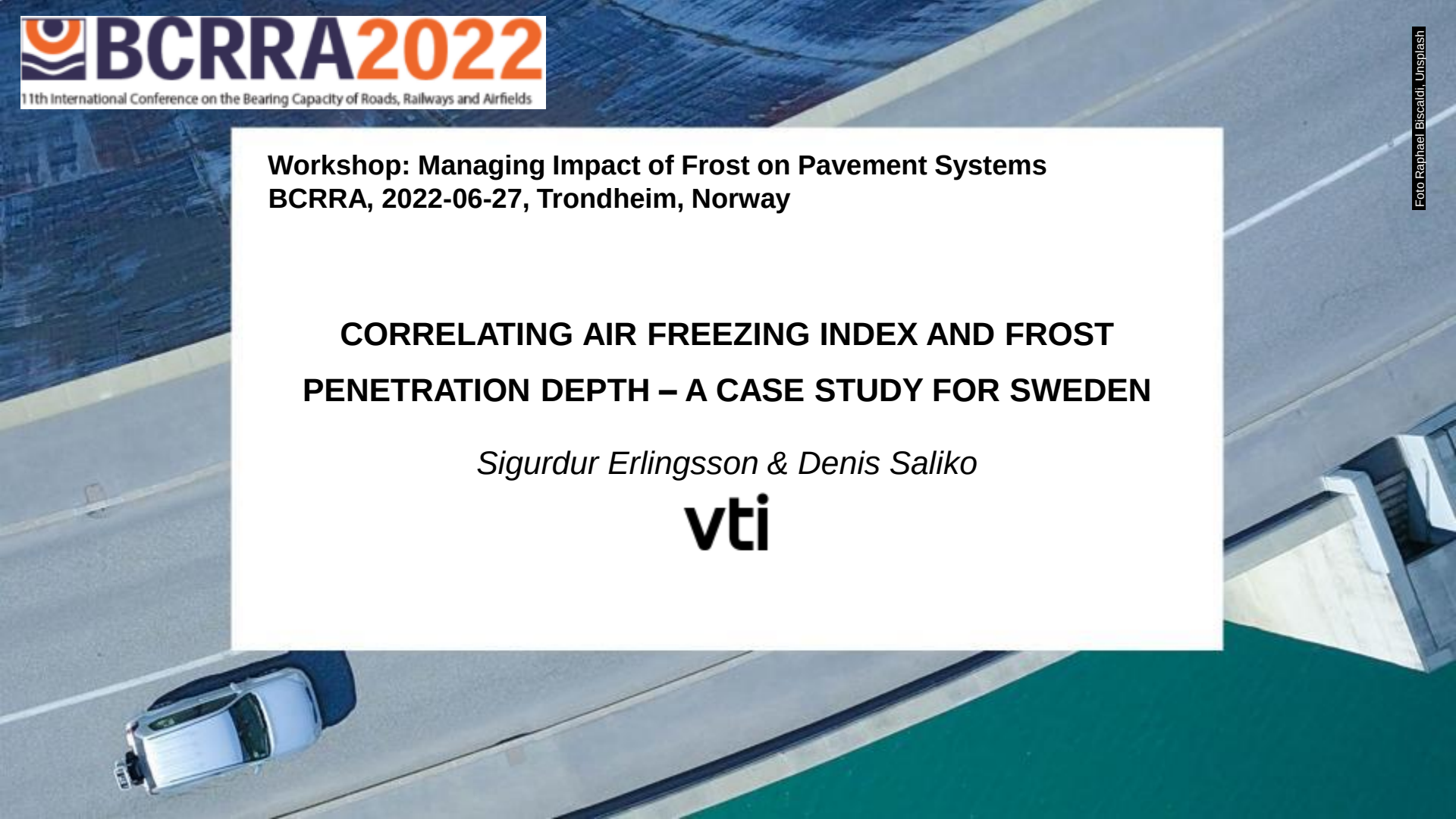


**Workshop: Managing Impact of Frost on Pavement Systems**
**BCRRA, 2022-06-27, Trondheim, Norway**

# CORRELATING AIR FREEZING INDEX AND FROST PENETRATION DEPTH – A CASE STUDY FOR SWEDEN

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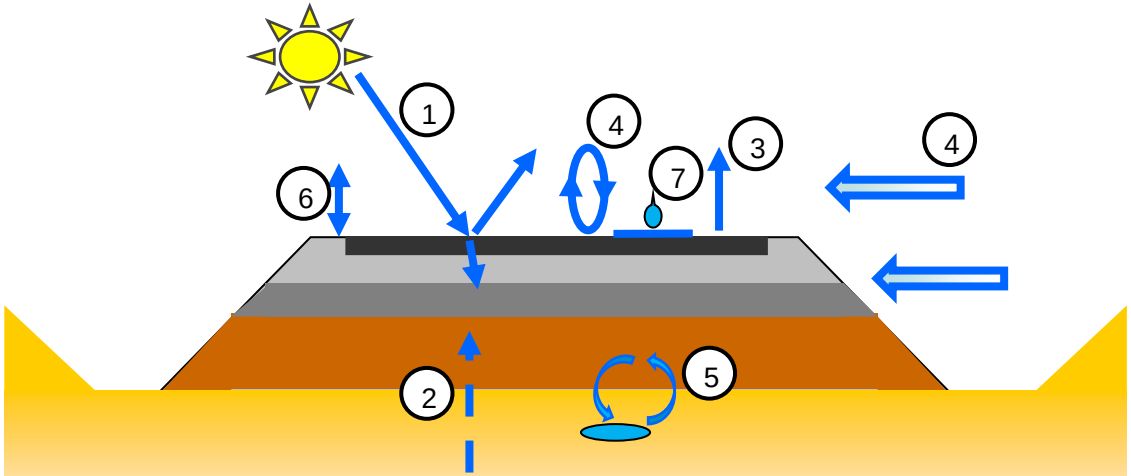
# THE EFFECT OF CLIMATIC FACTORS ON PAVEMENTS

- The properties of pavement materials are influenced by:
- Temperature (incl. **frost**)
- Moisture




# Temperature regime in pavements




Heat intake

1 Solar radiation

2 Geothermal heat

Heat extraction

3 Emitted radiation

