Impact of Climate Change on Airfield Structures in Permafrost Regions

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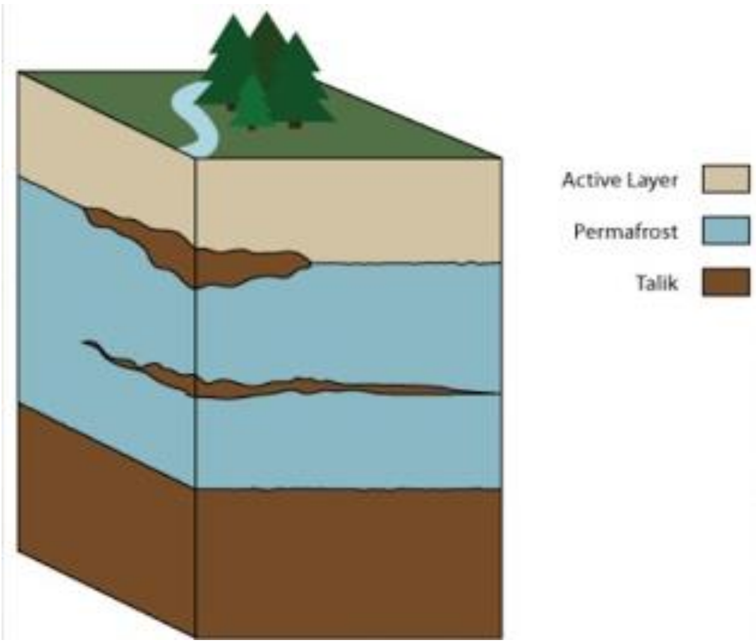
Outline

- Introduction
- Challenges of Paving in Permafrost Regions
- Climate Change Projections
- Pavement Design
- Conclusions and Recommendations

Introduction

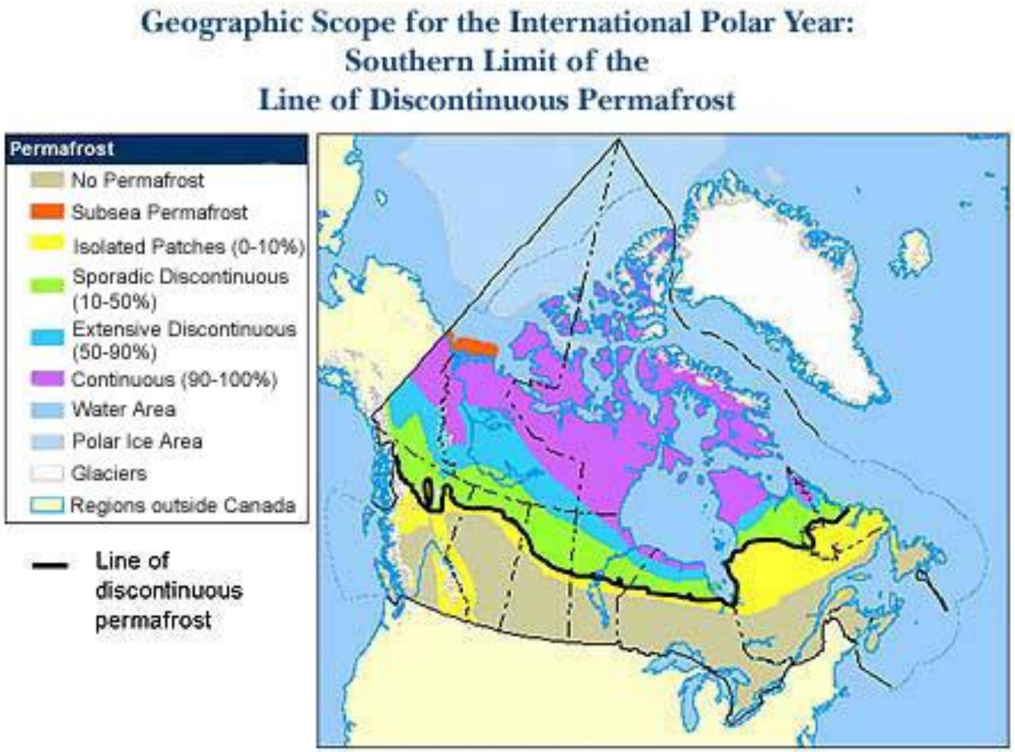
- Permafrost is defined as rock or soil which remains frozen throughout the year for multiple consecutive years
- Active layer is the area of interest for structural designers, including pavement engineers
- Active layer is subject to periods of thawing and freeze-thaw cycles which can seriously compromise bearing strength



