Assessment of frost heave for mechanistic-empirical design

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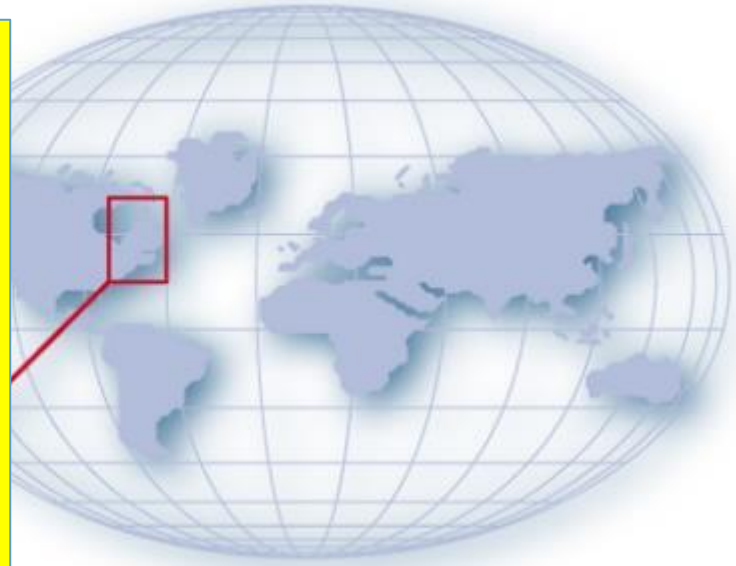
Context

Québec city:

- 4 months of winter (-10˚C on average)
- Coldest temperature ≈ -35˚C
- Freezing index ≈ 1200˚C·d
- Frost penetration under pavement surface ≈ 2 m
- Frost heave typically between 50 and 150 mm
- Snow fall between 3 and 4 m
- Total precipitation ≈ 1000 mm



Challenges

Large road network and low population density

- Vital communication links
- Low levels of funding

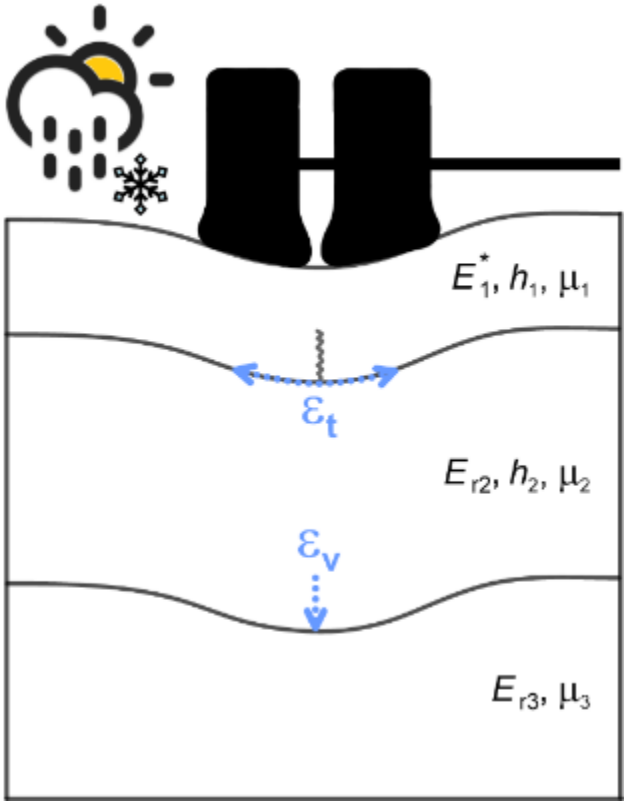
Severe climatic conditions

- Moisture, Frost action

Frost action on pavements

Design practice in Quebec

- Pavement structural design done using AASHTO method
  - HMA designed considering regional temperature averages
  - Pavement granular materials assumed to be stable
  - Seasonal variation of subgrade soil properties dealt with using “effective modulus”
- Frost heave design based on an allowable frost heave criterion and empirical frost protection
- Moving towards M-E design



