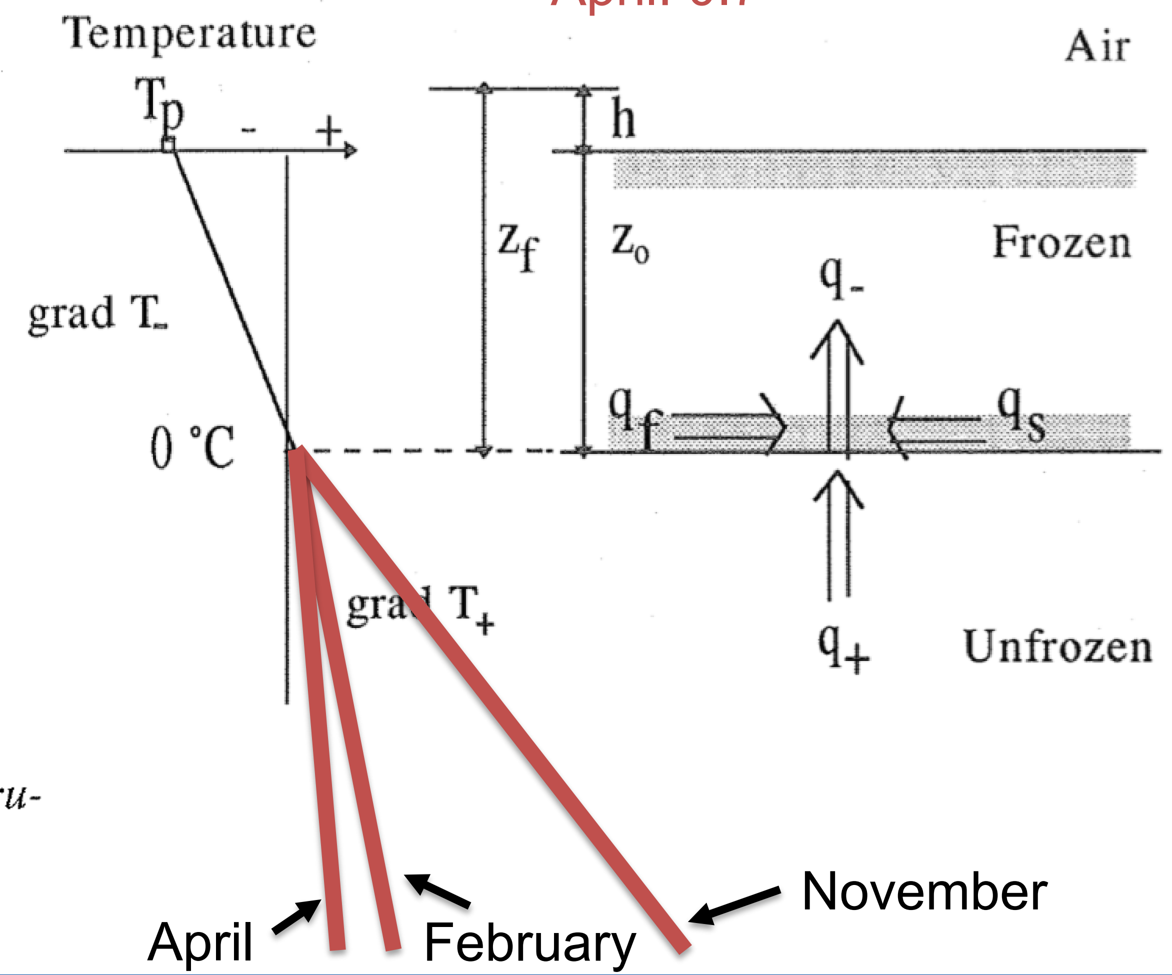


Fig. 2. The variation in the ground temperature gradient early February against the mean annual air temperature (Skaven-Haug 1971).

$$q_+ = k_t \nabla T_+ \cdot S$$

November: 1.0

April: 0.7



Konrad & Morgenstern (1981)

