Road Ice Prediction and Measurement in the 21st Century

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A UK Perspective

- Estimated UK spend is £1500m+ in a normal winter
- Salt corrodes £200m+ of structures each year
- Disruption in Winter 2010/11 was estimated to cost the UK economy over £600m per day.
- Even in a changing climate, winter maintenance is important!

A History of Road Ice Prediction

- Road Danger Warnings (up to 1980s)
- Ice Detection (early 1980's)
- Road Energy Balance Modelling (1984 Onwards)
- Thermal Mapping (1984 Onwards)
- National Ice Prediction System (1986 Onwards)
- Bureau Services (1988 Onwards)

…10 year gap!

- Sky View Factor Mapping GIS/GPS (1998 Onwards)
- Maintenance Decision Support System DSS (initiated in 2001)
- Route Based Forecasting (2004 Onwards)
- Selective salting / dynamic routing (2015?)

Ice Detection

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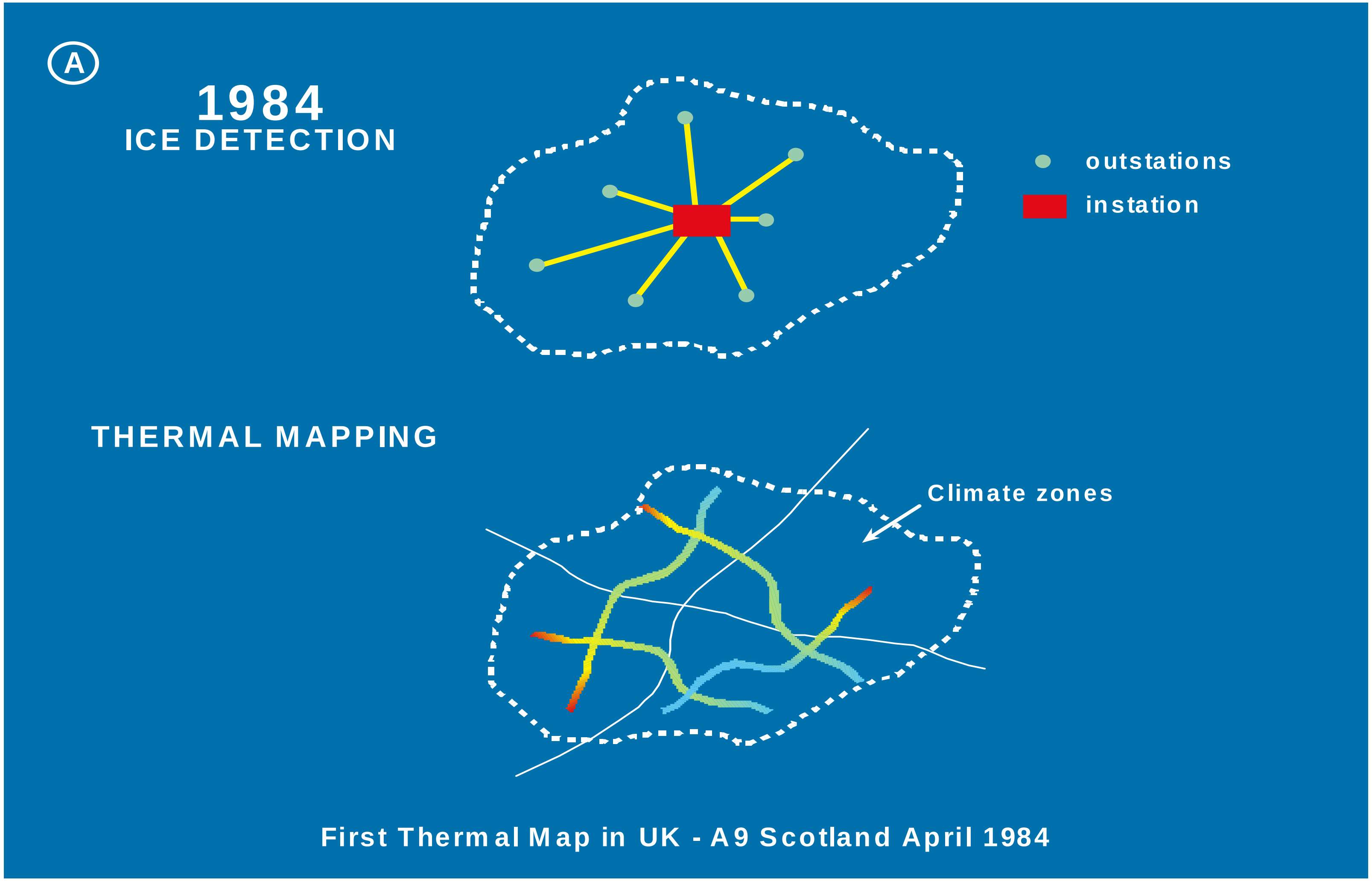
Ice Detection