4 Convection and turbulence

Heat intake or extraction

5 Latent heat of fusion

6 Evaporation/condensation

7 Heat exchange with precipitation

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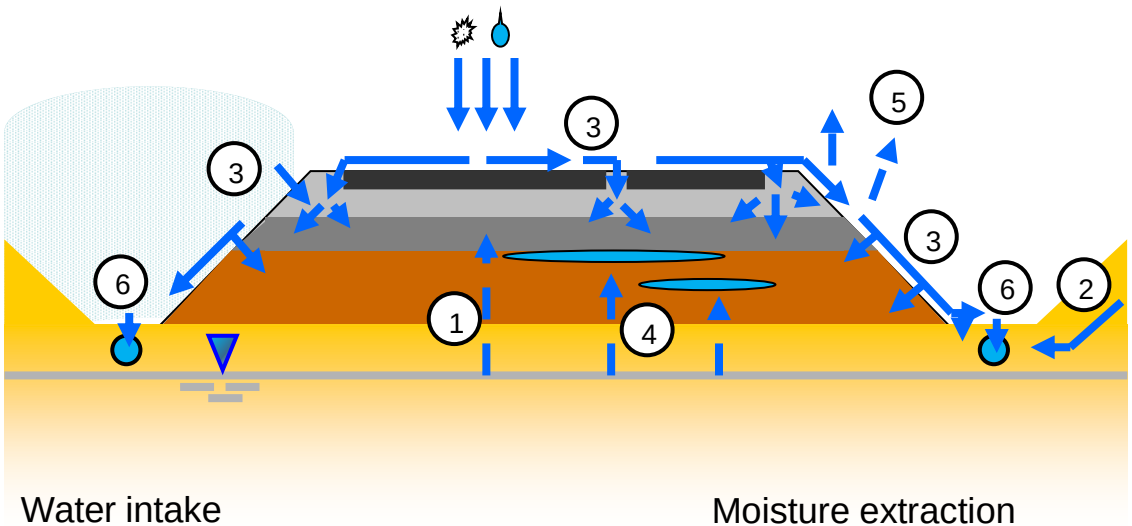
# Moisture regime in pavements




Water intake

1. Capillary rise
2. Lateral transfer of moisture
3. Infiltration from precipitation
4. Frost action - capillarity

Moisture extraction

5. Evaporation
6. Drainage

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# OBJECTIVE

To provide a simple way to estimate the maximum frost depth in pavements.