Frost design

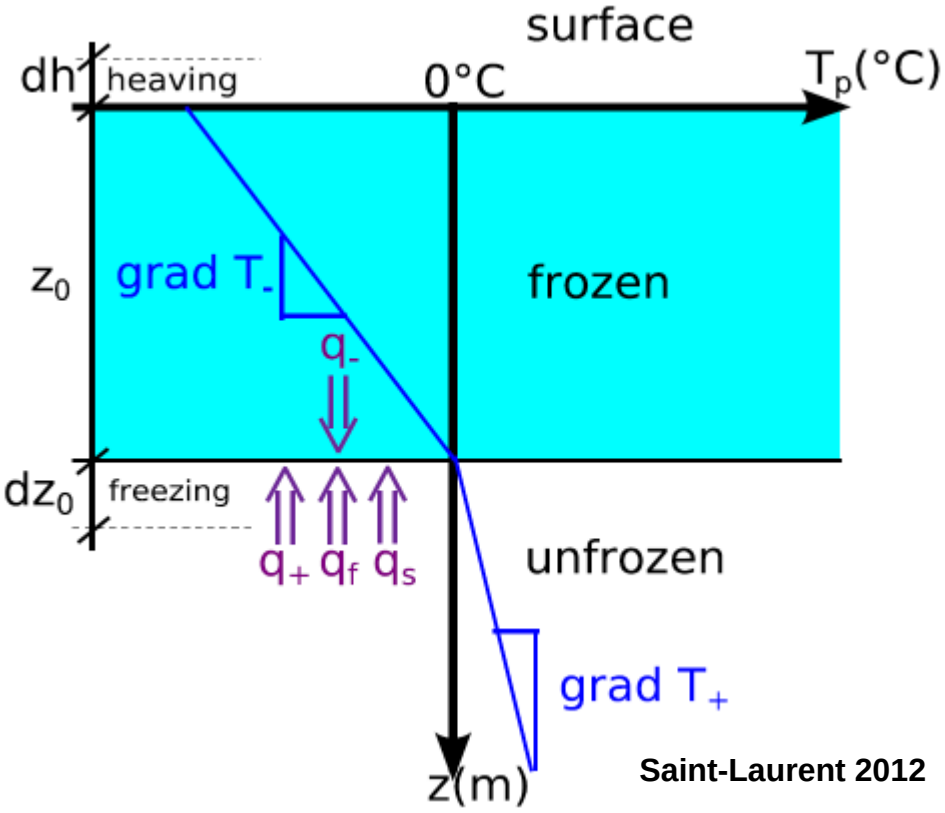
- Minimum pavement thickness based on freezing index, soil type and functional class
- Frost penetration and heave (SSR model):
  - Segregation potential (SP) + Climate/Site conditions
- Calculated frost heave vs allowable frost heave criteria
- Design : adjustment of total thickness, insulation replacement

Frost penetration calculation
Heat balance

- SSR Finnish model
- Heat balance at frost front for each time interval (dt)

$$q_- = q_+ + q_f + q_s$$
$$q_- = k_f \mathrm{Grad}T_-$$
$$q_+ = k_u \mathrm{Grad}T_+$$
$$q_f = L \, dz_0 / dt$$
$$q_s = L_w SP \times \mathrm{Grad}T_-$$

$$dh = 1{,}09 \times SP \times GradT \times dt$$



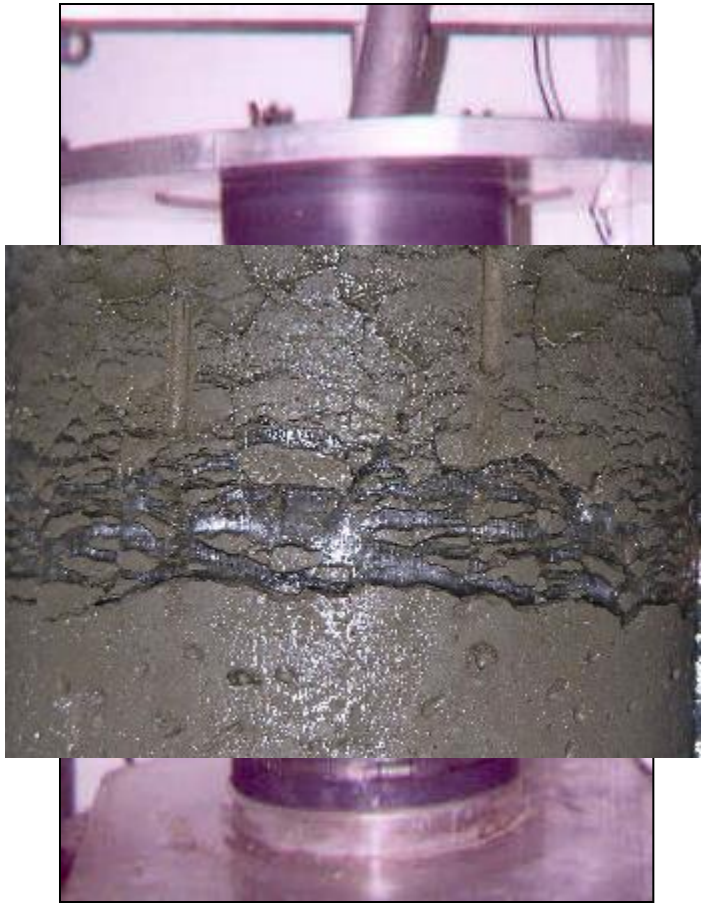
Saint-Laurent 2012

- Frost heave calculation for each time interval frost penetration increment using segregation potential theory

