Québec 2010
AIPCR · PIARC

XIII INTERNATIONAL WINTER ROAD CONGRESS

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SUSTAINABLE WINTER SERVICE FOR ROAD USERS

Real-time frost depth forecast model for thaw-induced axle load limitation management

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WORLD ROAD ASSOCIATION MONDIALE DE LA ROUTE
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VEGAGERÐIN

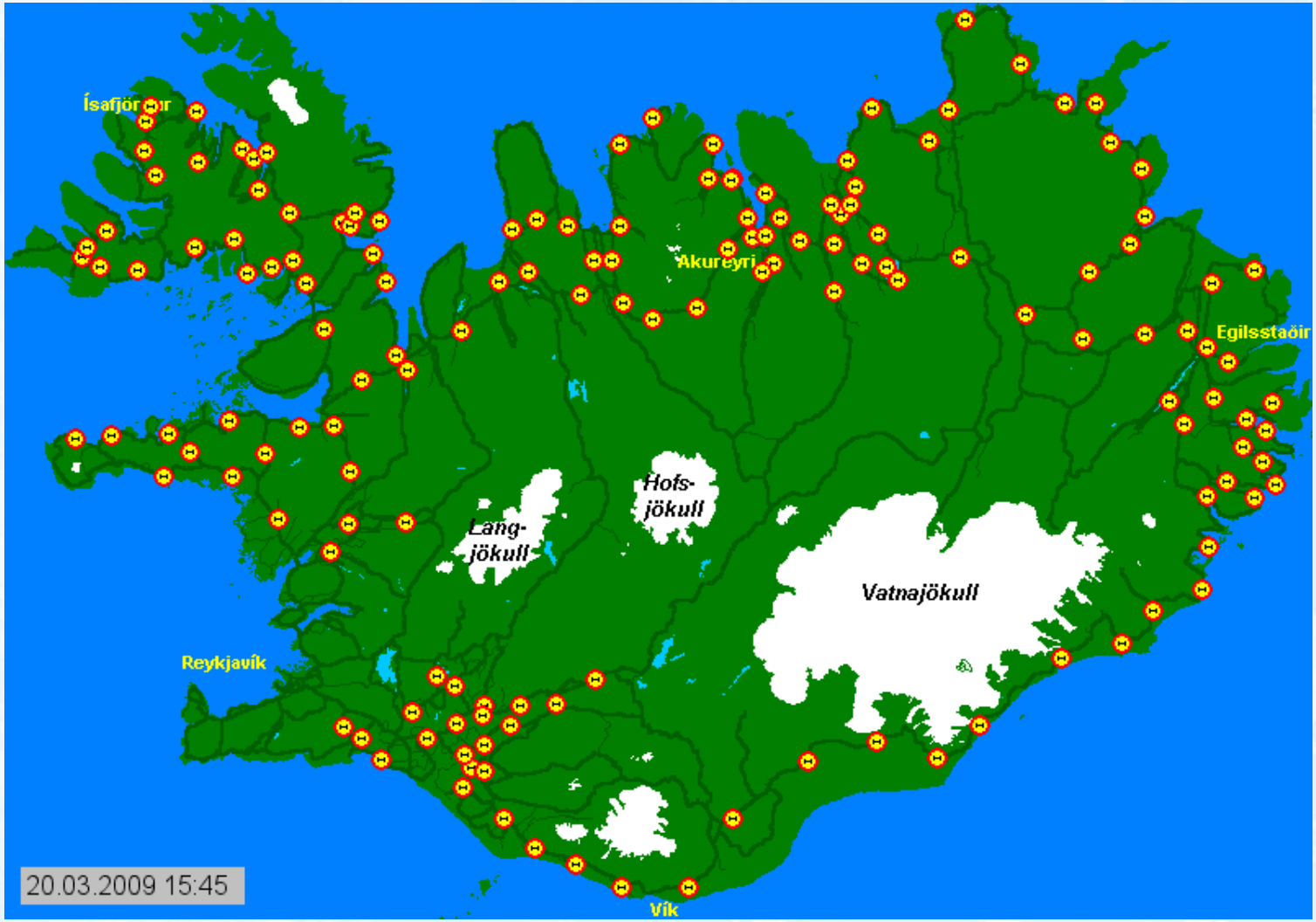
PRESENTATION OUTLINE

- The problem – thaw weakening on Icelandic roads
- Countermeasures
- Frost-depth monitoring system
- Frost-depth prognosis model
  - model description
  - model results
- Model application to study future climate effects