# The Monitoring Stations in Sweden

Data provided by:

**SMHI** - Swedish Meteorological and Hydrological Institute

**Trafikverket** - Swedish Transport Administration

- **SMHI:** Air temperature registrations
  - 30 minute intervals
  - 44 weather stations

- **Trafikverket:** Frost penetration depth
  - 1 hour intervals
  - 49 locations



10 year timespan 2007-2017

6 km average distance between weather and frost stations

Results classified based on climatic zones

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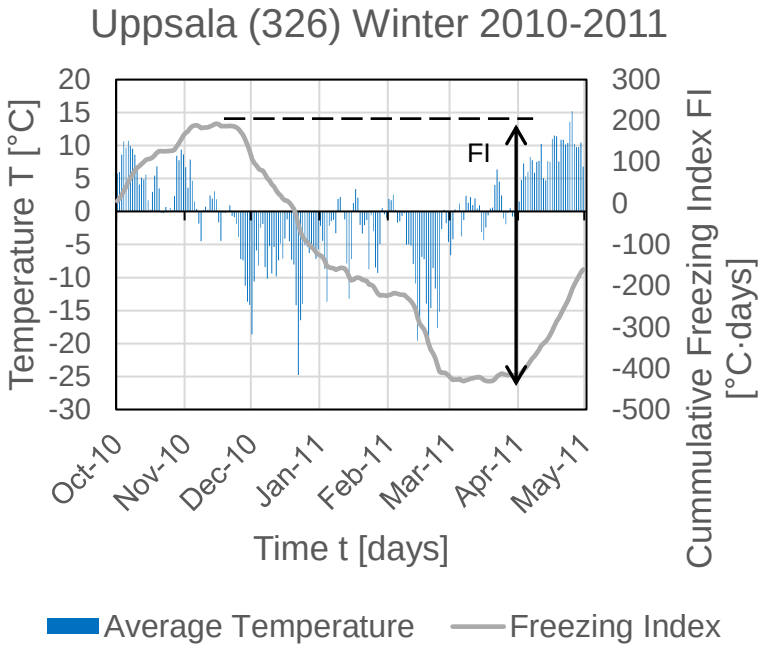
# Meteorological Data – SMHI




- SMHI: Air temperature registrations
  - Required input for evaluating the climatic effects
  - Computation of FI Freezing Index

- MDAT summed to obtain the FI variation
  - Mathematical method

$$FI = \int_0^t -T dt = \sum_0^t -MDAT$$

  - Graphical method

- Variation of FI by climatic zones

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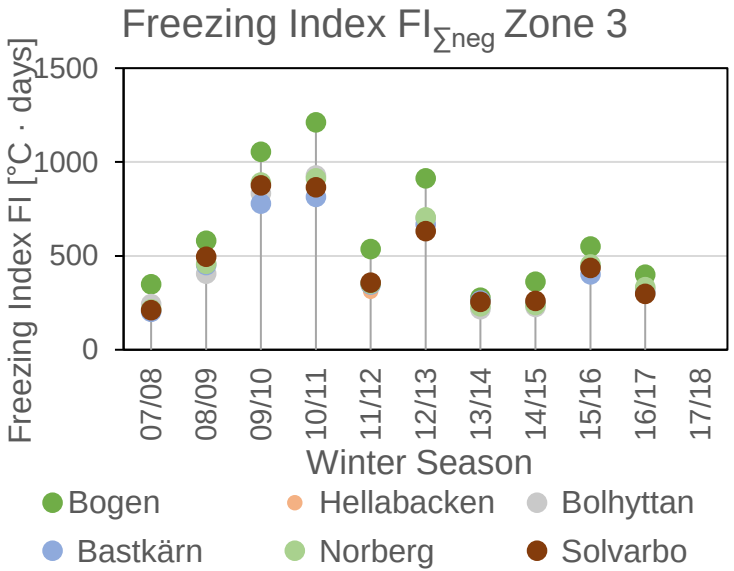
# Air Freezing Index by Climate Zone




| | Freezing Index [°C·days] | | |
|---|---|---|---|
| Zone | Avg. | Min. | Max. |
| 1 | 208.7 | 35.8 | 633.9 |
| 2 | 309.6 | 65.1 | 783.1 |
| 3 | 488.5 | 210.8 | 1211.8 |
| 4 | 732.0 | 266.5 | 1395.8 |
| 5 | 1190.7 | 528.7 | 2246.6 |