(Polartrec, 2014)

Introduction

- Permafrost regions exist across the globe
- Half of Canadian landmass is classified as permafrost regions
- Two main categories:
  - Continuous
  - Discontinuous
- Permafrost becomes continuous nearer the poles



(Government Canada, 2014)

Challenges of Paving in Permafrost Regions

- Thawing of active layer can result in a number of problems for pavement engineers:
  - Differential settlement
  - Frost Heave
  - Shoulder rotation
  - Creep
- Conventional paving approaches exacerbate permafrost related problems

Differential Settlement

- Occurs when active layer thaws
- Melted ice fills voids with water
- Result is a loss of bearing strength which leads to consolidation off sub-grade
- Natural variations of sub-grade material and depth lead to differential settlements
- Serious sustainability challenge, especially where utilities are present

(Natural Resources Canada, 2016)

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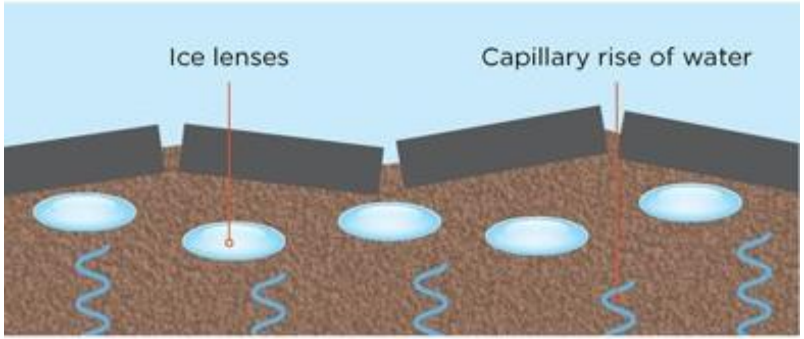
Frost Heave

- Occurs when thawed active layer begins to re-freeze
- Silts and clays within the active layer are particularly problematic due to formation of ice lenses
- A single season can have serious performance consequences on pavements due to frost heave and differential settlement



(Typar, 2017)

Shoulder Rotation

- Shoulder rotation is a phenomenon that occurs due to pavement temperature variation
- Winter snow removal deposits large snowbanks along pavement shoulders
- Snowbank acts as an insulator, preventing shoulders from cooling at the same rate as the roadway
- Pavement exerts lateral pressure on the shoulders

(Government of Yukon, 2012)

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Creep

- Two forms of creep within pavements in permafrost region
- Traditional pavement related creep is a result of secondary consolidation of sub-grade which begins after a few seasons of pavement placement
- Geological creep occurs on slopes as a result of drying/wetting periods or freezing/thawing periods

(Doré, 2016)

Climate Change Projections

- Information on climate change projections was obtained through the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)
- Near-term:
  - Defines the period from present to mid-century
  - Results of report focus specifically on years 2016 through 2035
  - Understood to be of importance to decision makers within government and industry
- Long-term defines the period towards the end of the 21st century and beyond