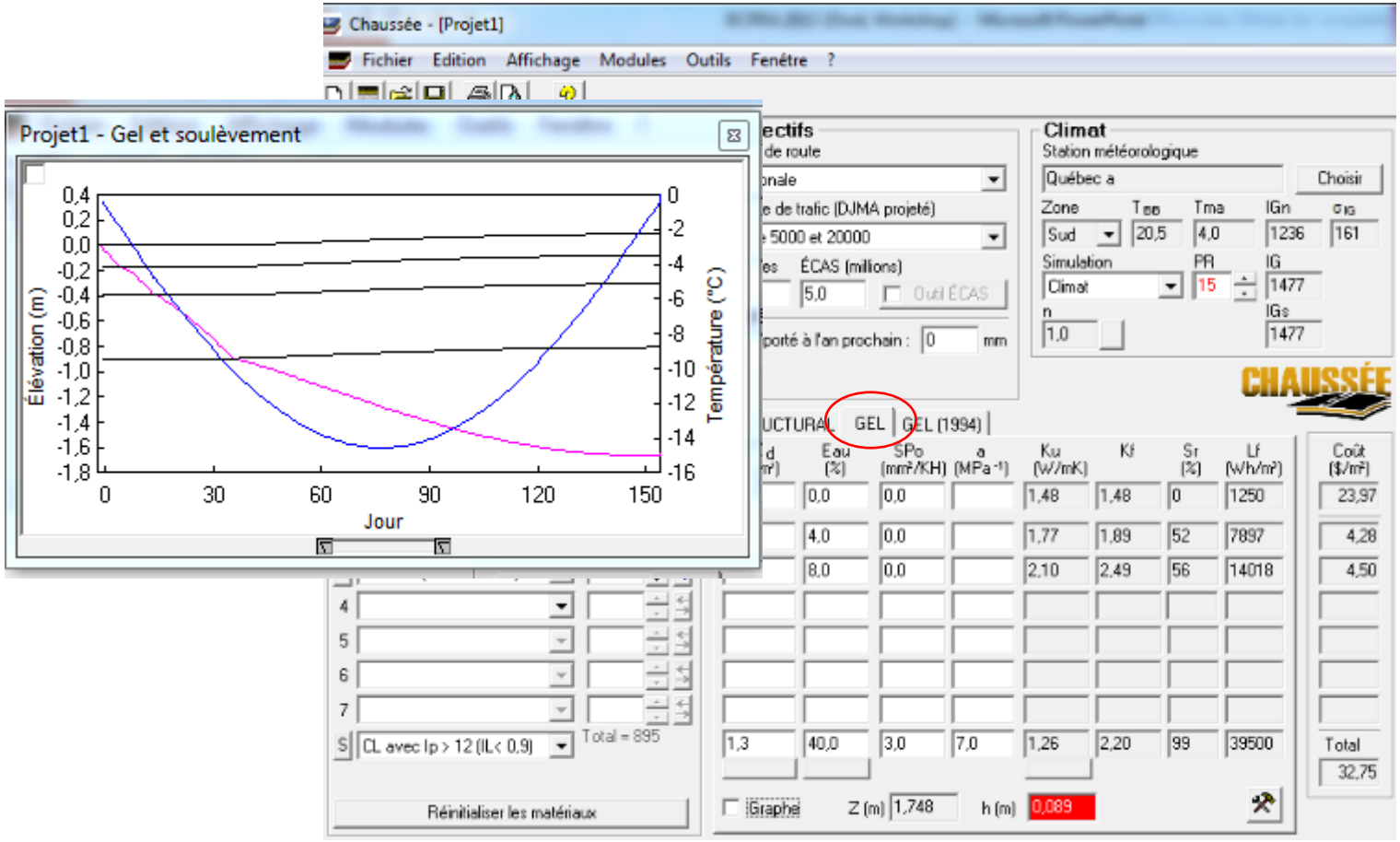
Frost susceptibility (SP)
Segregation Potential

Frost susceptibility	SP mm²/°C·hour
Negligeable	< 0,5
Low	0,5 à 1,5
Moderate	1,5 à 3
High	3 à 8
Very high	> 8