- Increasing freezing index (FI) values in the northern climatic zones

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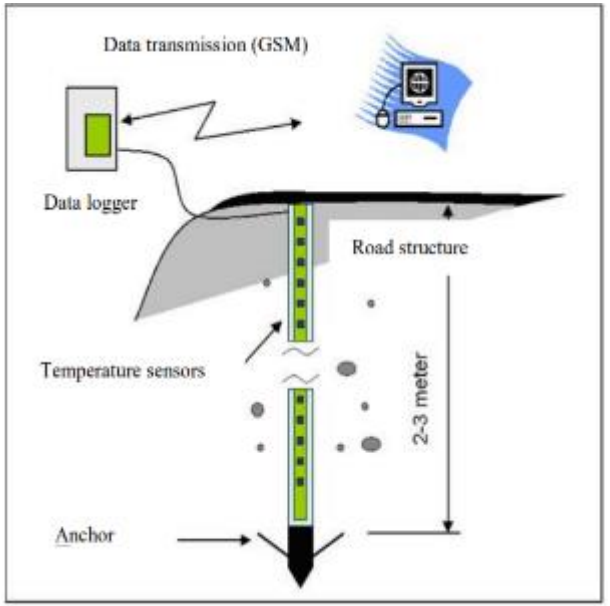
# Frost Penetration Depth Instrumentation

- Data collected by frost rods

- Tjälstav 2004 developed at VTI
  - 41 temperature sensors
  - 5 cm spacing
  - Max. length – 200 cm
  - Log every 30 minutes

- Frost penetration obtained by interpolating to obtain the 0°C isotherm

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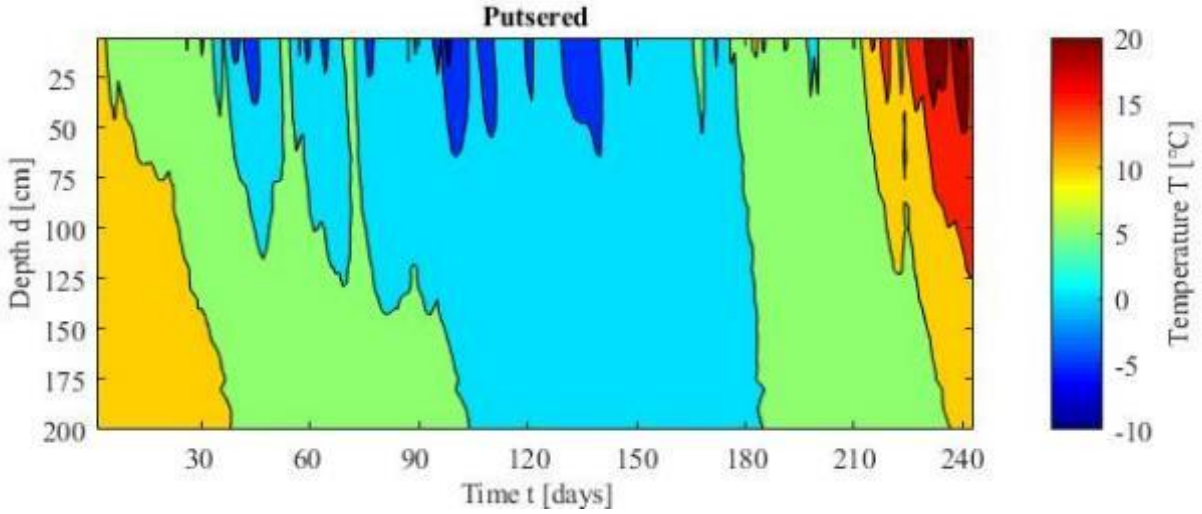
# Frost Penetration Depth – Climate Zone 1




- Multiple intermittent freezing periods observed
- Frost penetration depth approximately 70 cm