THAW WEAKENING ON THE ICELANDIC ROAD NETWORK

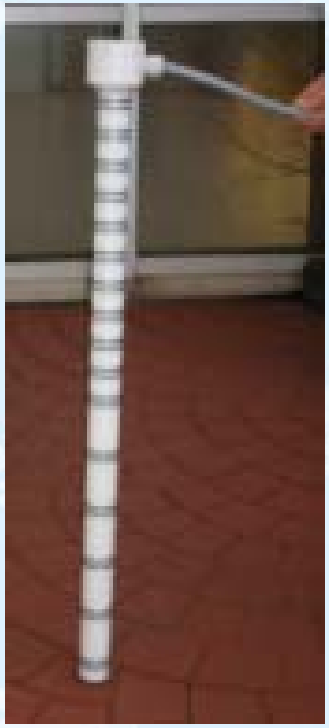
- Reduced bearing capacity during thaw
  - Road sub-base and pavement damage
- Axle load restrictions
  - Normal allowed maximum axle load 11,5 t
  - Restricted to 10 t during thaw
- Increased cost for heavy goods transport
- Since late 1990's, frequent thaw cycles in December through May, up to 4 times each winter
- Most of the trunk roads and secondary roads affected

ROAD SYSTEM DURING THAW PERIOD



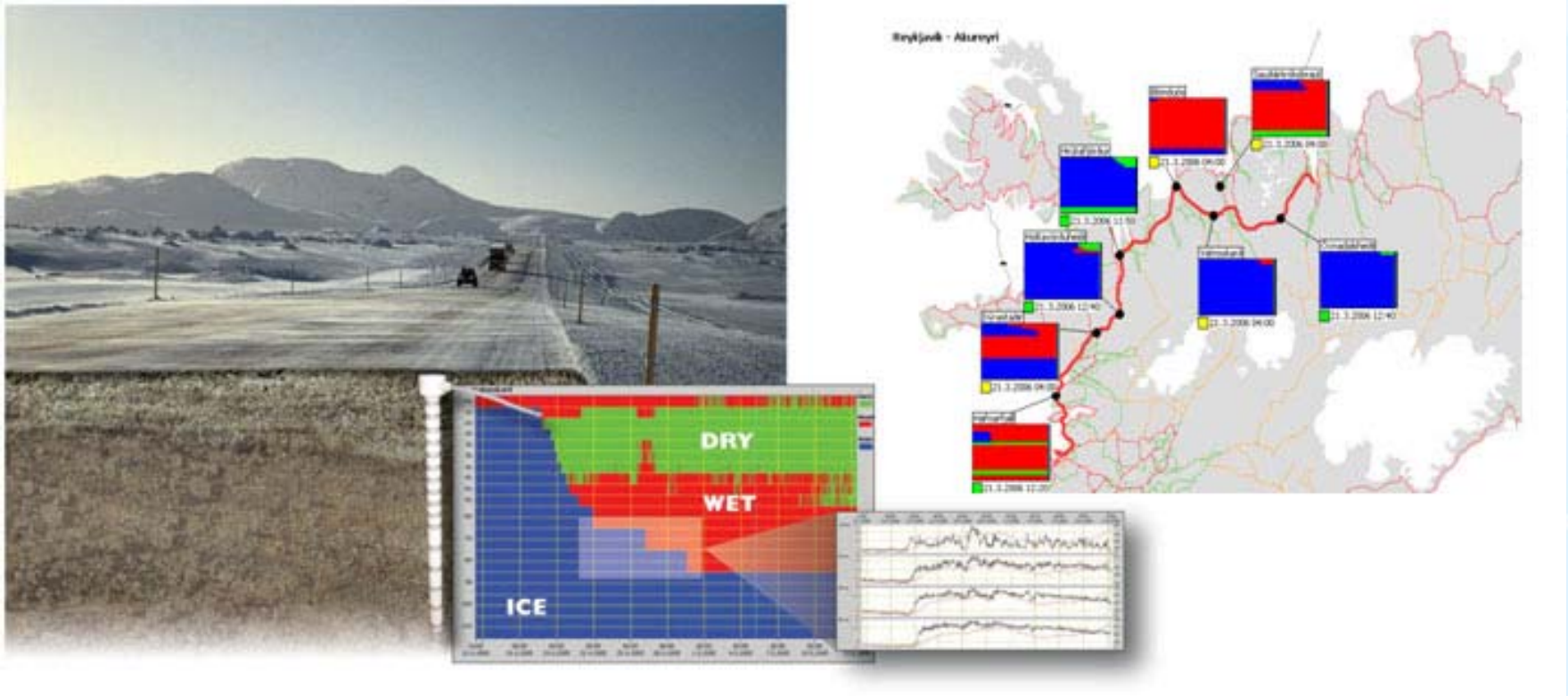
REAL TIME FROST-DEPTH MONITORING

- Measuring device installed in the road sub-base
- Temperature and electric conductivity of the soil
- 16 sensors in the range from surface down to 120 cm
  - 0 – 60 cm at 5 cm intervals