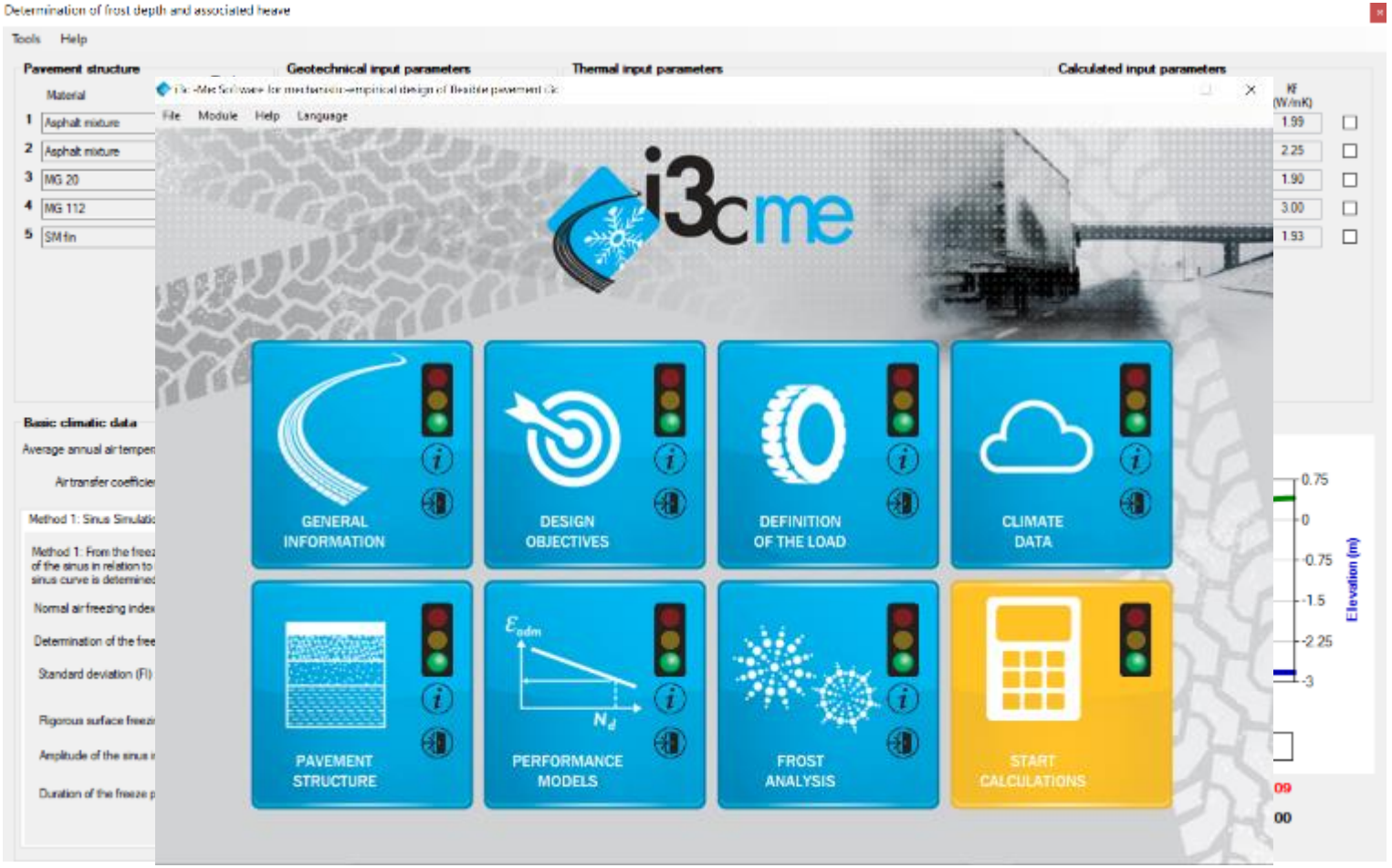
$$dh = 1,09 \times SP \times GradT \times dt$$