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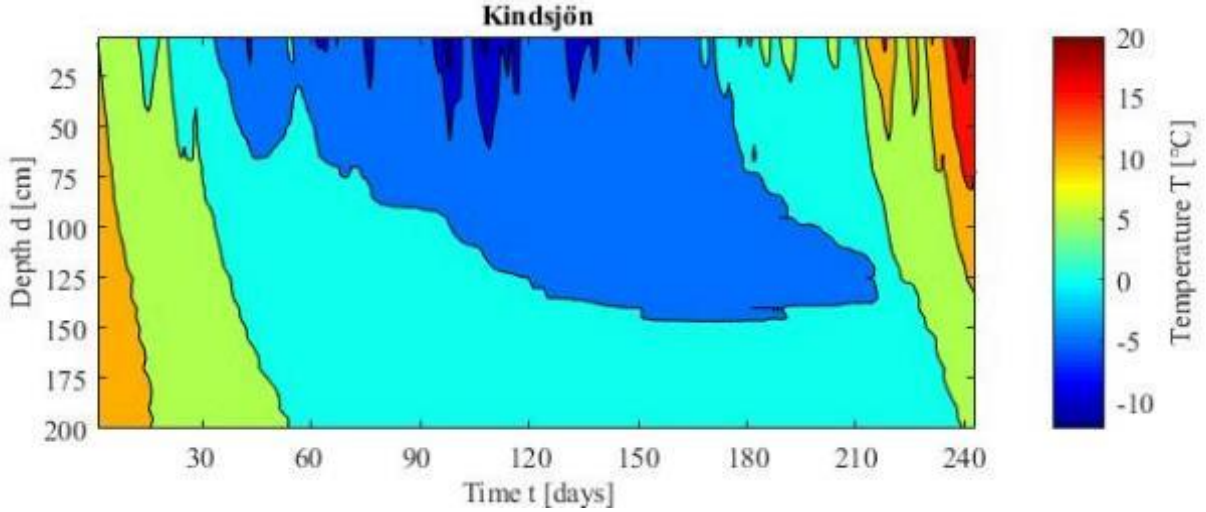
# Frost Penetration Depth – Climate Zone 4




- One single continuous freezing front observed
- Frost penetration depth approximately 150 cm

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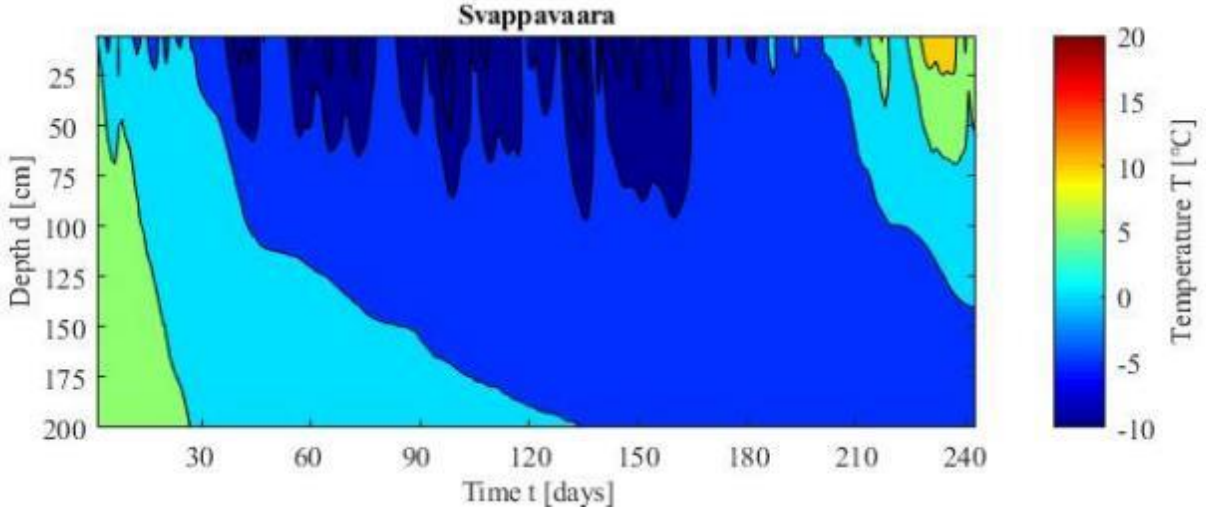
# Frost Penetration Depth – Climate Zone 5