  - 60 – 120 cm at 10 cm intervals
- Real time, online monitoring



FROST-DEPTH MEASURING SYSTEM

- Real time, online monitoring of frost depth, 40 sites
- Enables announcement of load restrictions the same day
- Correct timing is essential – prognosis needed !



FROST-DEPTH FORECAST MODEL

- Thermodynamic principles
- Uses weather forecast + frost-depth measurement reading
- Calculation with 1 hour time step
- Two physical models are coupled:

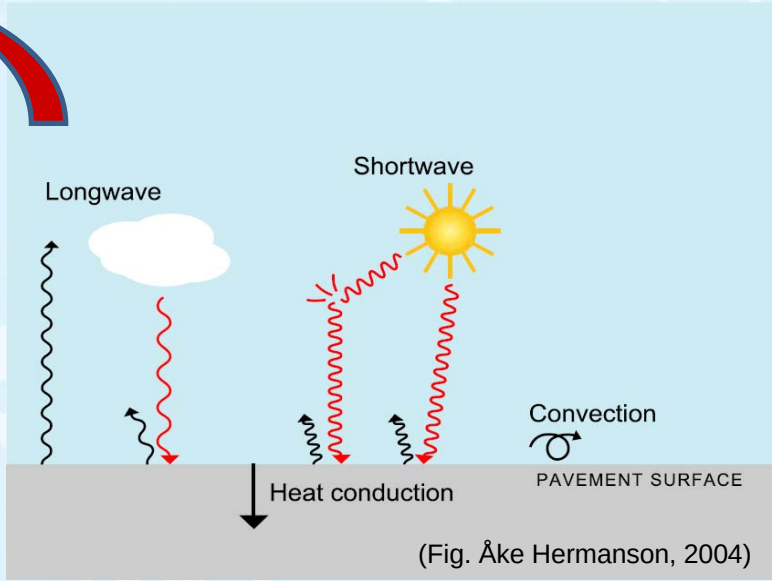
1) Road surface temperature prognosis

2) Ice development in the sub-base

Model 1:
Road Temperature Prognosis

- Input:
  - Weather forecast
  - Road temperature measurement

$$\Delta e = S \cdot C \cdot m \cdot \Delta T$$

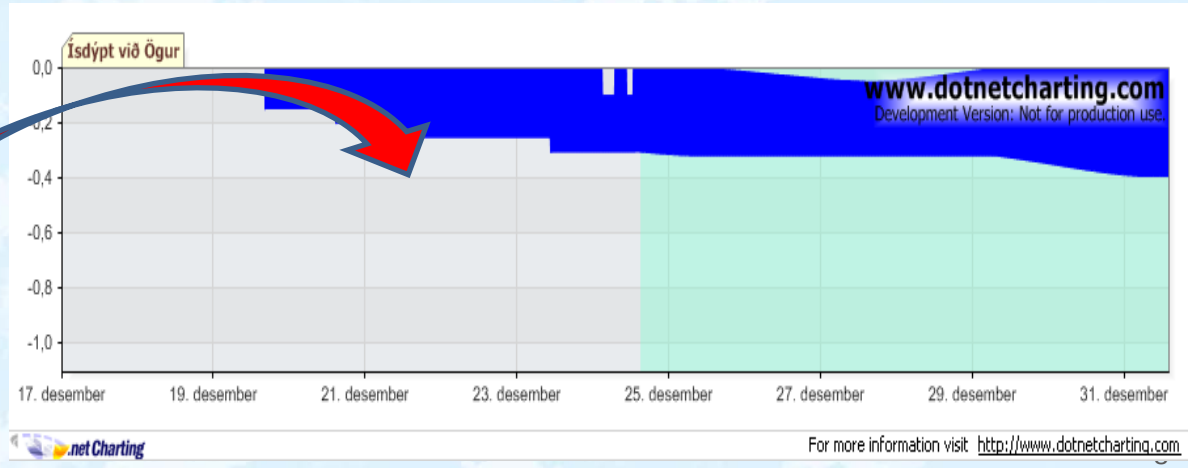


(Fig. Åke Hermanson, 2004)