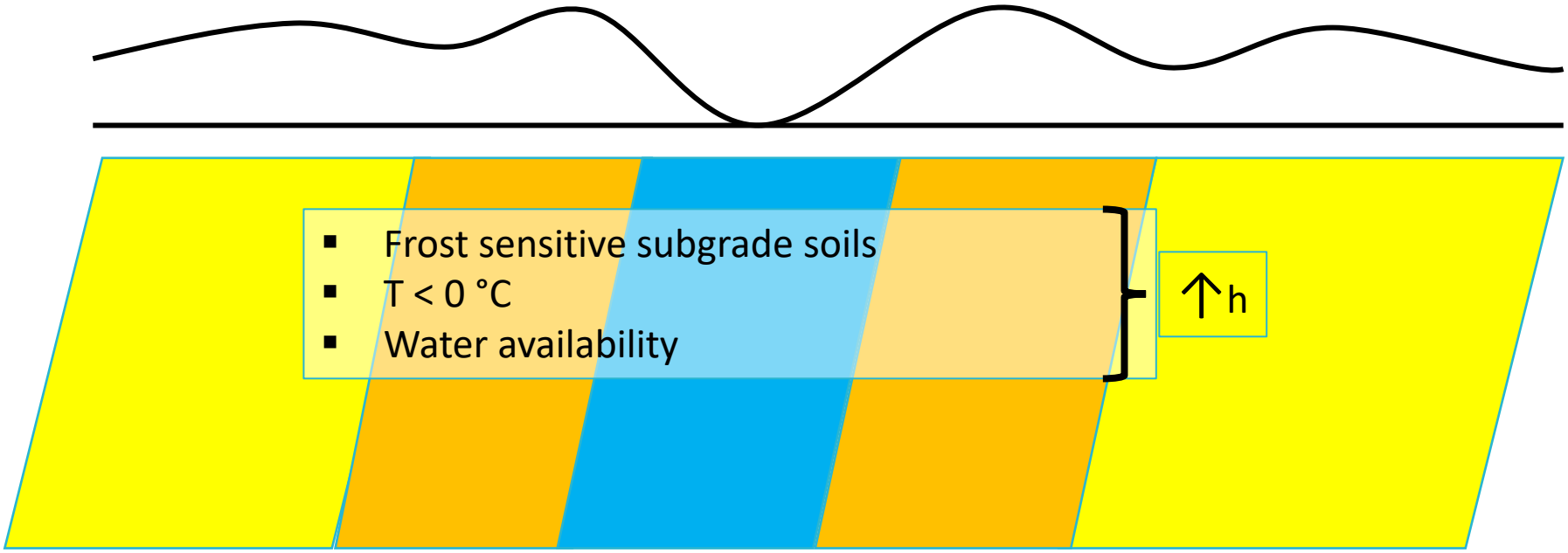
Frost design



Frost design



Frost action and its relationship with roughness



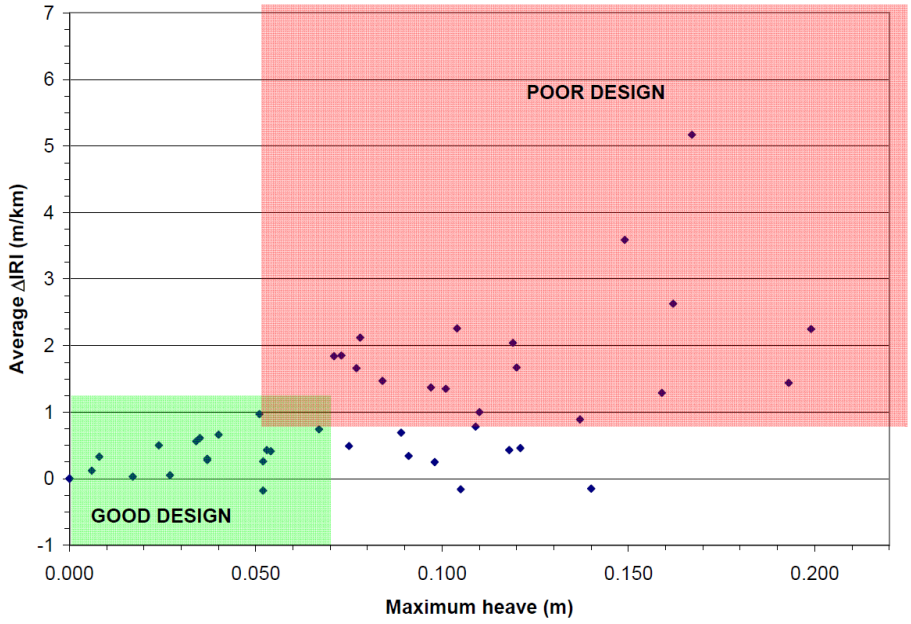
Roughness deterioration

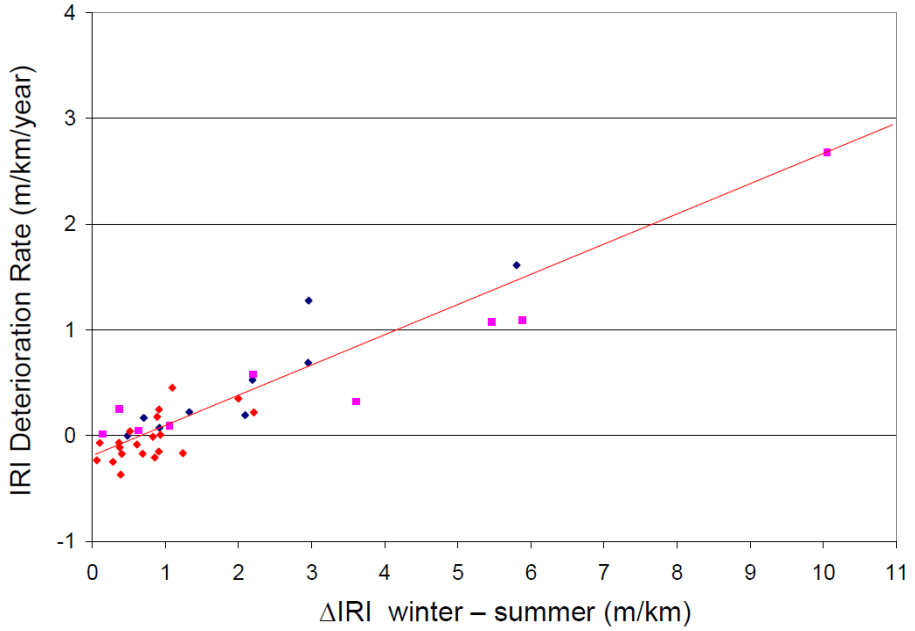
- Surface cracking
  - Transversal and longitudinal
- Surface distorsion
  - Longitudinal and transversal differential heaving

Frost action and its relationship with roughness

- Critera based on experience and some relationships between roughness development and frost heave