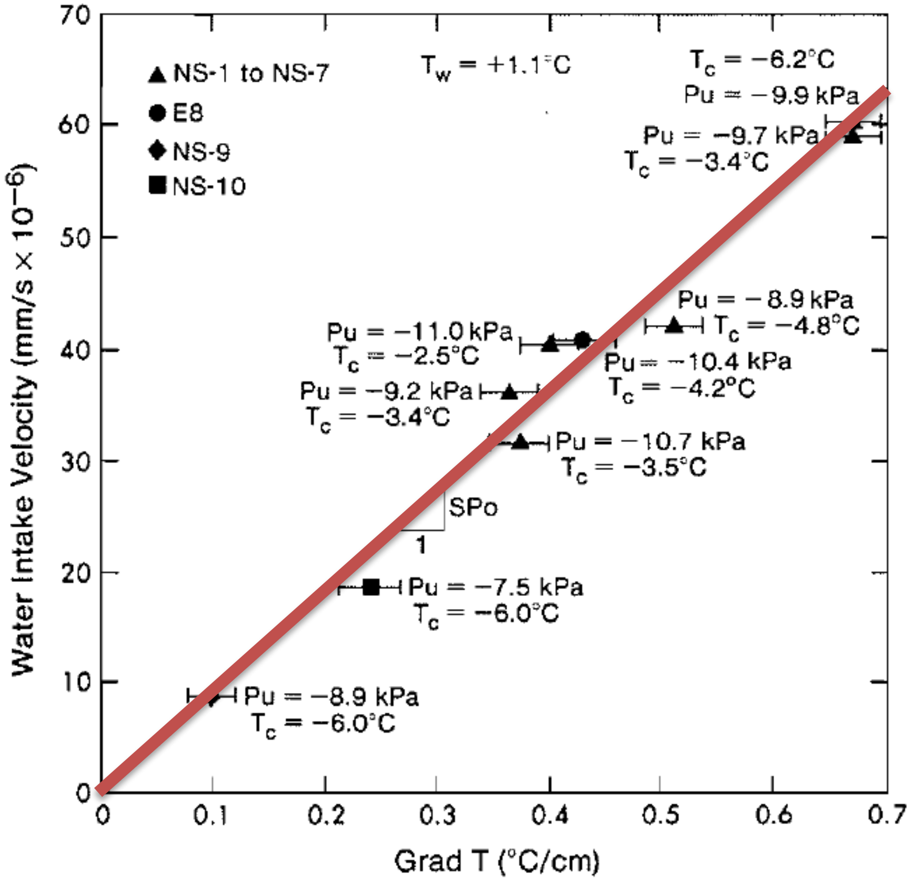
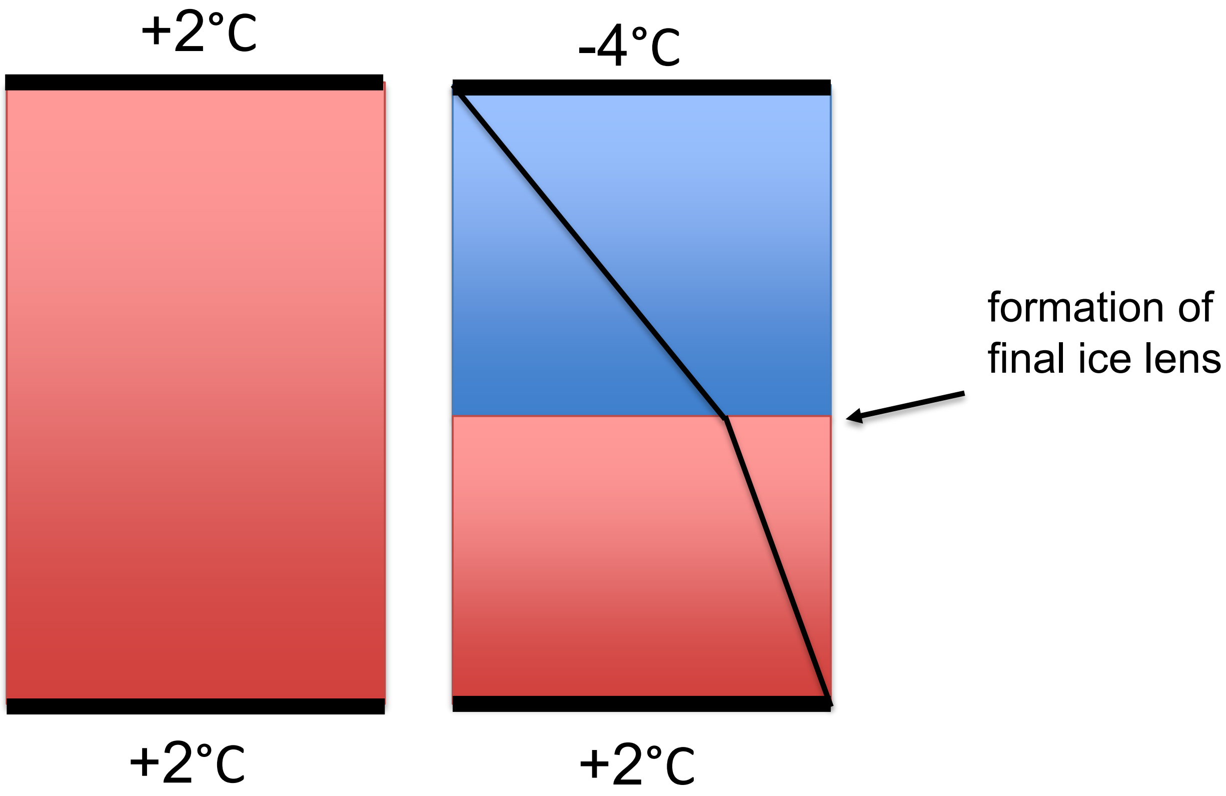