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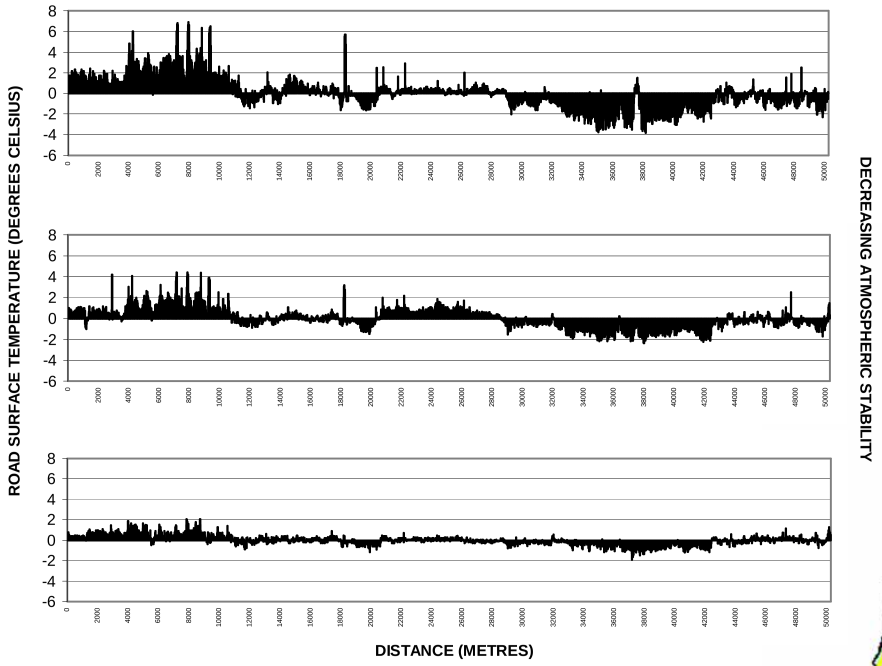
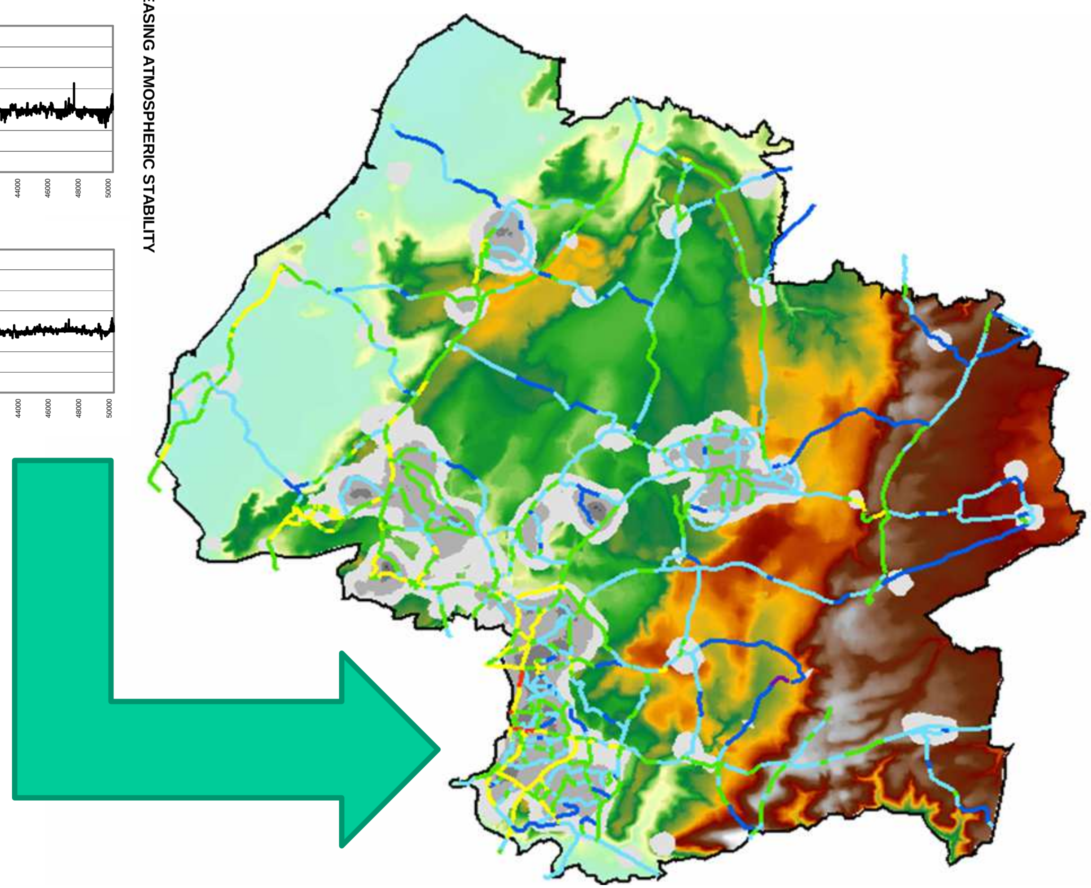
Thermal Mapping

