UNIVERSITÉ LAVAL

Thermal stabilization of transport infrastructure built on unstable permafrost using high albedo surface treatments

Arquluk
Permafrost engineering research program
Programme de recherche en ingénierie du pergélisol

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High albedo surface treatment (HAST)

- Coating applied on **asphalt or** BST
- BST with light colored aggregates
- **Light colored asphalt**

Dawson City Front Street, Yukon (Colas)

Alaska Highway, Yukon

Salluit, Nunavik

Alaska Highway, Beaver Creek, Yukon

Objectives

Develop a methodology for thermal stabilization based on surface albedo

- Quantify the effect of a pavement’s albedo on surface temperature
- Develop an approach to assess the technical properties of HAST
- Document the evolution of albedo with time for various pavement surfaces
- Develop a thermal stabilization method

Study sites


Beaver Creek
Burwash Landing
Salluit
SÉRUL
Image Landsat / Copernicus
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US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth

Properties of HAST

Proposed specifications for effective, durable and safe HAST in a northern context.

Reflectivity

- Albedo

Pyranometer - ASTM E1918

Properties of HAST

Proposed specifications for effective, durable and safe HAST in a northern context.

Reflectivity

- Albedo

Skid resistance

- Macro texture : Skid resistance in wet conditions, durability, thermal benefit
- Micro texture : Skid resistance in dry conditions

Sand patch - ASTM-E965

British Pendulum - ASTM E303

Properties of HAST

Proposed specifications for effective, durable and safe HAST in a northern context.

Reflectivity

- Albedo

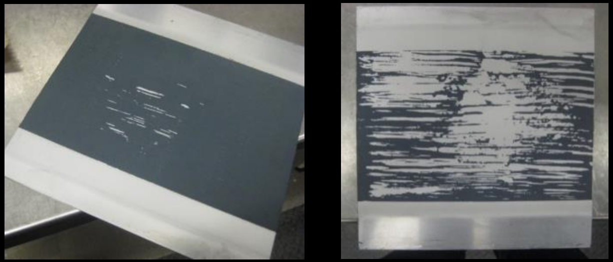
Skid resistance

- Macro texture : Skid resistance in wet conditions, durability, thermal benefit
- Micro texture : Skid resistance in dry conditions

Durability (Laboratory test)