FIG. 1. Relation between water intake velocity and temperature gradient across the active system at the formation of the final ice lens.



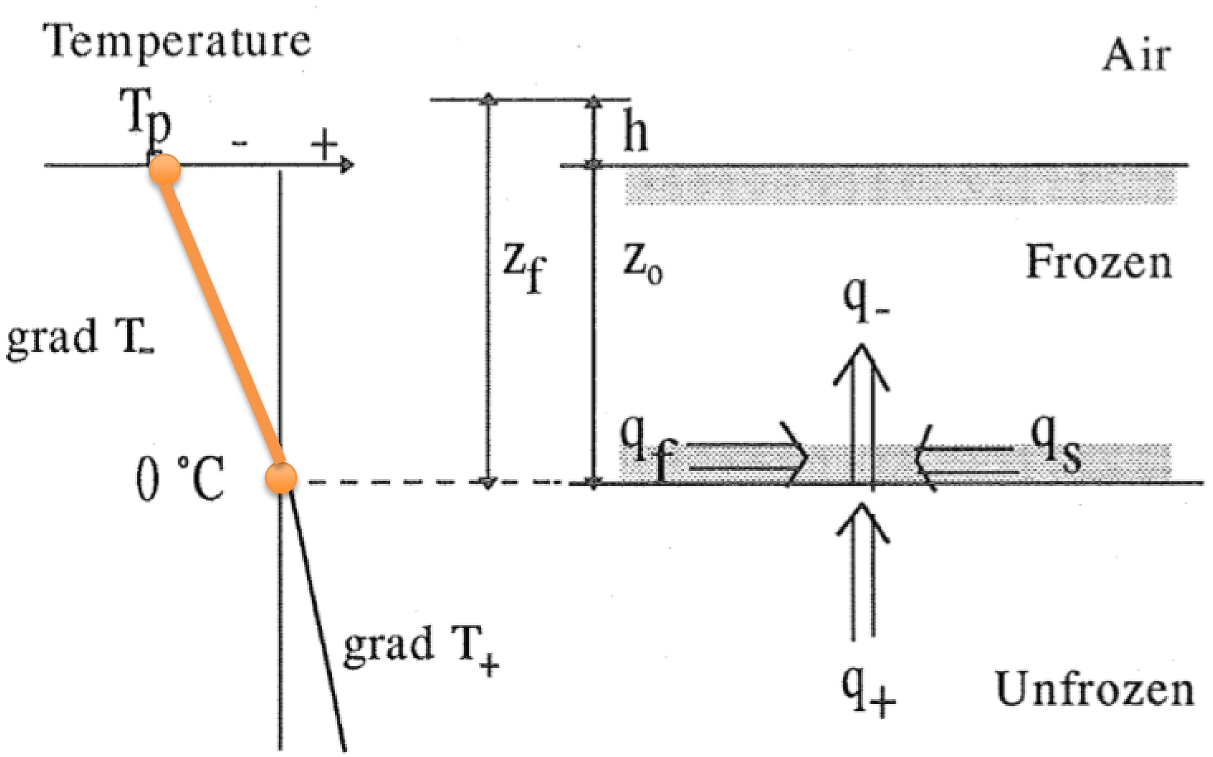
$$SP = \frac{\text{Water intake velocity}}{\text{Temperature gradient}}$$