- On a given night there could be as much as 15°C difference in road surface temperatures around the road network.
- Thermal mapping was used to quantify these differences.
- Involves driving the road network with a thermal thermometer pointing at the road surface and taking readings every 20m.
- Before GPS, this involved connected the odometer to the datalogger.
- Currently done under 3 different weather conditions – damped, intermediate & extreme
- Provides an estimate of minimum temperatures on the road network

Meteorological	**Geographical Parameters**	**Road Parameters**
Solar radiation	Latitude	Depth of construction
Terrestrial radiation	Altitude	Thermal conductivity
Air temperature	Topography	Thermal diffusivity
Cloud cover and type	*Screening*	Emissivity
Wind speed	*Sky-View Factor*	Albedo
Humidity / dew-point	Landuse	*Traffic*
Precipitation	Topographic exposure	

Thermal Fingerprints and Maps





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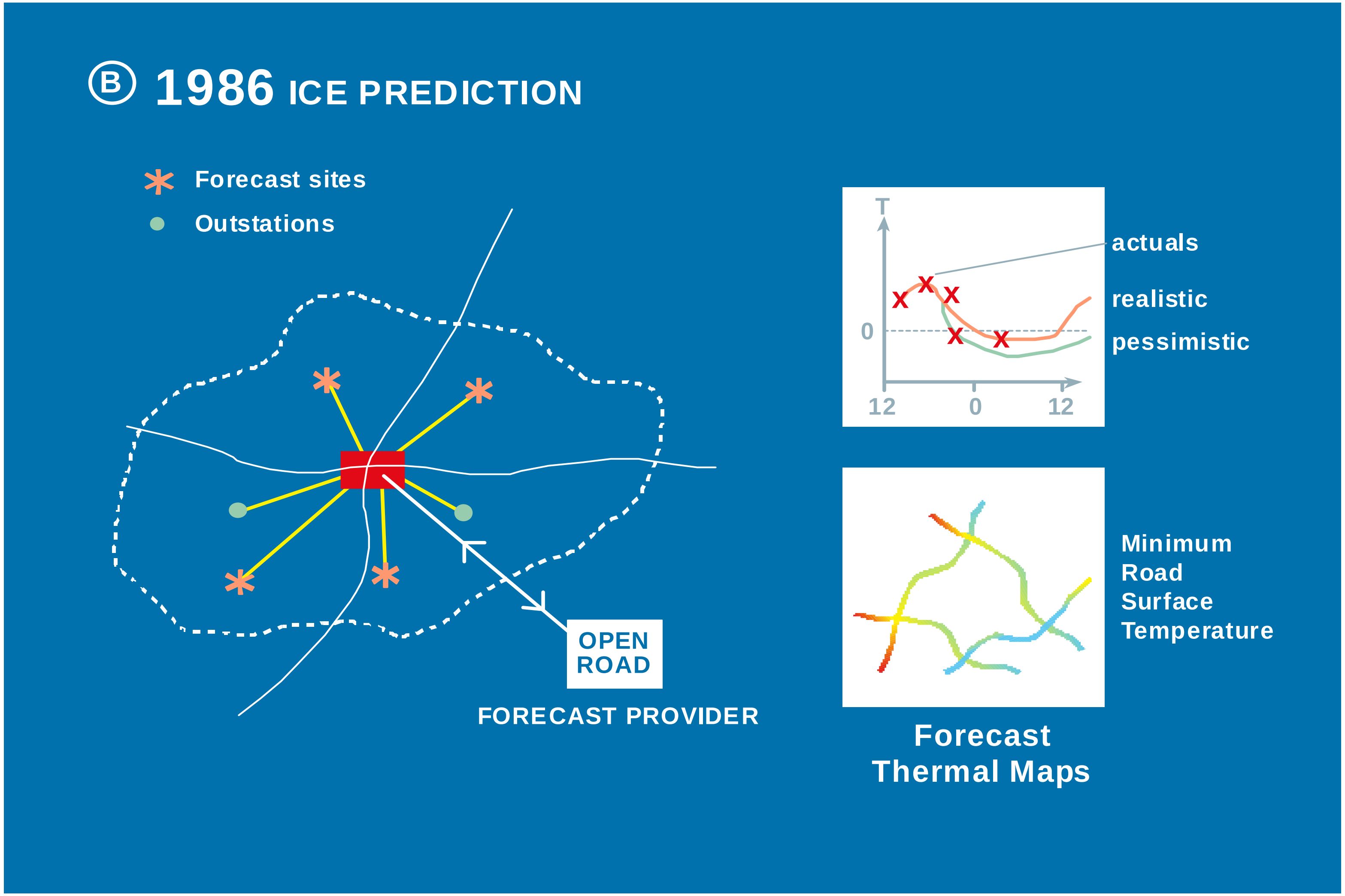
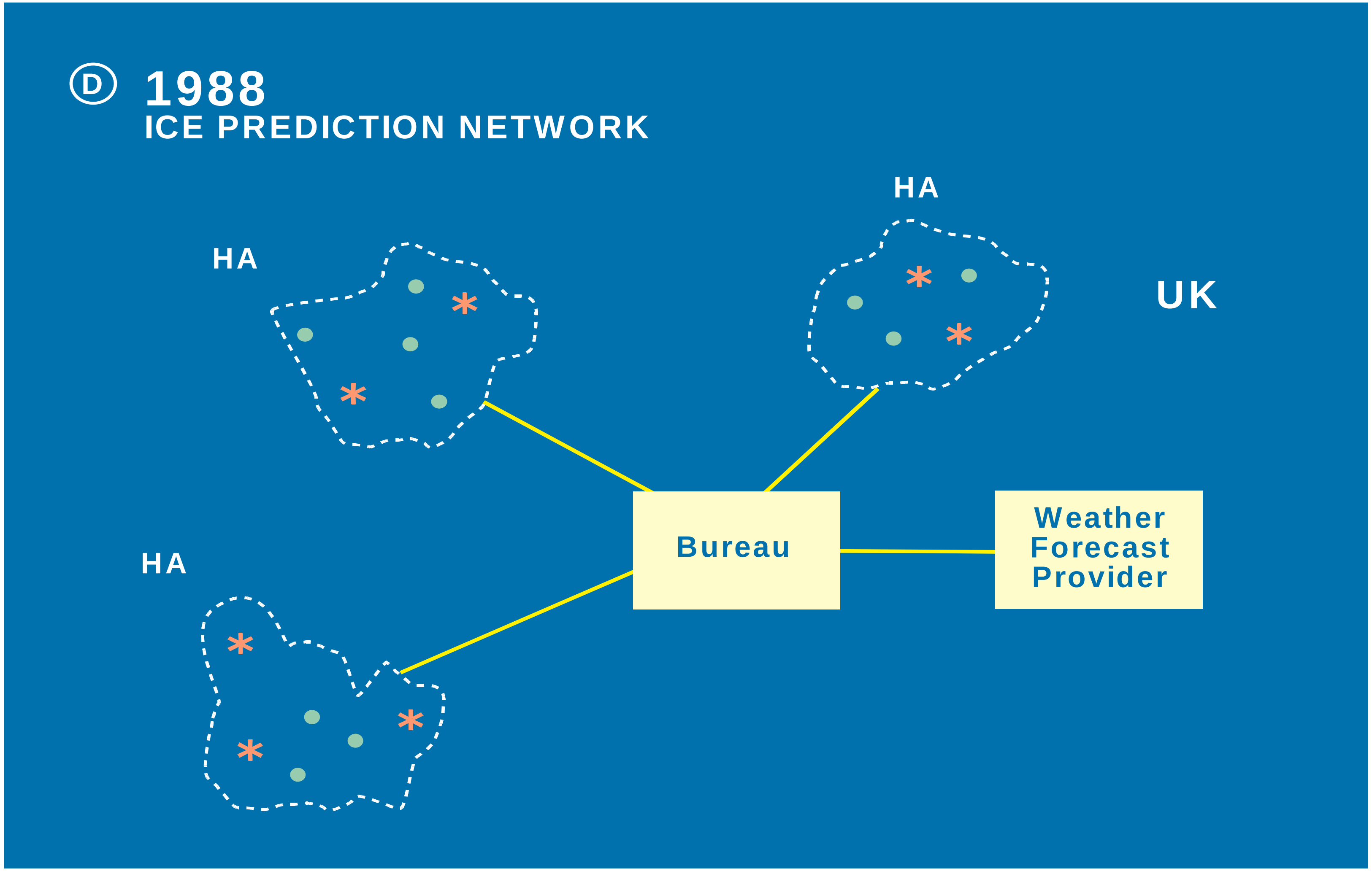
Ice Prediction