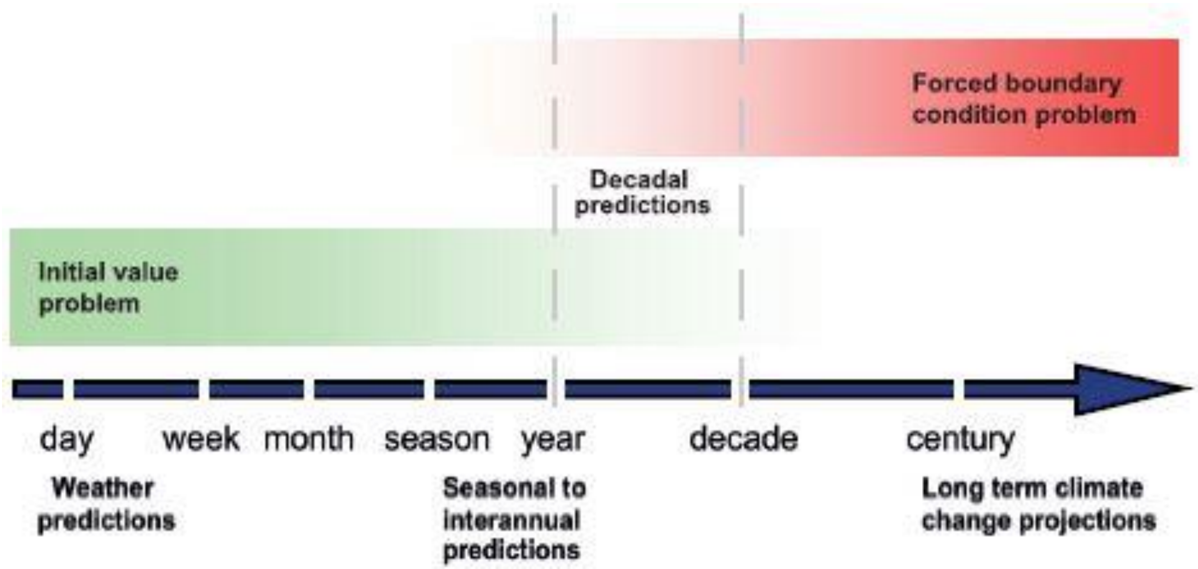
Climate Change Projections

- Internal Forces:
  - Natural variations and interactions of climate, as represented in the pre-industrialized era
  - Can be thought of as a “baseline” for natural climate variability
- External Forces:
  - Factors which disrupt the equilibrium state in which internal forces occur
  - Includes events such as volcanic eruptions, solar fluctuations, and human impacts such as atmospheric composition and land use change
- Climate system models are based on the combination of these two categories of variables
- e.g. Mean Annual Temperature:

$$T(t) = T_i(t) + T_f(t)$$

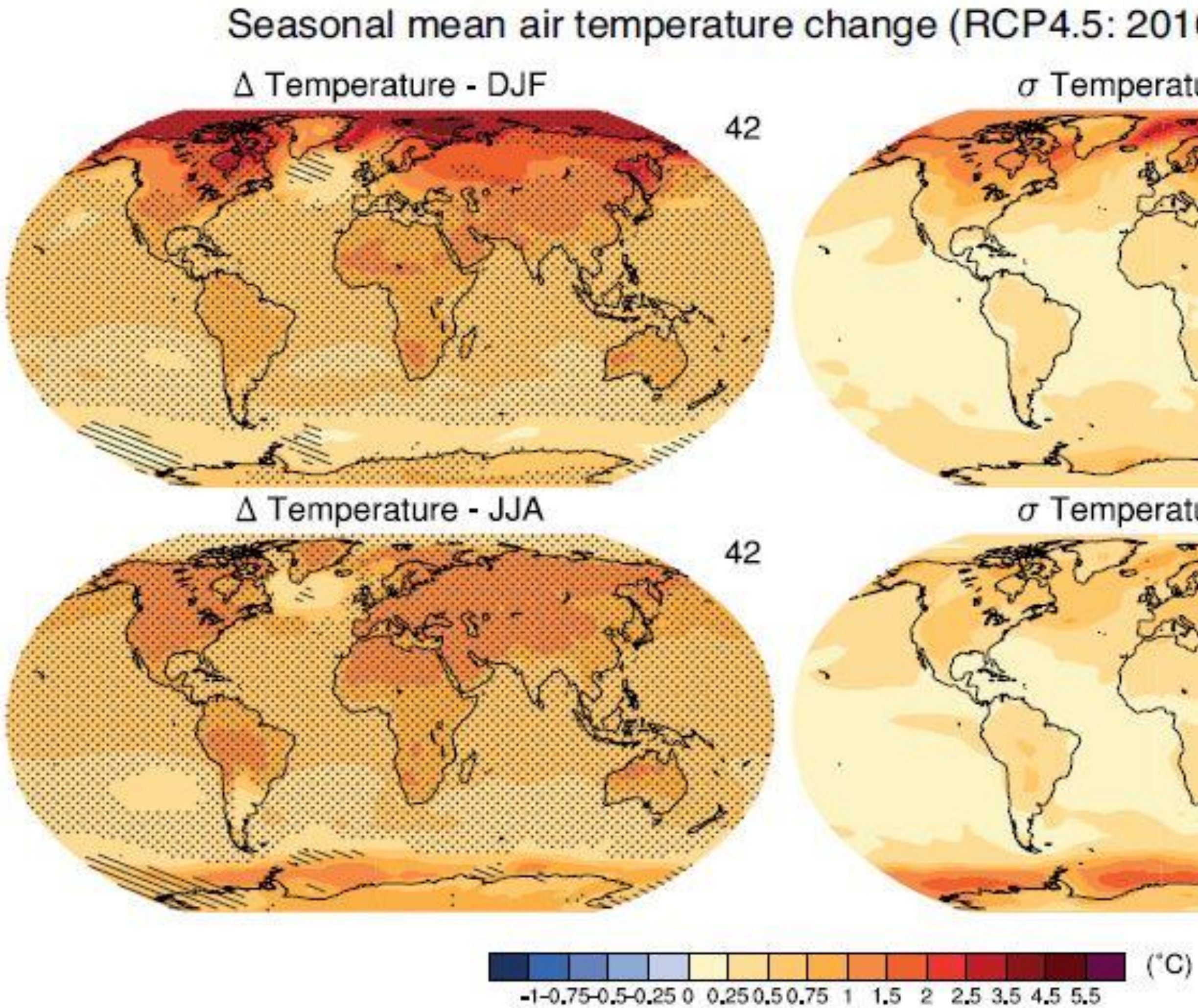
Climate Change Projections – Near-term

- Near-term projections are of most interest to our industry with respect to planning
- Decadal predictions are emerging as the temporal boundary of choice



(Based on Meehl et al., 2009b)

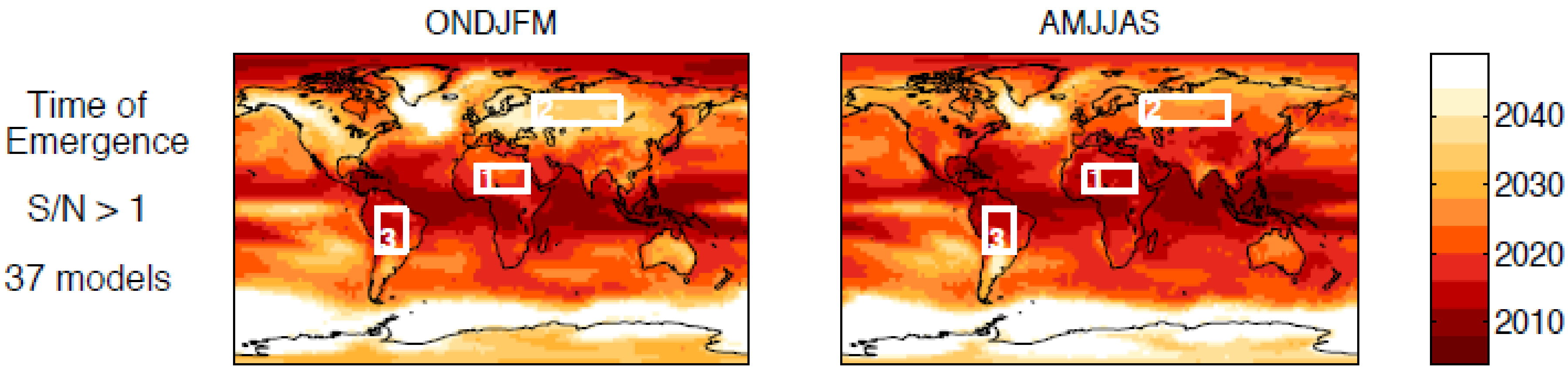
Climate Change Projections – Near-term



(IPCC Chapter 11 p. 982, 2013)

Climate Change Projections – Near-term

- Time of Emergence for half-year mean temperature anomaly relative to the period from 1986-2005
- Values included meet the minimum threshold of signal to noise ratio >1



(Based on Hawkins and Sutton, 2012)