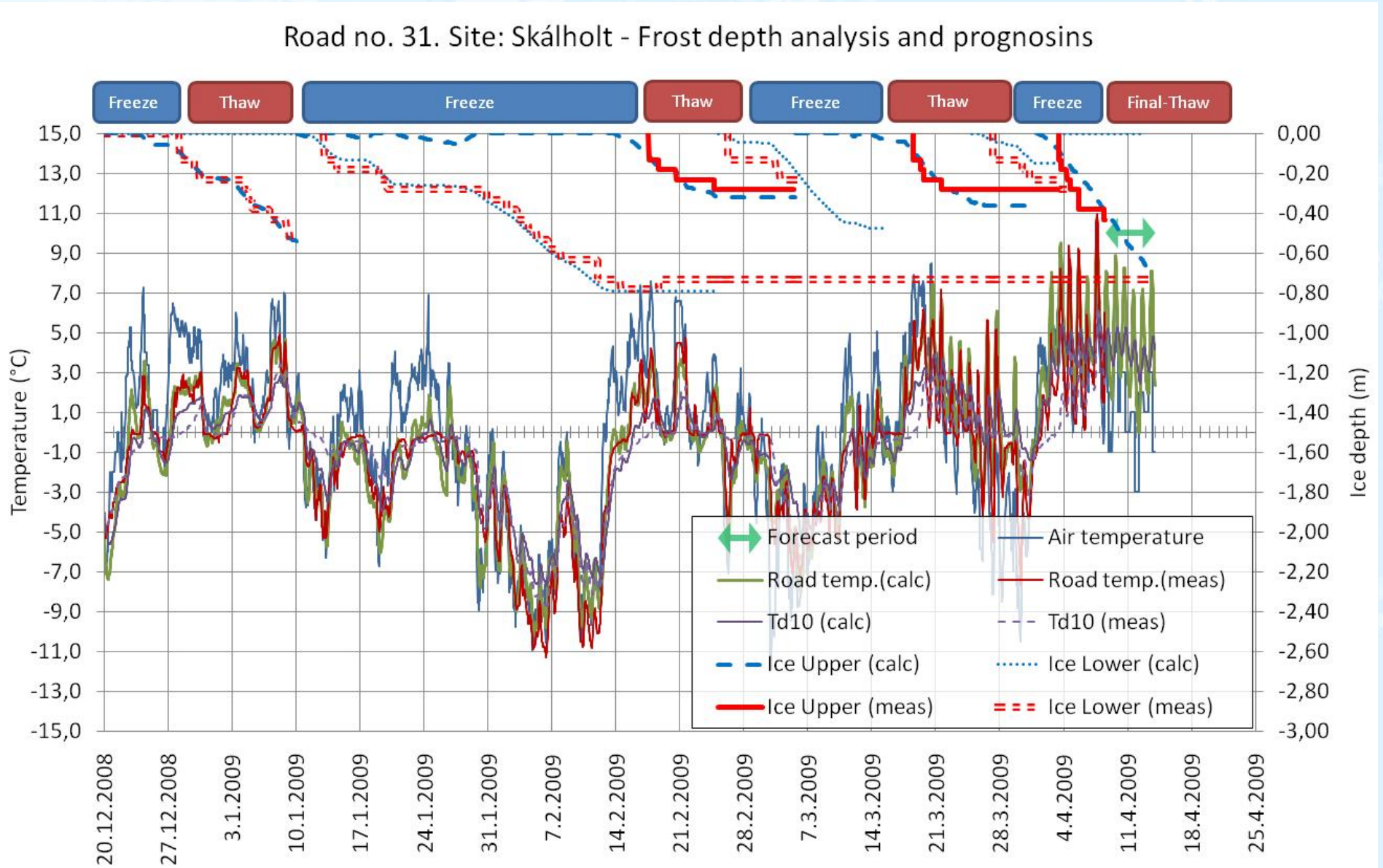
Model 2:
Ice development in road structure