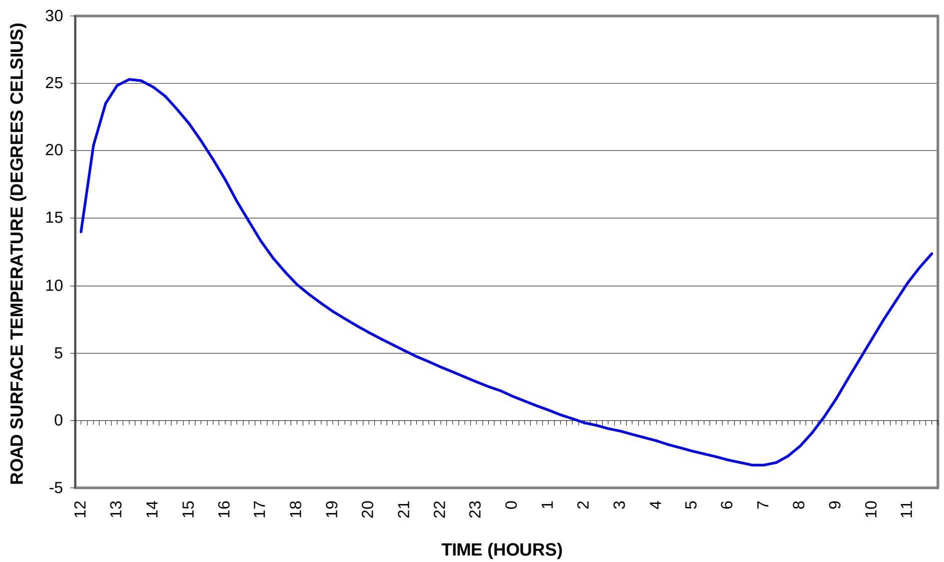


Ice Prediction



<u>Ice Prediction</u>

- The key difference here was the inclusion of a forecast model.
- This was a simple 0D energy balance model which provided a site specific 24 hour forecast of road surface temperatures.
- This was issued at midday so that decisions regarding treatment for the forthcoming night could be made.
- The forecast curve was verified / updated using sensor data from the outstation.
- Originally pessimistic and optimistic forecasts were issued (by varying the meteorological input data), but later this was changed to a best estimate.



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Limitations (Part 1)

- Models were very site specific – typically 1 forecast per ‘climate zone’
- Limited verification data – again 1 outstation per ‘climate zone’
- Reliant on thermal mapping to fill the gaps but this was the most flawed component of the system:
    - Only provides a snapshot of minimum temperature data – no scientific information provided regarding time of freezing
    - Only three surveys are taken – how can you be sure that these are representative?
    - Why use extreme, intermediate or damped when a continuous range of atmospheric stability exists?
- Ice prediction systems remained largely untouched until recent years.
- This original concept was limited by technology. It used to take 30 minutes to run the simple forecast model.
- Until 2000, no attempt had been made to embrace new technology such as GIS, GPS or vastly increased computing power…

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Route Based Forecasting

- With the recent increase in technology, why not model road surface temperatures around the entire road network?

- Temporal component (meteorological parameters) has existed since the mid 1980's.
- Need to add a spatial model component which considers geographical and road parameters:

Meteorological	**Geographical Parameters**	**Road Parameters**
Solar radiation	Latitude	Depth of construction
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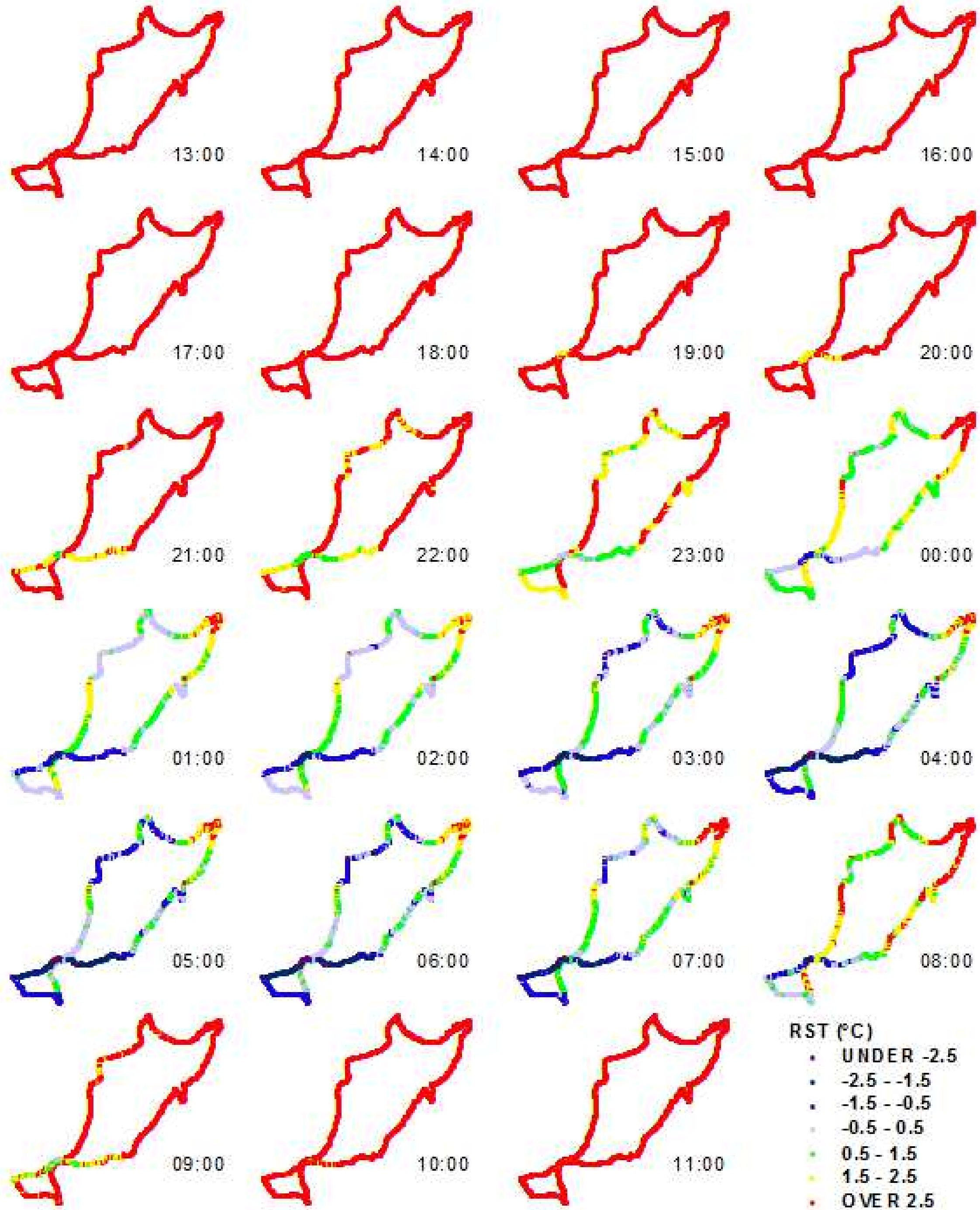
Air temperature	Topography	Thermal diffusivity
Cloud cover and type	*Screening*	Emissivity
Wind speed	*Sky-View Factor*	Albedo
Humidity / dew-point	Landuse	*Traffic*
Precipitation	Topographic exposure	

Route Based Forecasting

- All the problems of thermal mapping can be overcome by using the spatial modelling approach
- The temporal road weather model reads in geographical data on a loop and modifies the forecast curve with respect to geography e.g:
  - High Altitude: Decrease RST in line with lapse rates
  - Busy Roads: Increase RST to account for heavy traffic
  - Urban Areas: Low SVF means warmer temperatures (e.g. Urban Heat Island)
- The result is a dynamic display of road surface conditions throughout the night showing exactly when and where the road will freeze
- Disseminated to end-users via an internet based GIS.