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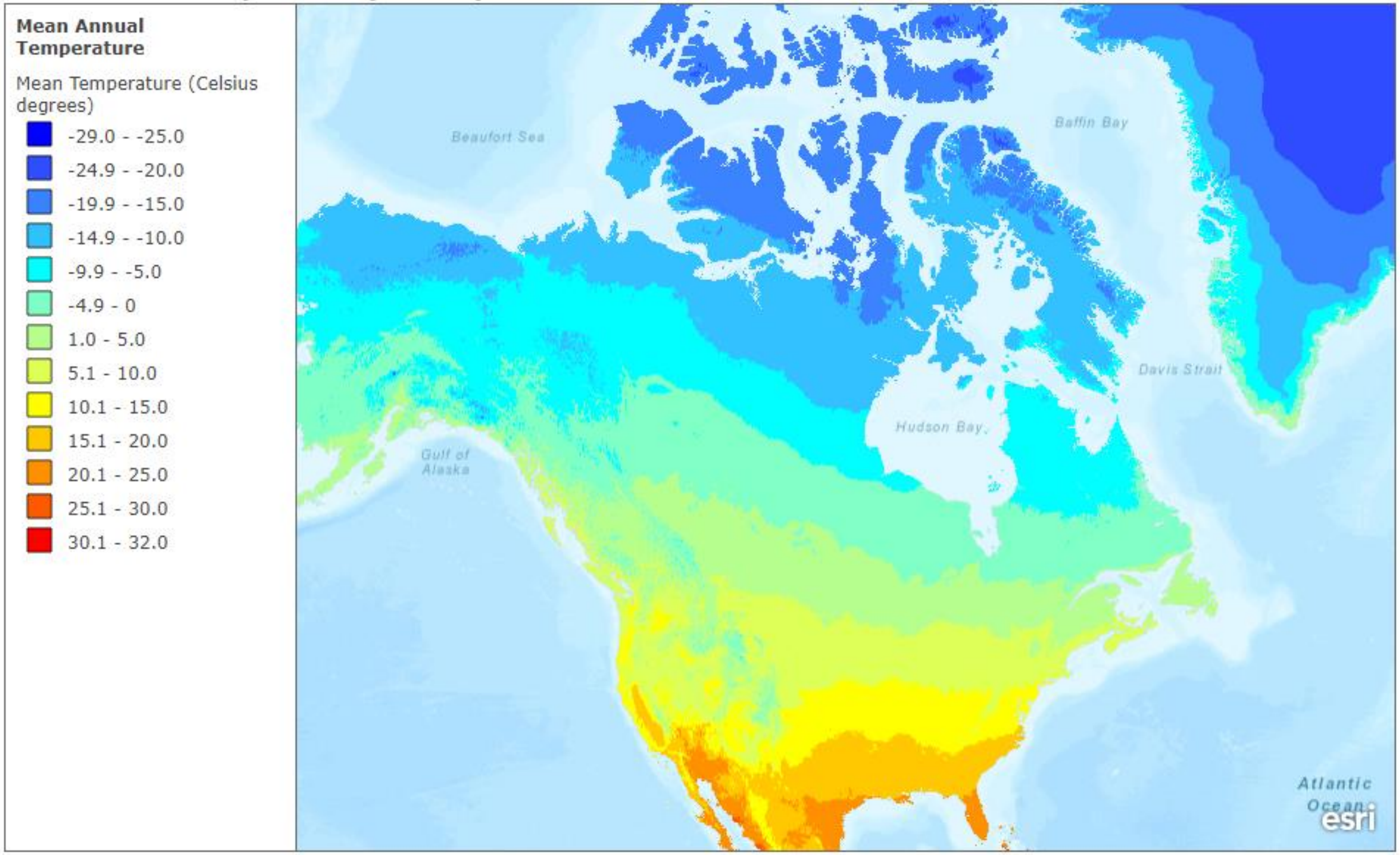
Climate Change Projections – Near-term



(ArcGIS and WorldClim – Climate Data, 2017)

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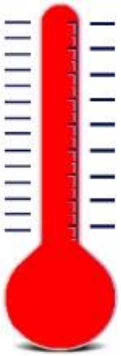
Climate Change Projections – Near-term