- Depth of the frost rod exceeded – unable to measure the frost penetration
- Unable to measure the time of thawing

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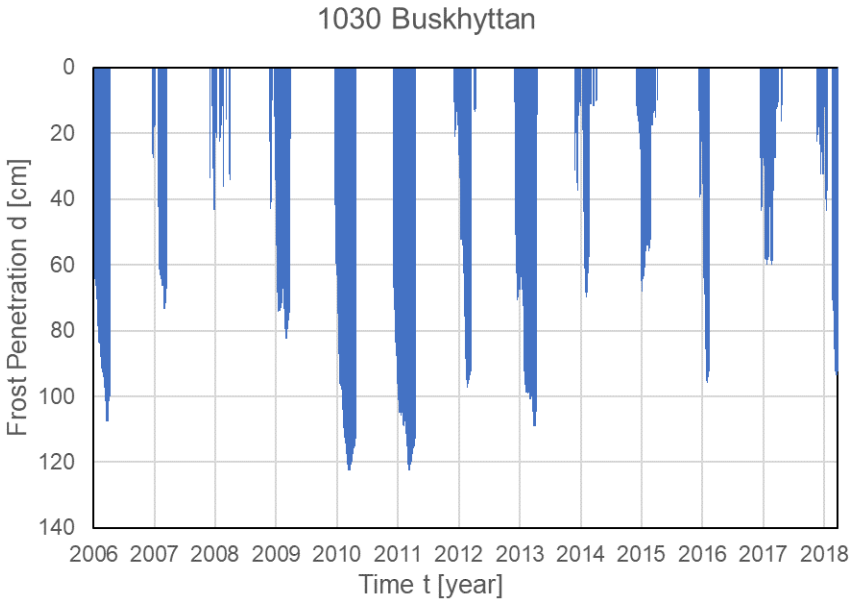
# Frost Penetration Depths

- Obtained by interpolating for the 0°C isotherm
- Maximum value recorded for each location for the last 10 seasons
- Limitation: 2 meters length of frost rod – unable to capture frost penetration in multiple stations in northern Sweden

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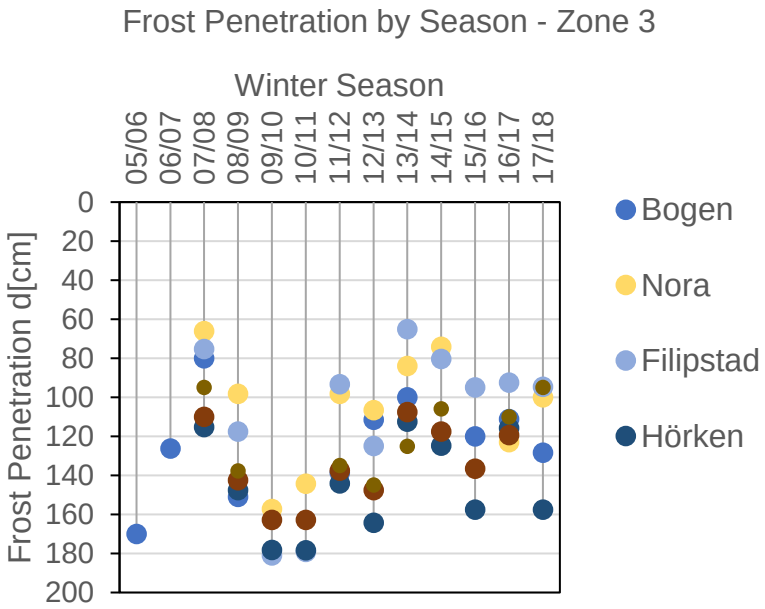
# Frost Penetration Depth by Climatic Zone




| Zone | Frost Penetration [cm] | | |
|---|---|---|---|
| | Avg. | Min. | Max. |
| 1 | 85.4 | 31.2 | 162.8 |
| 2 | 107.1 | 35 | 168.3 |
| 3 | 122.8 | 50.7 | 181.0 |
| 4 | 148.9 | 65.2 | 196.7 |
| 5 | - | - | - |