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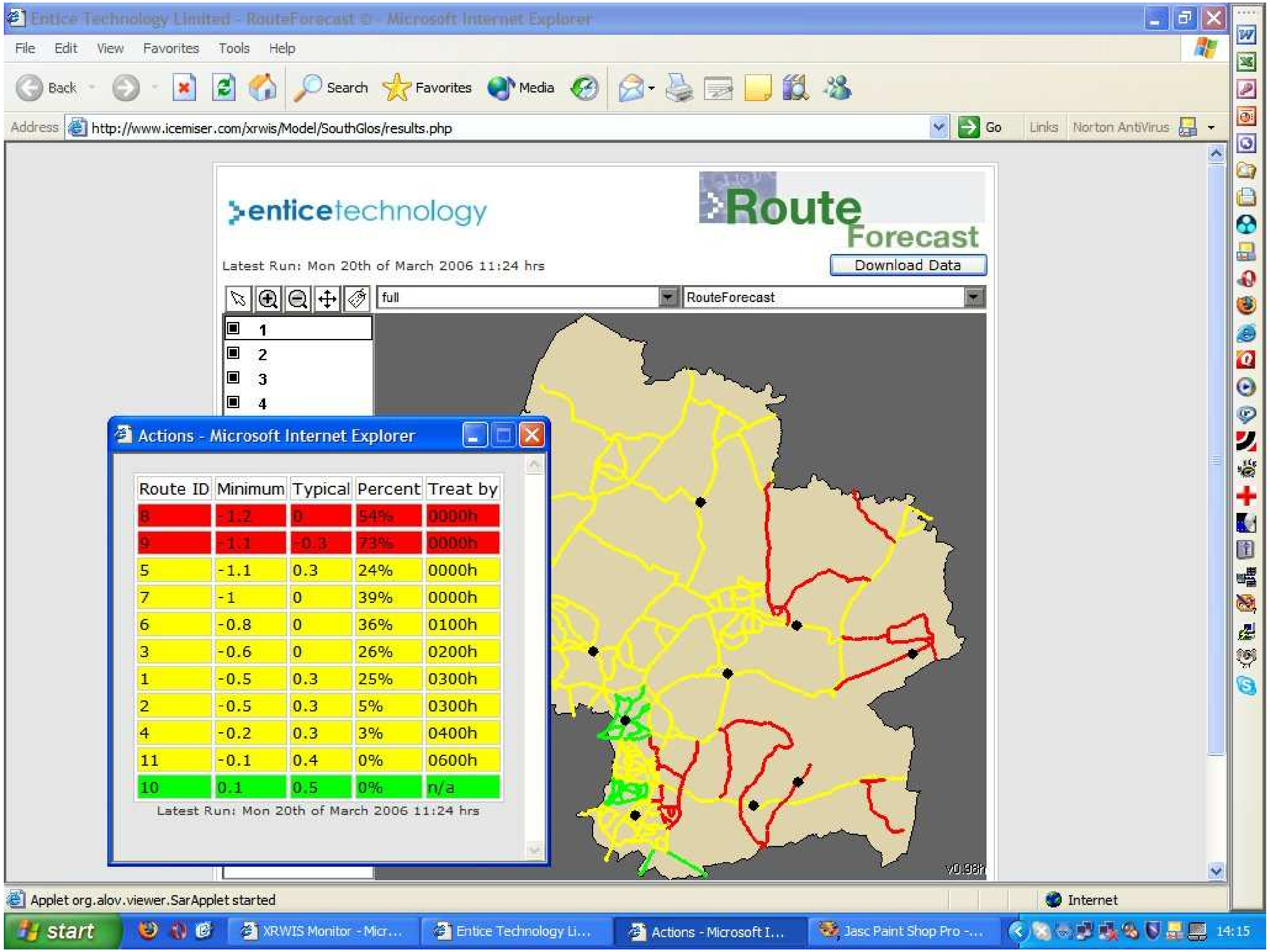
Sample Forecast



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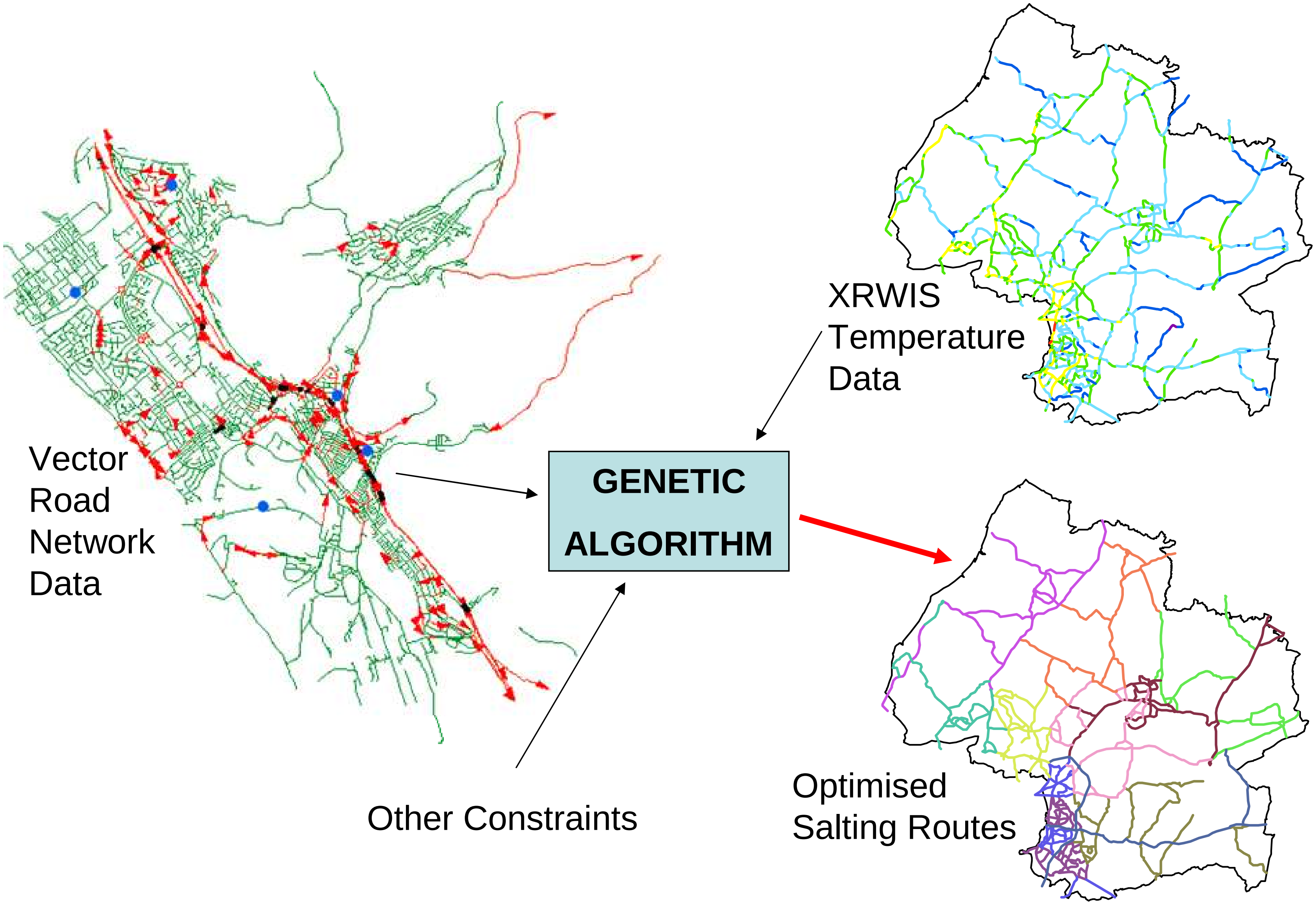
Reducing Salt