- Abrasion resistance
- Adhesion to substrate

5 cycles   30 cycles



Sand blast - LC 21-102

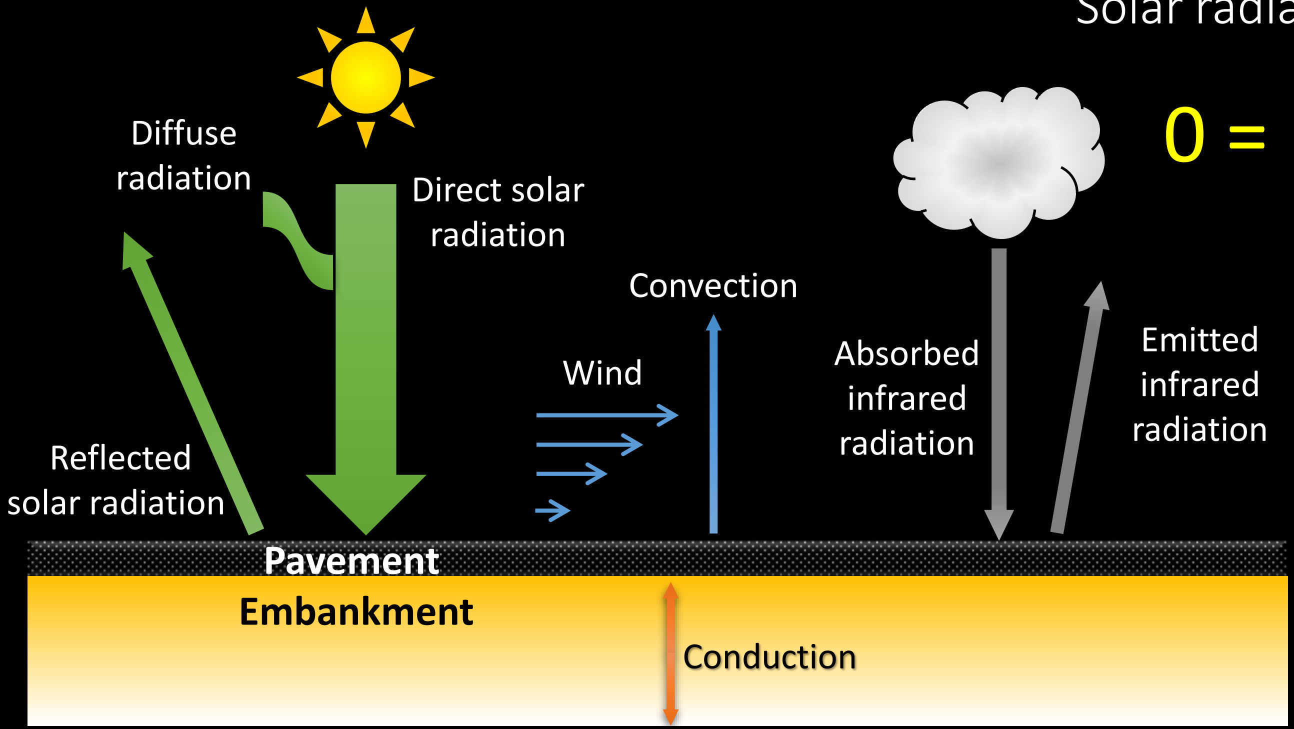
Direct tension test – LC 25-010

Model – Calculation of surface temperature

Allowing a quick and accurate assessment of the thermal benefits of using high albedo surface treatment.

- Simple calculation tool
- Model adapts to different climate conditions

Simplified energy balance



Energy balance

Solar radiation — Infrared radiation

$$0 = q_r + q_e + q_c + q_g$$

Convection — Conduction

Model – Calculation tool

3 types of data are needed to calculate surface temperature:

- Air temperature
- Solar radiation
- Wind speed

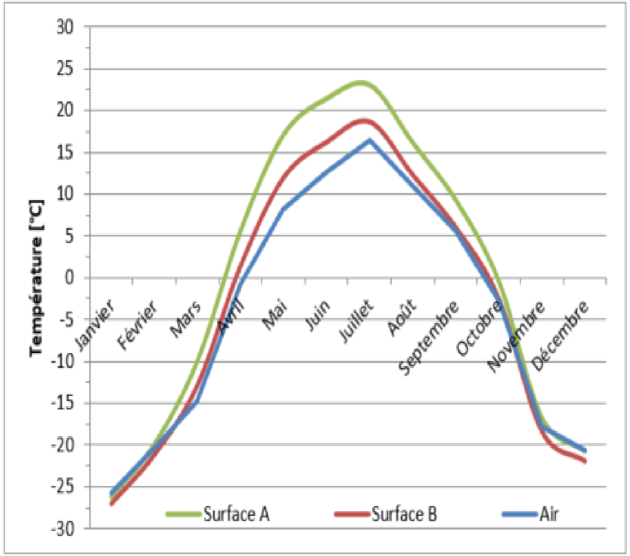
Use of monthly averages recommended

ARQULUK - Calcul des températures superficielles des revêtements routiers

Mode d'emploi	Données à saisir
	Données calculées

Albédo surface A	Albédo surface B
0,15	0,50

Rad 2015	Radiation solaire [W/m²]	Vitesse du vent [km/h]	Température de l'air [°C]	Température surface A [°C]	Température surface B [°C]
Janvier	5,6	3,4	-25,7	-26,3	-27,0
Février	31,3	3,6	-20,3	-20,0	-21,1
Mars	106,2	4,8	-14,8	-10,0	-12,8
Avril	166,5	4,4	-0,8	5,5	1,4
Mai	236,8	6,6	8,1	17,0	11,9
Juin	232,9	6,0	12,6	21,3	16,2
Juillet	191,6	6,1	16,4	23,0	18,6
Août	143,5	5,1	11,0	16,1	12,3
Septembre	98,1	4,4	5,6	9,2	6,0
Octobre	45,4	4,8	-2,8	-0,5	-2,5
Novembre	13,8	2,9	-17,9	-16,8	-18,3
Décembre	3,2	1,9	-20,6	-20,8	-21,9
	Indice de gel (°C*jour)		3111	2848	3131
	Indice de dégel (°C*jour)		1648	2823	2035