Konrad & Morgenstern (1981)

$$SP = \frac{\text{Water intake velocity } (V_0)}{\text{Temperature gradient } (\nabla T)}$$

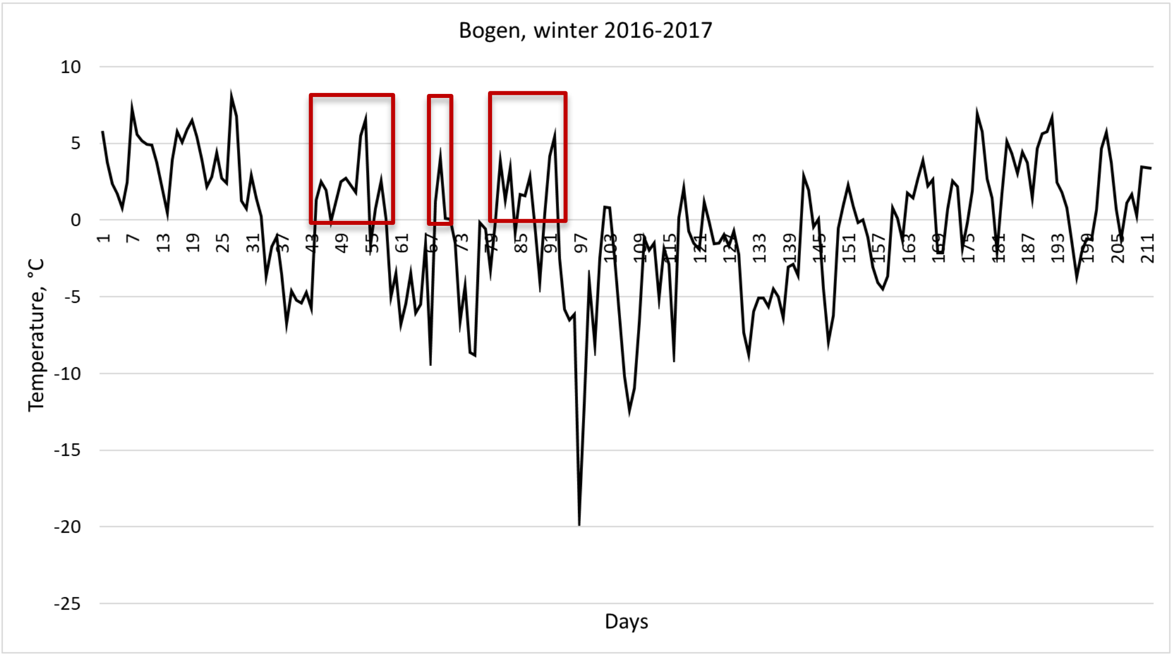
$$V_0 = SP \cdot \nabla T$$

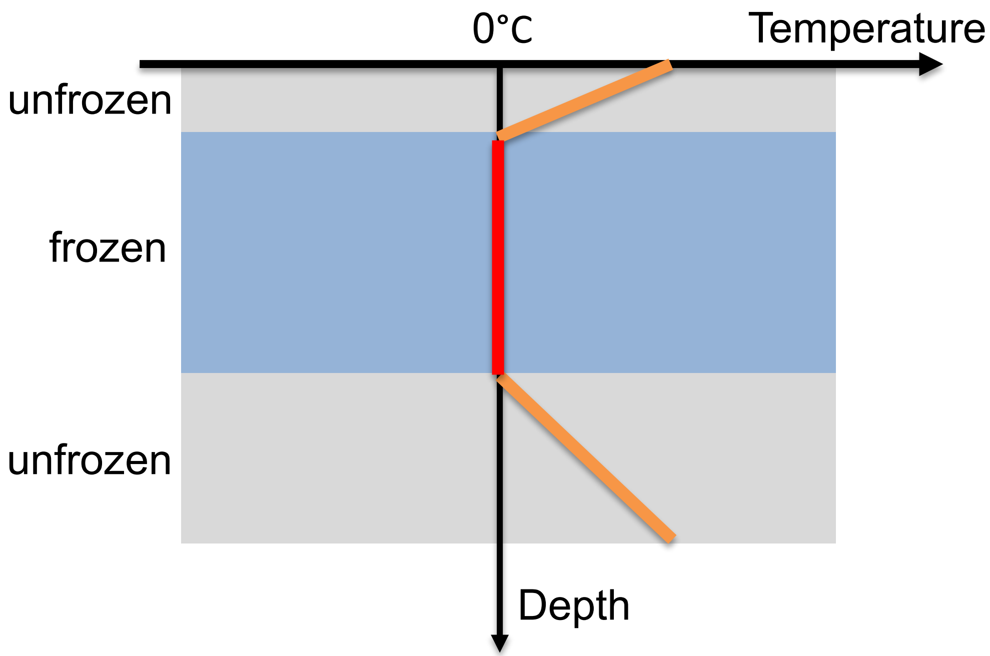
$$q_s = L_w SP\ \nabla T_-$$

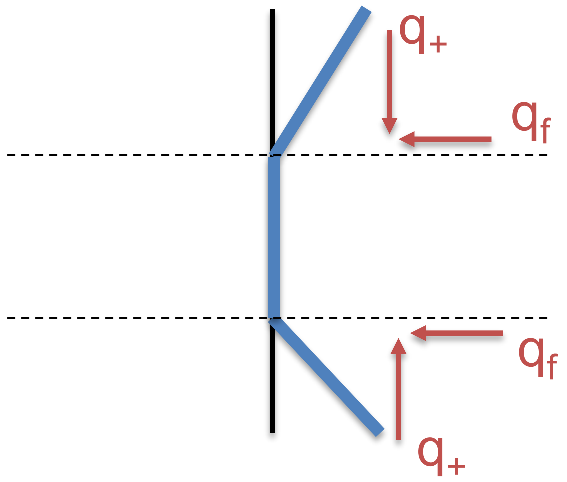


Surface temperature input

Measured values







Stefan’s equation

Ground flux

$$k_f \nabla T_- = L \frac{\Delta z_0}{\Delta t} + k_t \nabla T_+ + L_w SP\, \nabla T_-$$