- Input :
  - Frost-depth measurement
  - Road surface temperature prognosis

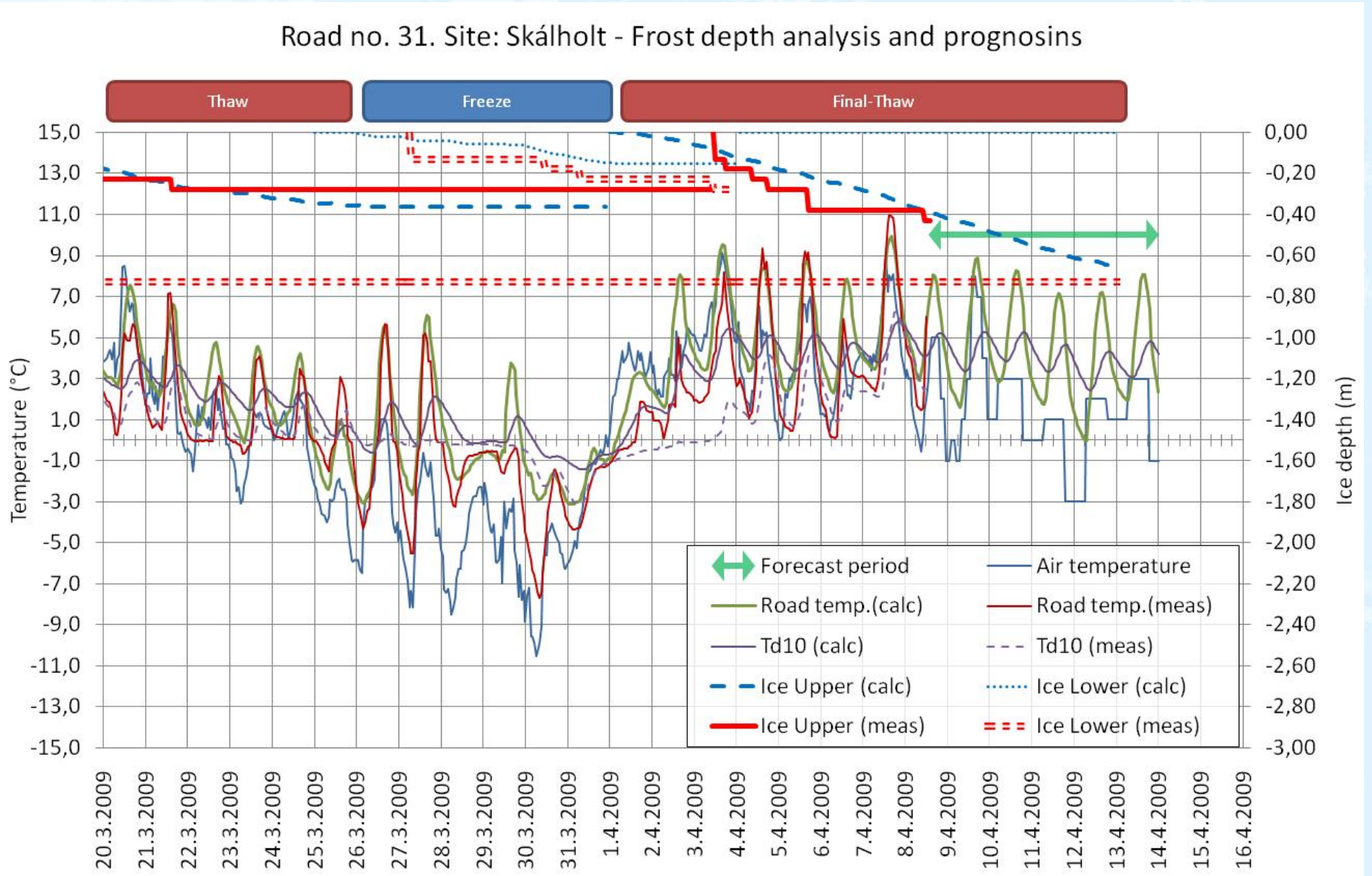
$$X = \sqrt{\frac{2k}{L}\int v_s \, dt}$$