Use of the model

- Resolution by iterative calculation
- Calculation tool (Arquluk website)
- Calculation chart

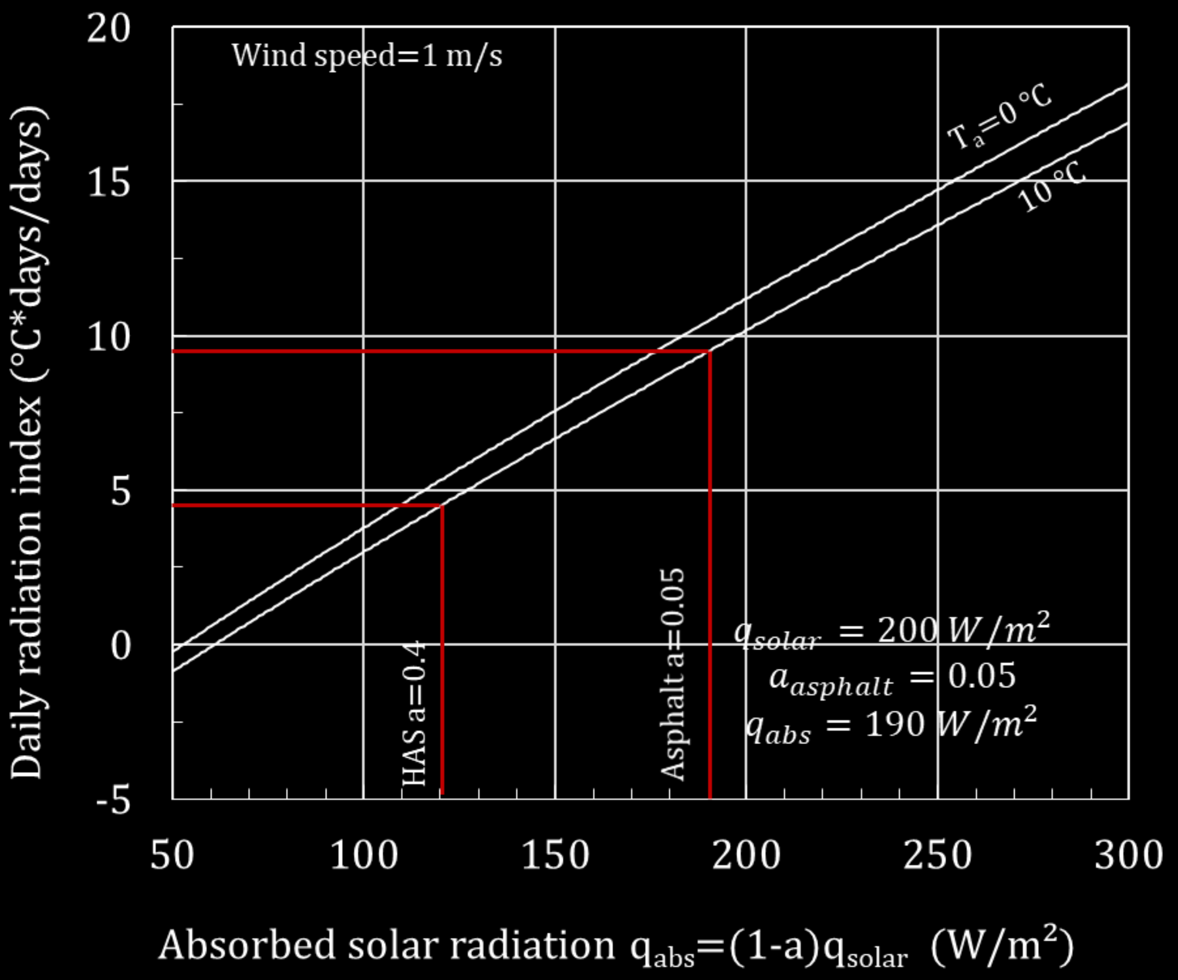
Model - Chart

Thawing Index of the Surface