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# Freezing Index – Frost Penetration Chart

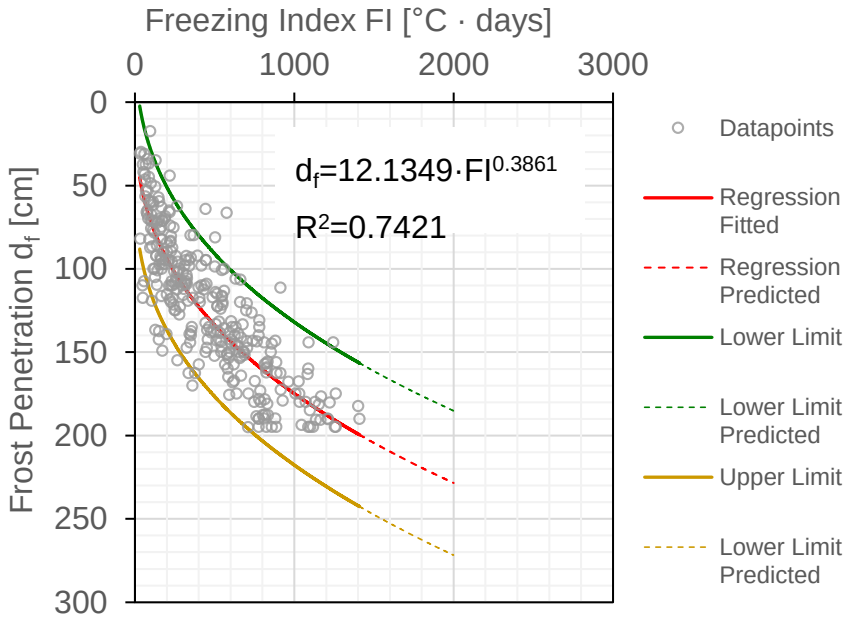
- Power regression based on 391 data points

$$d_f = 12.1349 \cdot FI^{0.3861}$$

$$R^2 = 0.7421$$

- 95% prediction line – 95% of the points fall within the boundaries
  - Scattering indicator

Can be used to estimate the depth of the frost penetration $d_f$ on a new location from the freezing index *FI*.

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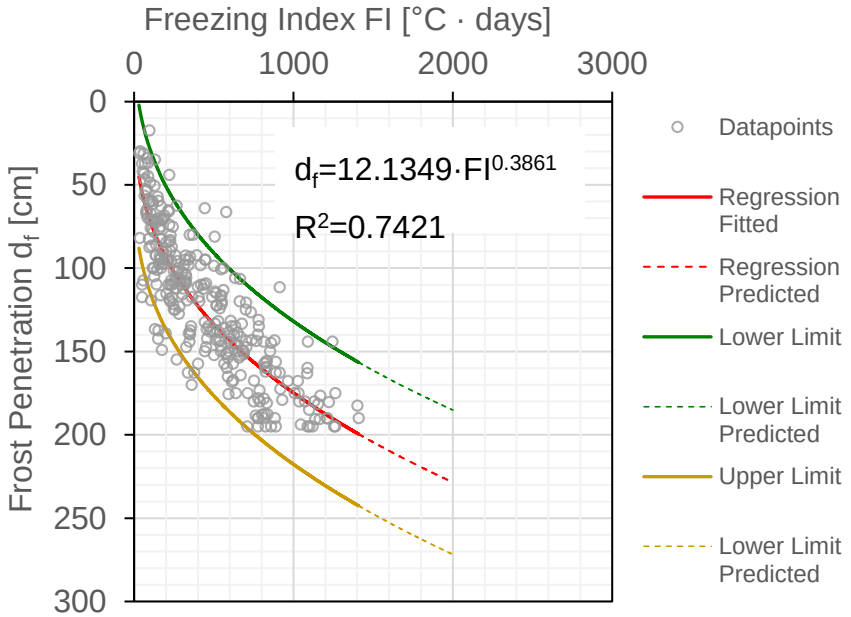
# Discussion Points

- Which factors determine the location of points in the chart?
  - Thermal conductivity of layers
  - Access to water
  - Frost susceptibility of the materials
  - Snow covering




Is the degree of simplification acceptable to be used in pavement design?

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# Thanks

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