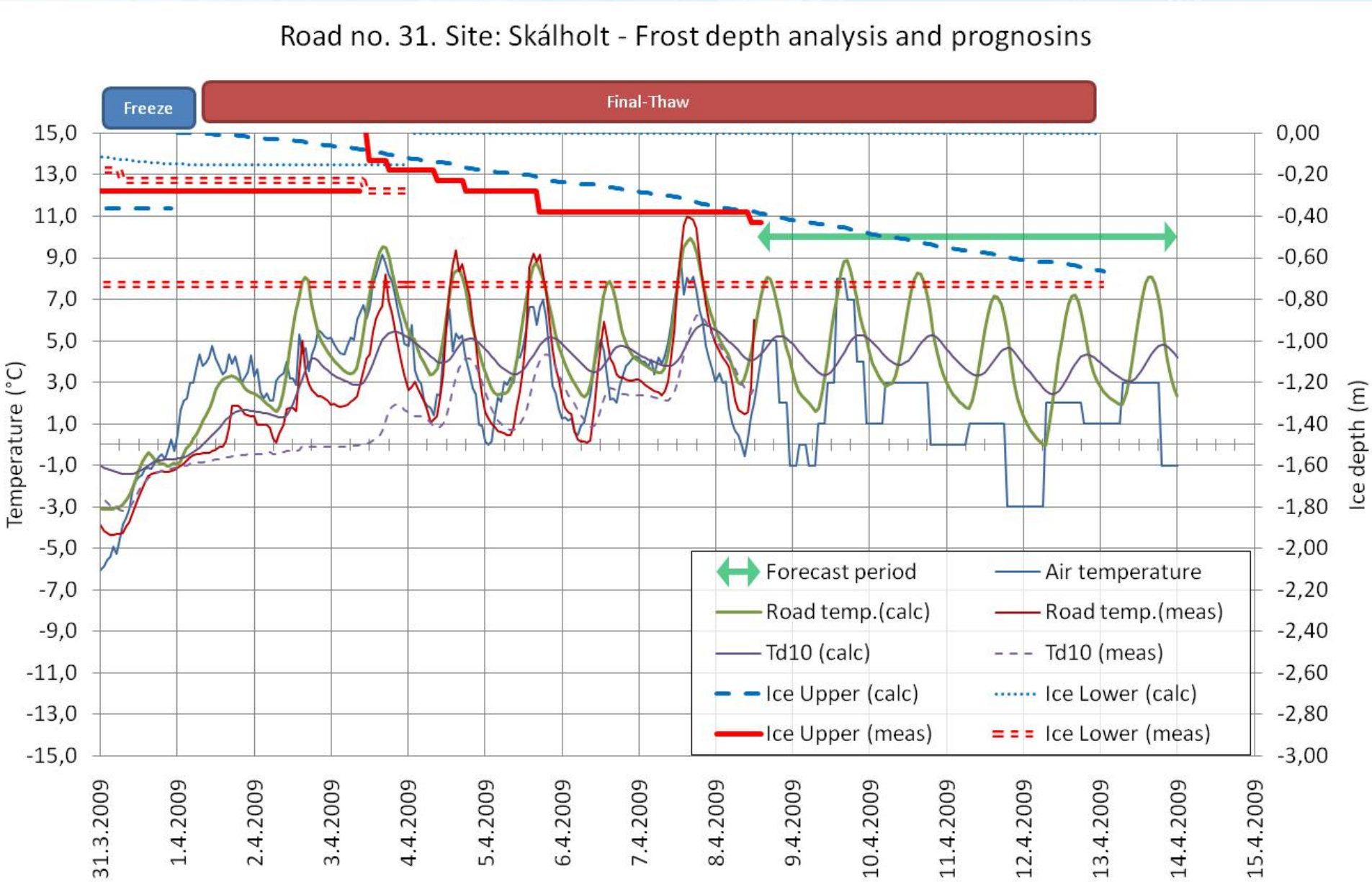


MODEL RESULTS



CLOSER LOOK


Road no. 31. Site: Skálholt - Frost depth analysis and prognosins
Thaw
Freeze
Final-Thaw
Temperature (°C)
Ice depth (m)
15,0
13,0
11,0
9,0
7,0
5,0
3,0
1,0
-1,0
-3,0
-5,0
-7,0
-9,0
-11,0
-13,0
-15,0
0,00
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
-1,40
-1,60
-1,80
-2,00
-2,20
-2,40
-2,60
-2,80
-3,00
Forecast period
Air temperature
Road temp.(calc)
Road temp.(meas)
Td10 (calc)
Td10 (meas)
Ice Upper (calc)
Ice Lower (calc)
Ice Upper (meas)
Ice Lower (meas)
20.3.2009
21.3.2009
22.3.2009
23.3.2009
24.3.2009
25.3.2009
26.3.2009
27.3.2009
28.3.2009
29.3.2009
30.3.2009
31.3.2009
1.4.2009
2.4.2009
3.4.2009
4.4.2009
5.4.2009
6.4.2009
7.4.2009
8.4.2009
9.4.2009
10.4.2009
11.4.2009
12.4.2009
13.4.2009
14.4.2009
15.4.2009