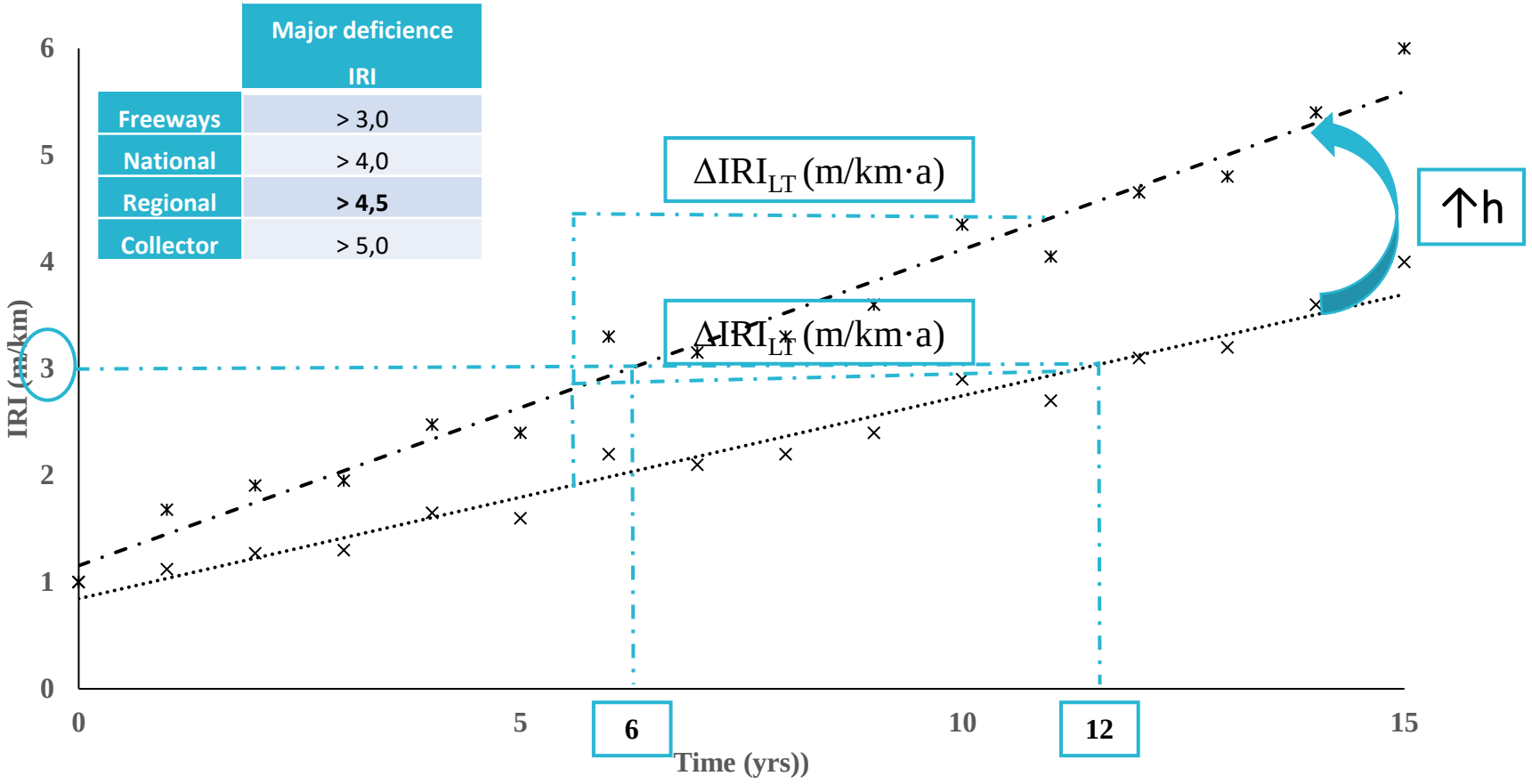
Freeways	< 50 mm
National	< 55 mm
Regional	< 60 mm
Local	< 70 mm