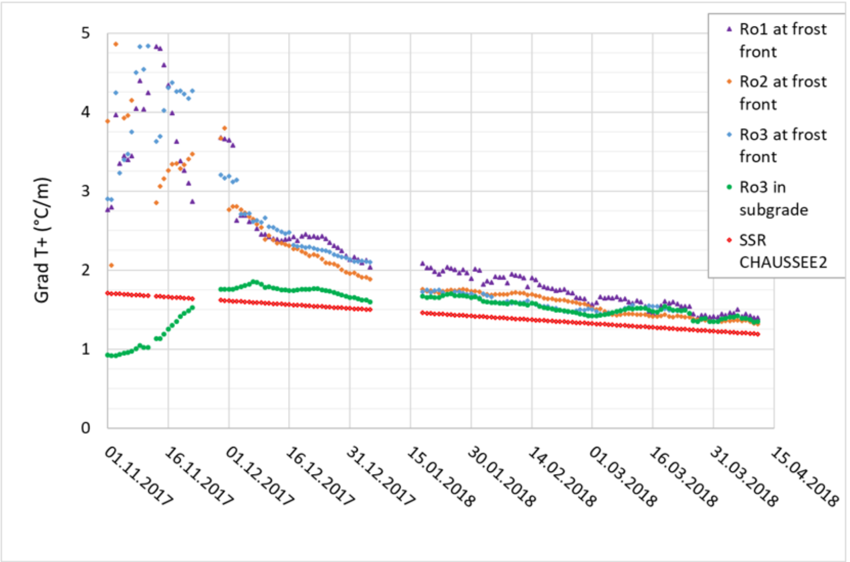
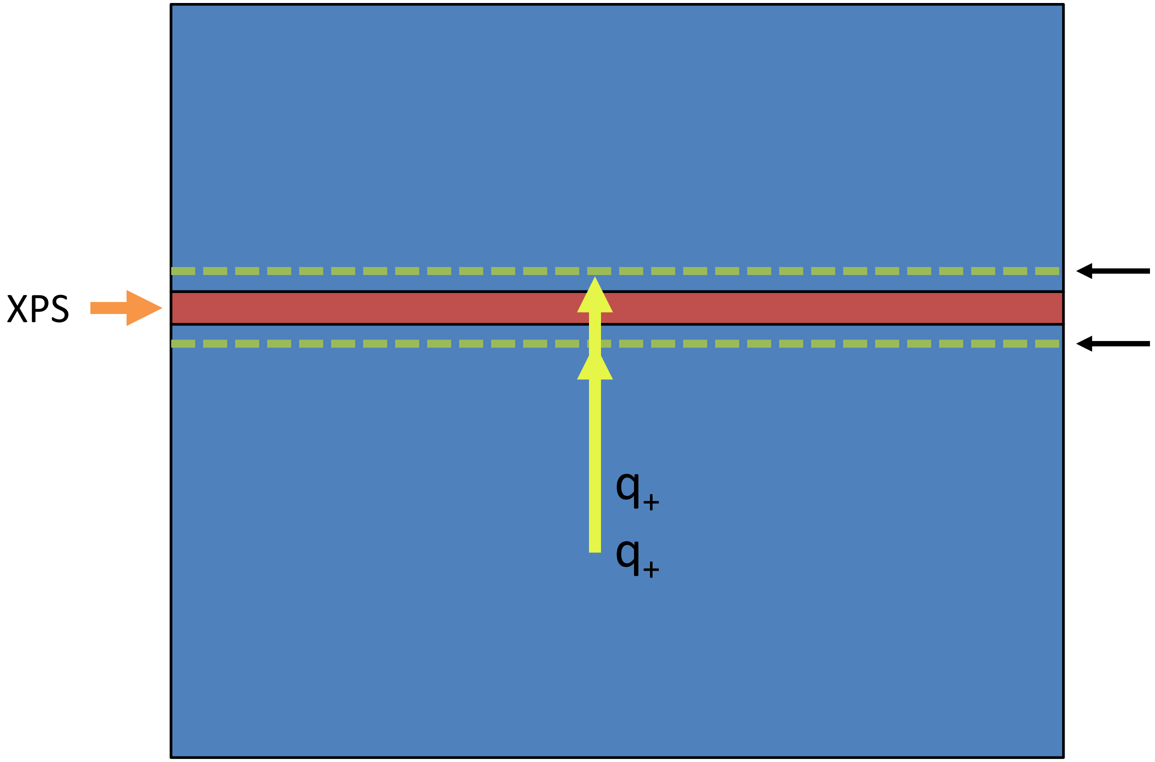