16.4.2009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Freeze
Final-Thaw
Temperature (°C)
Ice depth (m)
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13,0
11,0
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-9,0
-11,0
-13,0
-15,0
0,00
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
-1,40
-1,60
-1,80
-2,00
-2,20
-2,40
-2,60
-2,80
-3,00
31.3.2009
1.4.2009
2.4.2009
3.4.2009
4.4.2009
5.4.2009
6.4.2009
7.4.2009
8.4.2009
9.4.2009
10.4.2009
11.4.2009
12.4.2009
13.4.2009
14.4.2009
15.4.2009
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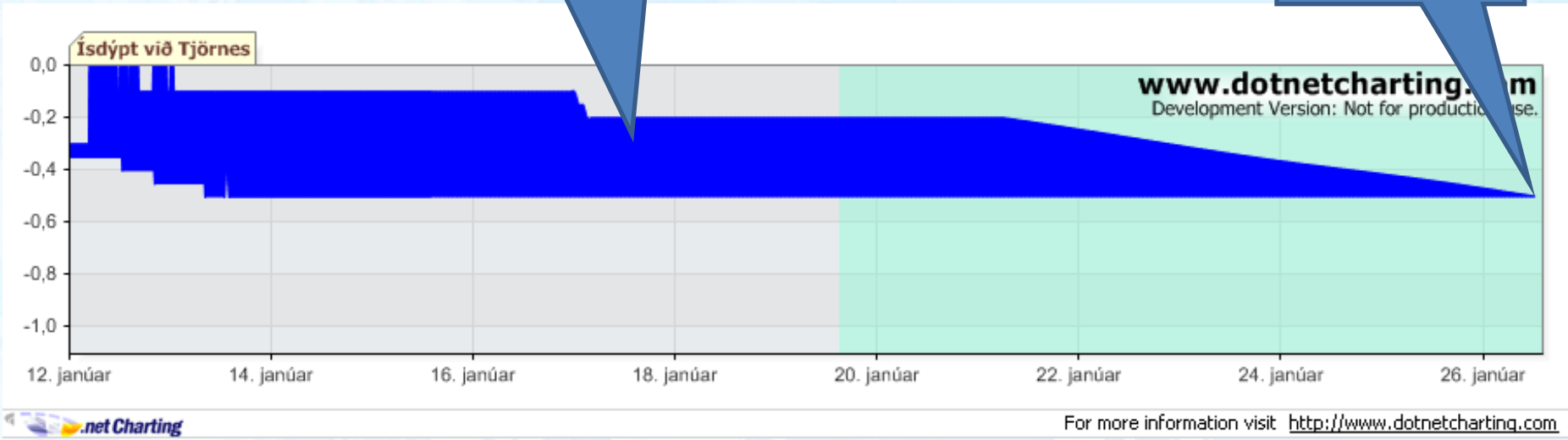
Air temperature
Road temp.(calc)
Road temp.(meas)
Td10 (calc)
Td10 (meas)
Ice Upper (calc)
Ice Lower (calc)
Ice Upper (meas)
Ice Lower (meas)

PROTOTYPE, USER INTERFACE

Ice layer in the road

Ice free!