$$TI_s = TI_a + RI_t$$

Thawing Index of Air

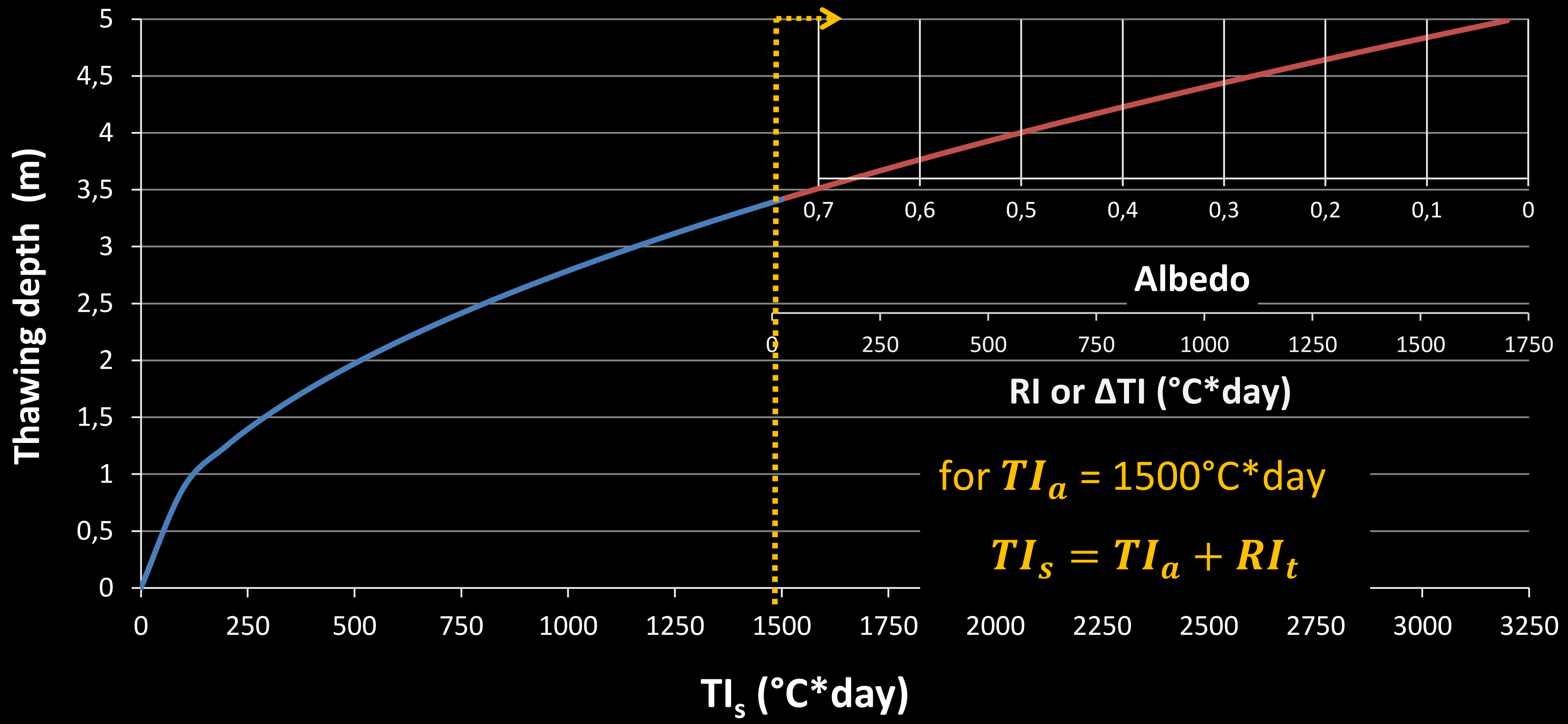
Thawing Radiation Index



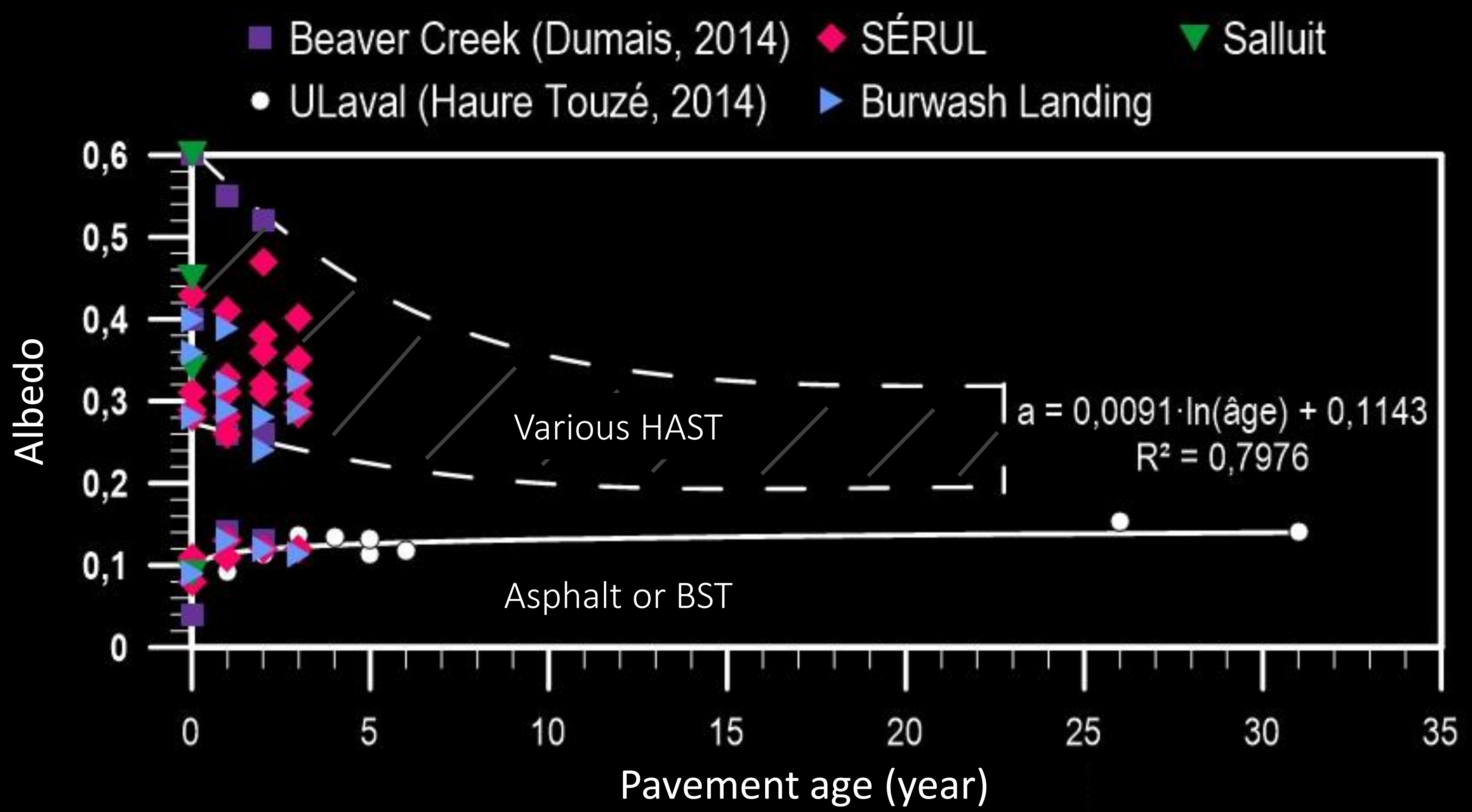
S. Dumais, G. Doré
Cold Regions Science and Technology 123 (2016) 44–52

Thawing depth - Example

Thawing depth according to Stefan with k_u = 1.8 W/m°C et L_s = 40 MJ/m³



Evolution of albedo with time



Thermal model

Mean Annual Temperatures used:

- Surface (using calculation tool and simplified energy balance)
- Interface natural soil/embankment (numerical simulation)
- Permafrost (zero amplitute depth)

*measured or estimated from available data for a specific site

Simplified climatic data used:

- An upper limit condition is imposed and is determined by the simplified energy balance

Thermal model – Chart development

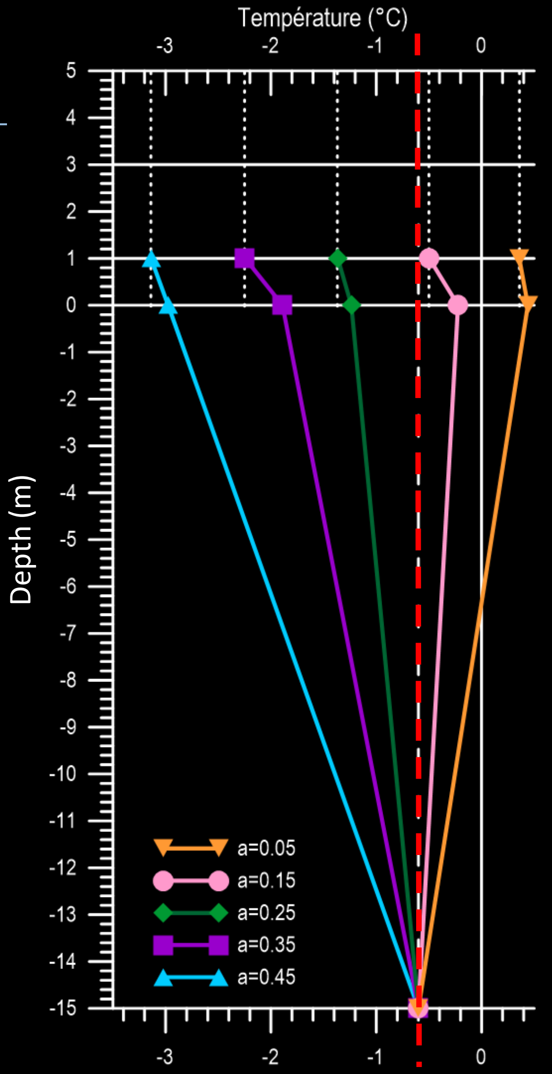
Influence of albedo and embankment thickness on average annual temperature at soil/embankment interface (0 m)

- Embankment thickness: 1 m - 3 m - 5 m
- Surface albedo : 0.05 - 0.15 - 0.25 - 0.35 - 0.45

Low albedo **0.05** → thick embankment = positive heat balance

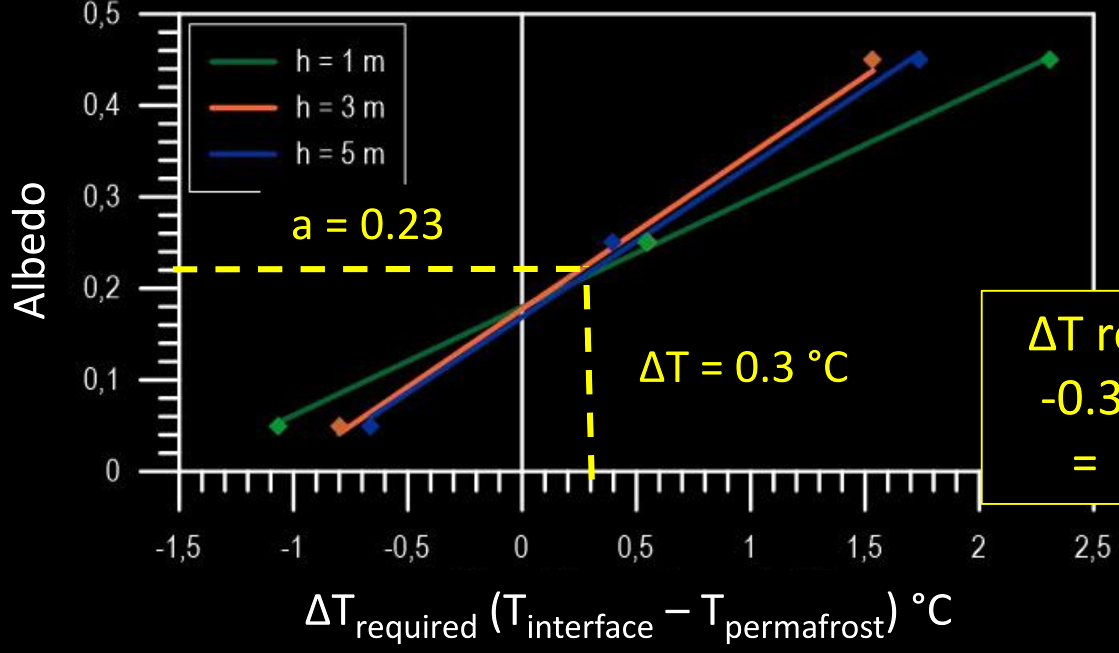
High albedo **0.45** → thin embankment = more effective