Figure 25: Thermal gradient according to time at Røros test site for winter 2017-18

Benoit et al. (2020)



$$k_t \nabla T_+ \rightarrow q$$

Ground flux

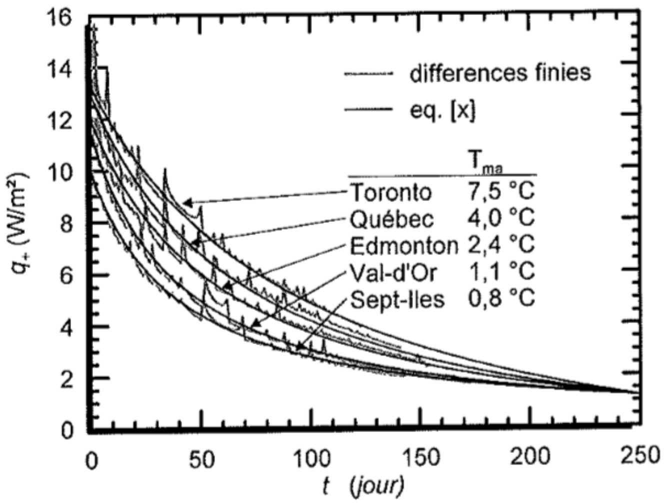


Figure 9. Distribution du gradient thermique sous le front de gel pour différentes régions du Québec et du Canada.

Côté & Konrad (2009)

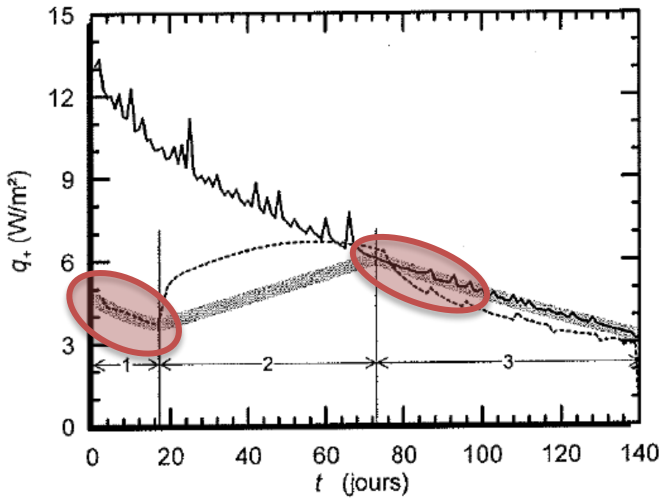


Figure 12. Modèle simplifié du flux thermique sous le front de gel pour une route isolée thermiquement.

Côté & Konrad (2009)

$$qp = \left\{ \frac{(250 - t)[9.62 + 1.44\, ln(Tma)]}{250 + [5.78 - 1.62\, ln(Tma)] \cdot t} + 1.2 \right\} \cdot C_q$$

- Above the insulation: $log(C_q) = -4.5\, \alpha^{0.8}$
- Below the insulation: C_q = 1.0

Why choose SSR model?

- calculates frost depth continuously;
- calculates frost heave;
- easy to program;
- easy to modify;
- easy to implement other models as modules;
- judged as a good equilibrium between simple/ rigid-empirical and complex fully-integrated
- used successfully by Quebec Ministry of Transportation (Canada) for > 15 years + Finnish experience