Saint-Laurent 2012

Performance model related to frost action



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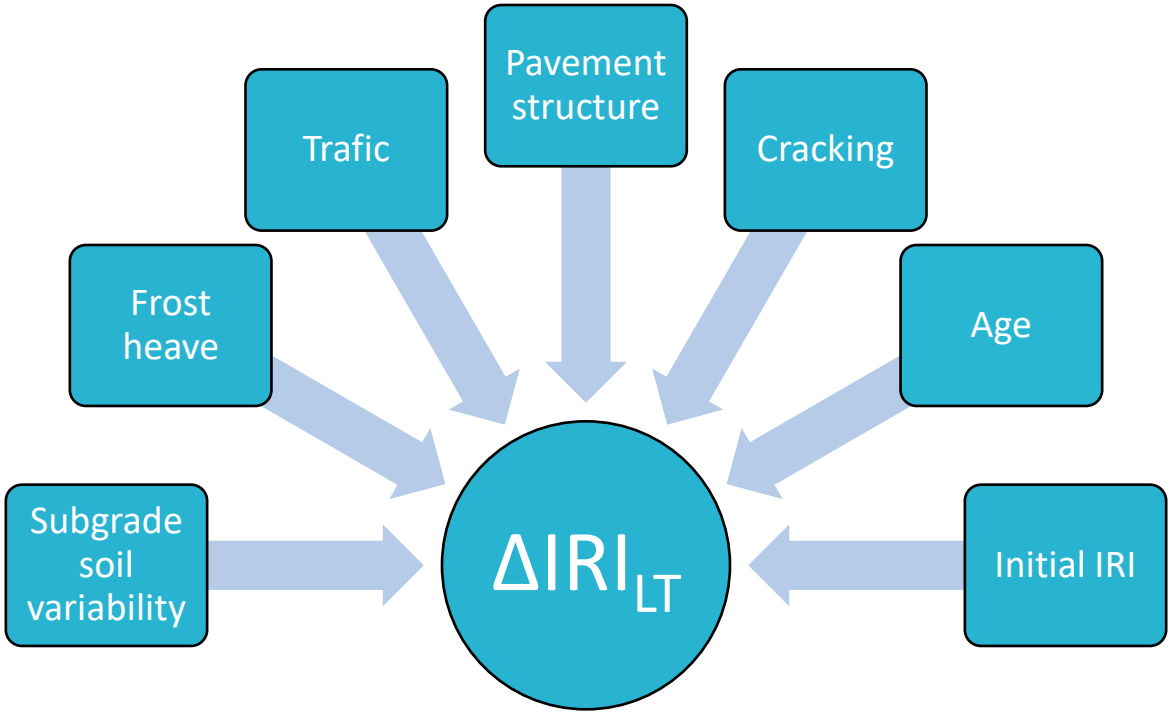
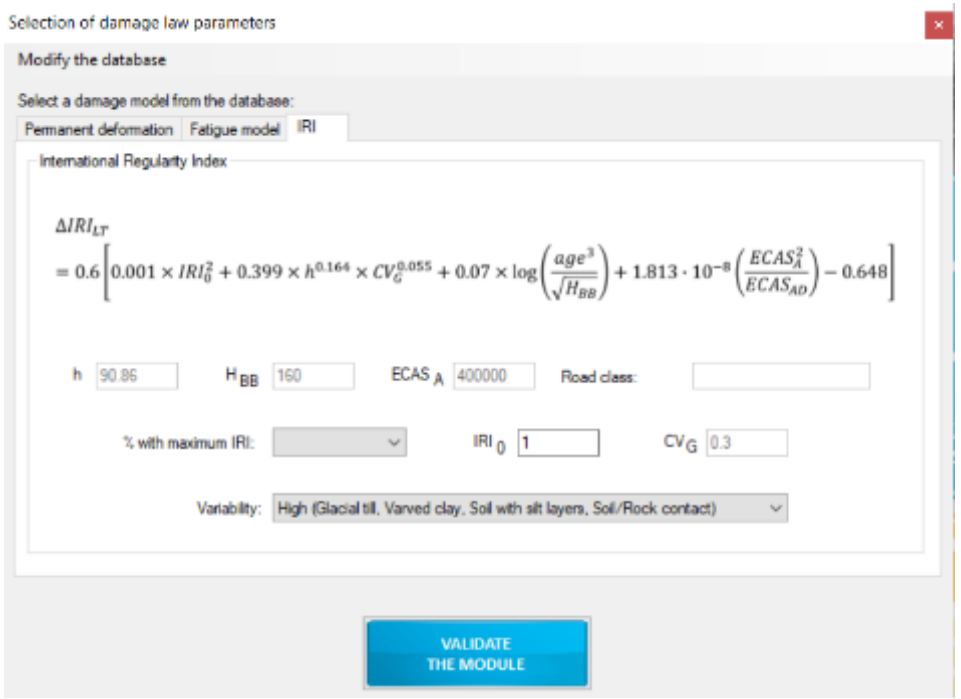
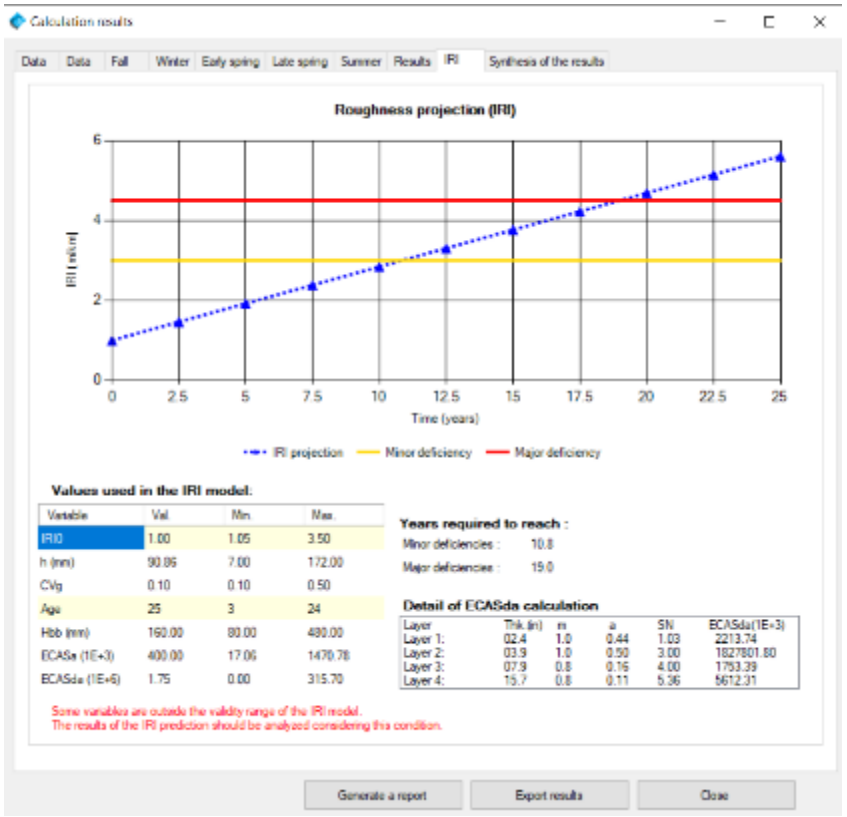