In this case, albedo of **0.25** is required for thermal stabilization: T interface ≤ T permafrost

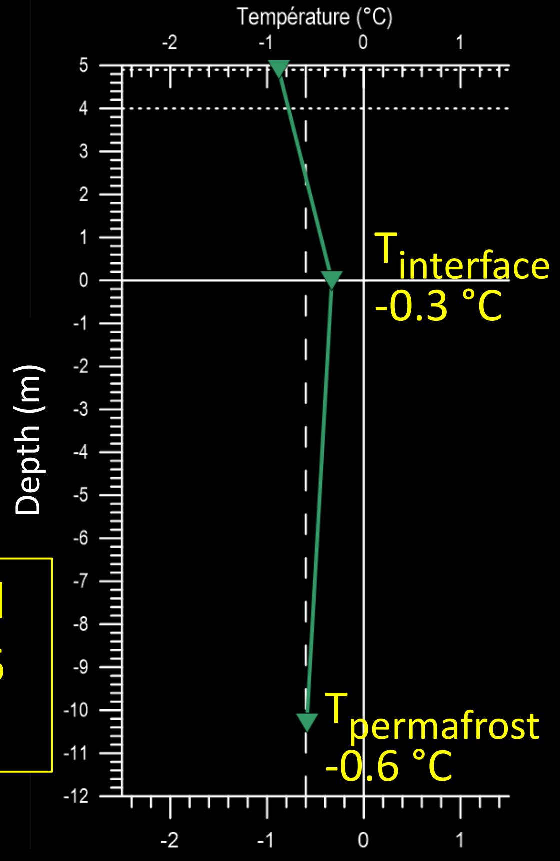


Thermal model – Design chart

Surface albedo required for thermal stabilization of paved roads as a function of required $\Delta T = T_{interface} - T_{permafrost}$



ΔT required
-0.3 – -0.6
= 0.3°C



Conclusion

- Relationship between :
  - pavement surface temperature and albedo
  - albedo and pavement age

- Calculation tool of surface temperature and thaw penetration, using a simplified energy balance and a chart, allowing to quickly determine the need to use HAST on a specific site.

- Framework to assess technical properties of HAST for laboratory and in-situ tests.

Conclusion

- Thermal stabilization approach including :

  - Model to determine thaw depth depending on site characteristics and albedo

  - Difference of temperature required ($T_{interface} - T_{permafrost}$) to limit heat intake and achieve thermal stabilization

Benefits

- The thermal stabilization approach proposed allows engineers to achieve thermal stability of paved roads or airstrips built on thaw-sensitive permafrost based on embankment thickness and albedo.
- Program partners Colas Canada (Skookum, Whitehorse) and Nippo Corporation (Japan) have developed high albedo surfacing products adapted for application in permafrost environments. Availability of well adapted products combined with testing procedures and design methodology make HAST a promising technique for thermal stabilization of paved roads and airfields in Northern Canada, Alaska and Asia.
- The next step will be to perform a large scale pilot application (~ 1 km) to document the cost-benefit of the technique.

THANK YOU!

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