- Snowfall in the high Northern latitudes has conflicting forecasts, both of which could be probable outcomes
- Some models indicate a reduction in snowfall accumulation of over 30% by the year 2050
- Other models propose an increase in snowfall accumulation as a result of significant sea ice loss in the Arctic ocean, resulting in increased moisture source
- Competition between the factors of increased temperature and moisture source will govern whether snowfall trends will experience an increase or decrease

Pavement Design

- To achieve sustainability, pavement design in permafrost regions must overcome these challenges for an extended period of time
- Traditional pavement design increases the impact by warming the underlying permafrost during warm periods and slowing the rate of cooling during cool periods
- Two main approaches can be taken to mitigate the negative effects of paving in permafrost regions:
  - Reducing heat gain of the pavement structure
  - Removing heat from the pavement structure



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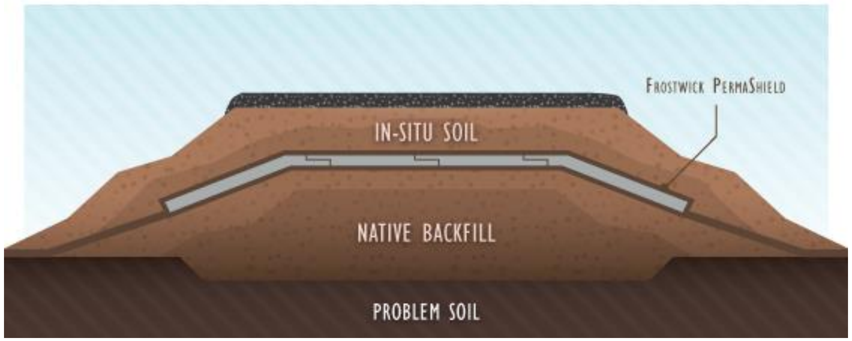
Reducing Heat Gain - Insulation

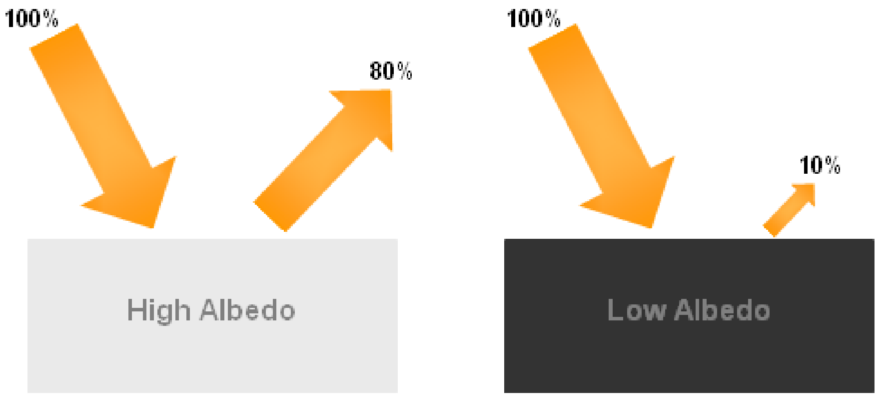
- Expanded polystyrenes have seen use in various applications throughout the world with high success rate
- Insulations can be used nearer the surface in permafrost regions to reduce heat transfer to the sub-grade
- Can only be used in areas that have a Mean Annual Surface Temperature below 0°C
  - Insulation also hampers heat transfer out of the sub-grade during the winter



(Frostwick, 2012)

Reducing Heat Gain – Raising Albedo

- Traditional pavements are dark in colour and absorb a significant amount of solar energy
- Modifying the pavement colour is an effective means of reducing surface temperature and has been used with success in Dawson, Yukon
- Issues with using light pavements centre on high cost and user safety concerns



(North Carolina State University, 2013)