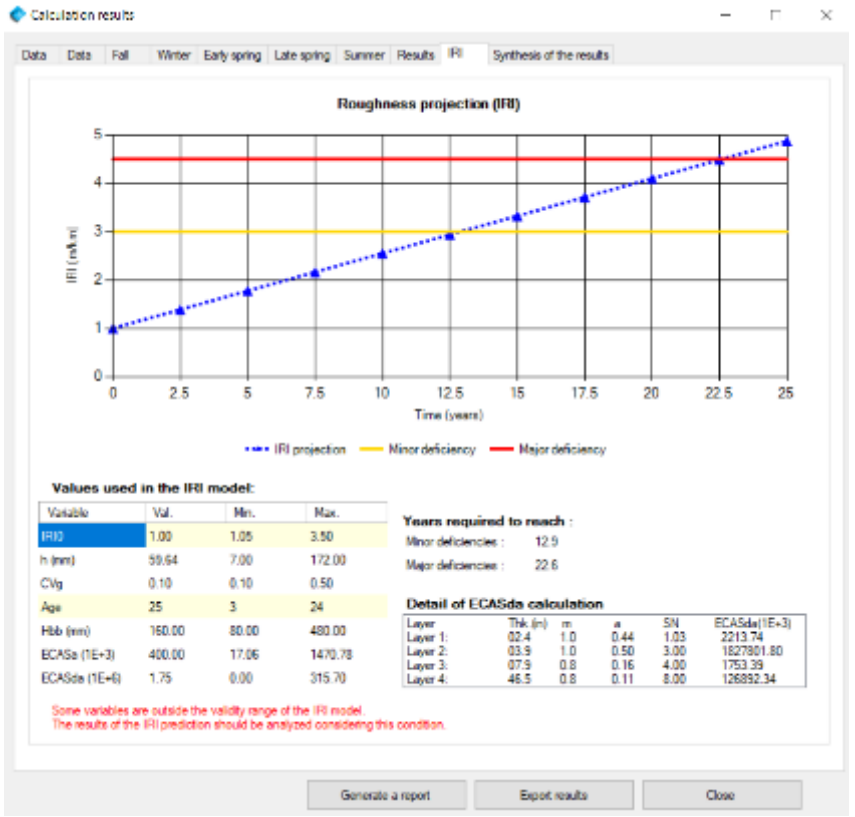
Performance model related to frost action

- Empirical model (Sylvestre et al., 2017)
- Development with 44 monitored test sections and validated with 22 test sections



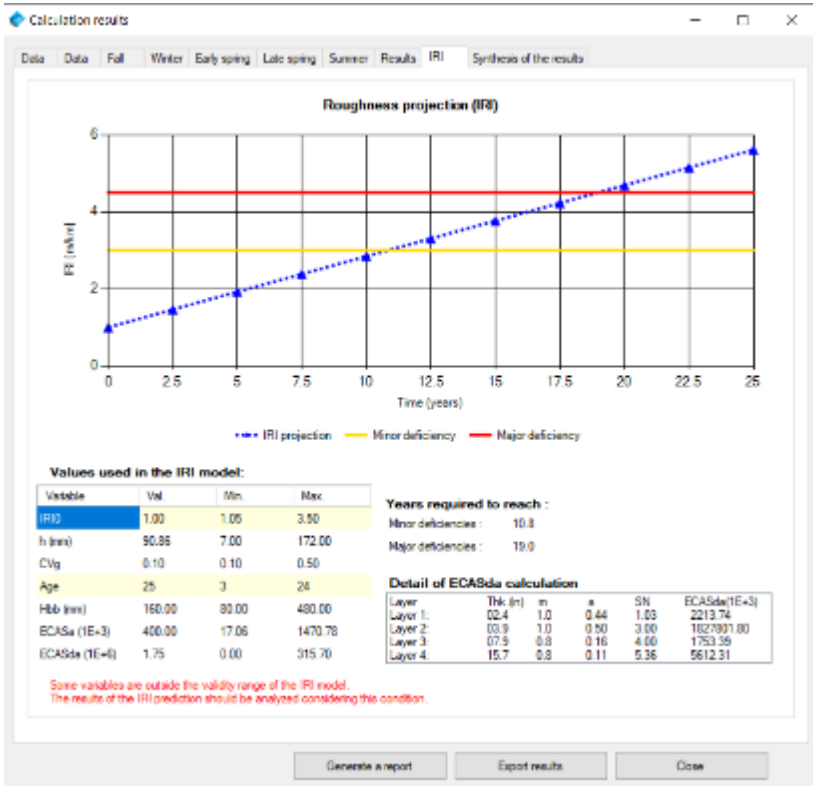
Example of decreasing frost heave (and increasing bearing capacity)





Increasing pavement thickness

Example of increasing subgrade soil variability



Increasing subgrade soil variability

Conclusion

- Frost action is a major factor of pavement damage in Quebec
- Frost heave criteria used for frost design of pavements in Quebec
  - Empirical and ME model
- ΔIRI used to assess frost action on existing pavement
- IRI deterioration rate includes frost heave to assess pavement life


Merci!
Thank you!
Tusen takk!