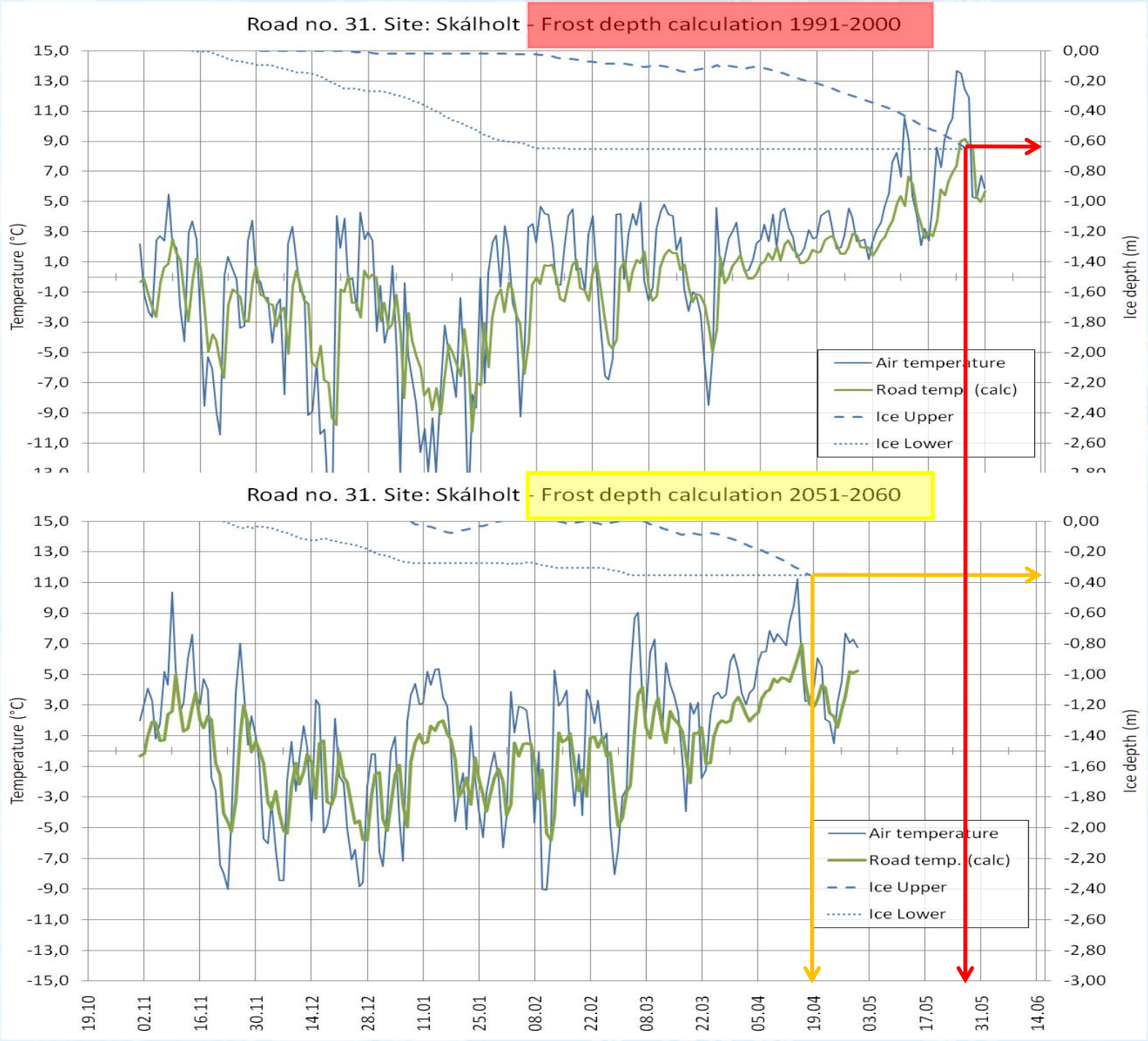


Past (measurements)

Future (prognosis)

MODEL ADAPTION TO CLIMATE CHANGE STUDIES

- The model was modified to work with 24 hour temperature series (daily mean temperature)
- Applied to downscaled future climate scenarios
  (from the ENSEMBLES project, EU 6th Framwork Programme)
- Simulated climate scenario for 1991 – 2000 compared to results for 2051 – 2060
  - (IPCC: A1B1 scenario, increase of 2,2°C in the mean annual temperature in South-Iceland by year 2060)


Road no. 31. Site: Skálholt - Frost depth calculation 1991-2000
Temperature (°C)
Ice depth (m)
Air temperature
Road temp. (calc)
Ice Upper
Ice Lower
Road no. 31. Site: Skálholt - Frost depth calculation 2051-2060
Temperature (°C)
Ice depth (m)
Air temperature
Road temp. (calc)
Ice Upper
Ice Lower
19.10
02.11
16.11
30.11
14.12
28.12
11.01
25.01
08.02
22.02
08.03
22.03
05.04
19.04
03.05
17.05
31.05
14.06

CONCLUSIONS

- Using a 5 day weather forecast, the model is capable of predicting ice movements in the road resonably well
- Software is under development, calibration for 40 sites is under way
- Possible to announce axle load limits 2 - 3 days in advance
- More accurate road management, less road damage, less inconveniance for heavy goods transport
- Possible to study the effect of climate change on ice development in the road structure

Thank you