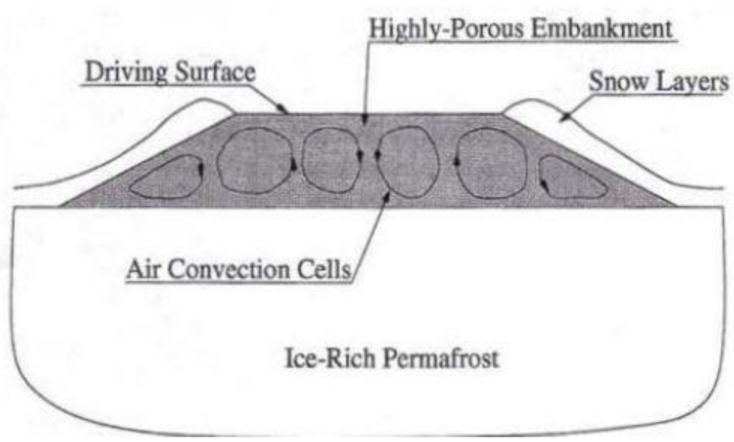
Reducing Heat Gain – Snow/Sun Shields

- Snow/sun shields are low roofed structures placed on embankment slope
- In winter months, snow is held off of the embankment and allows for convective cooling of the pavement structure
- In summer months, solar radiation is absorbed by the shield structure and convection dissipates the heat
- Maintenance costs and user safety are of concern

(Feng et al., 2006)

Removing Heat – Air Convection Embankments

- Air convection embankments are an innovation in traditional embankment construction
- Use of low fines, poorly graded granular promotes a continuous network of air voids
- Air voids allow for convective cooling to lower temperature within the pavement structure
- Higher cost of implementation



(Goering, 1998)

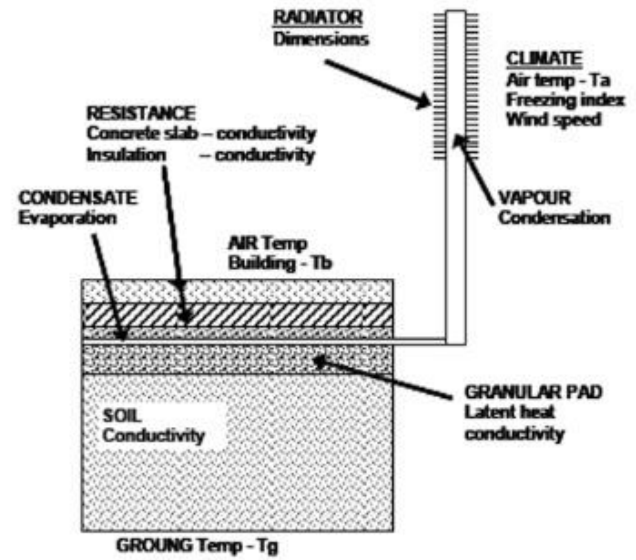
Removing Heat – Air Ducting

- Air ducting uses pipes or tubing within the pavement structure to promote convective cooling
- Can be oriented longitudinally or in the transverse direction
- During warm periods, a thermal break must be placed at the openings to prevent deleterious convection
- Maintenance requirements can be intensive

(Cheng, Sun, and Niu, 2008)

Removing Heat - Thermosyphons

- Thermosyphons utilize latent energy release to transfer heat from the pavement structure to the atmosphere
- Refrigerants such as ammonia and propane exist in liquid phase within the metal piping system
- As they warm, some liquid is volatilized and rises to the radiator above grade, where it condenses and the process repeats
- High cost of implementation, user safety concerns, and environmental concerns



(Government of Northwest Territories, 2012)

Other Design Approaches

- Geosynthetic reinforcement
- Pre-thawing
- Gravel surfacing

(Geosynthetica, 2017)

(Carmacks, 2017)

Conclusions and Recommendations

- Near-term climate projections predict significant increase in challenges associated with structures in permafrost regions within the next 30 years
- Permafrost formations will likely recede towards the pole as mean temperatures rise
  - Northern regions of the provinces could experience increased permafrost discontinuity
  - Southern regions of the territories could experience introduction of permafrost discontinuity
  - Significant temperature increase is likely within the years 2020-2040
- Regional solutions to paving on permafrost may no longer be as effective as traditionally experienced
- Implementation of strategies should be made with consideration of near-term projections

Conclusions and Recommendations

- Two main strategies exist for reducing effects of permafrost related pavement challenges
  - Reduction of heat gain within the permafrost and active layers
  - Removal of heat from the permafrost and active layers
- Each approach has its own benefits and capabilities
- In practice, a combination of reduced heat gain and improved heat removal will likely optimize the pros and cons of various solutions
- Further research is required to study effect of combined approaches

Thank you

Questions?

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