- Route based forecasting offered great opportunities to reduce salt usage.
- To maximise the benefits, salting route optimisation is required
- Traditionally involved maximising efficiency by minimising untreated lengths of road
- Complicated as there are numerous constraints:
  - Road network (width / one-way streets)
  - Vehicle numbers & capacities
  - Material characteristics
  - Locations of depots and refilling locations
  - Treatment times

- Why not include road network temperature variations
  - Sub divide the network into road segments which need treating or not…



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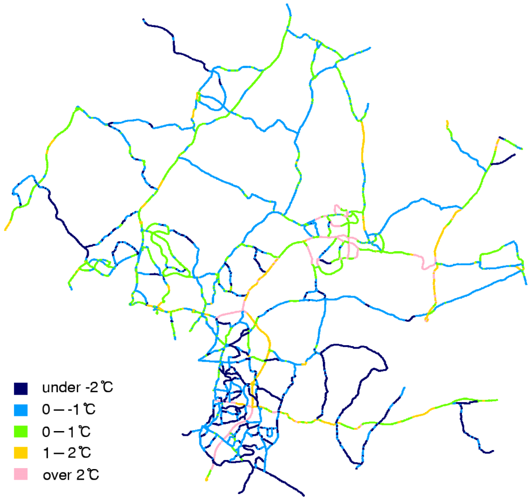
Capacitated Arc Routing Problem

a)



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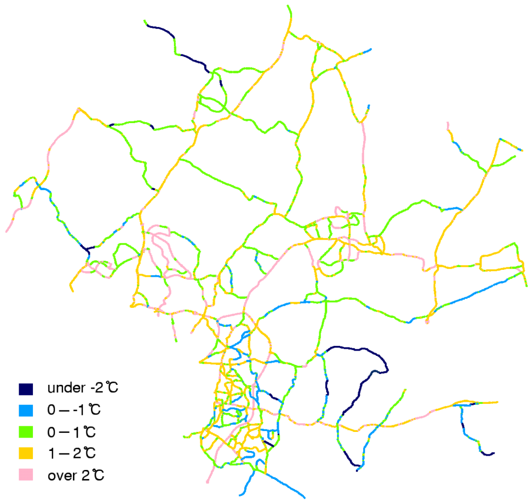
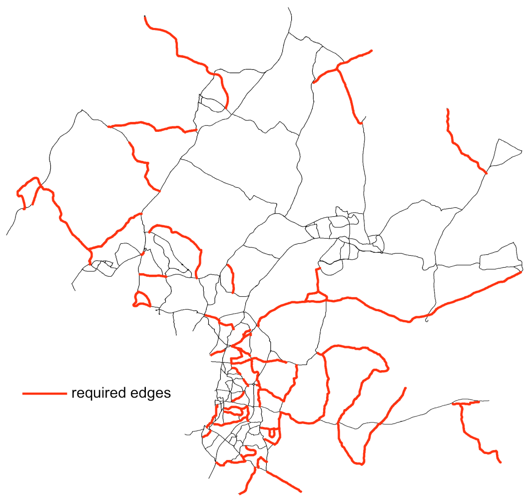


c)

d)



A Simple Solution (pre RBF)

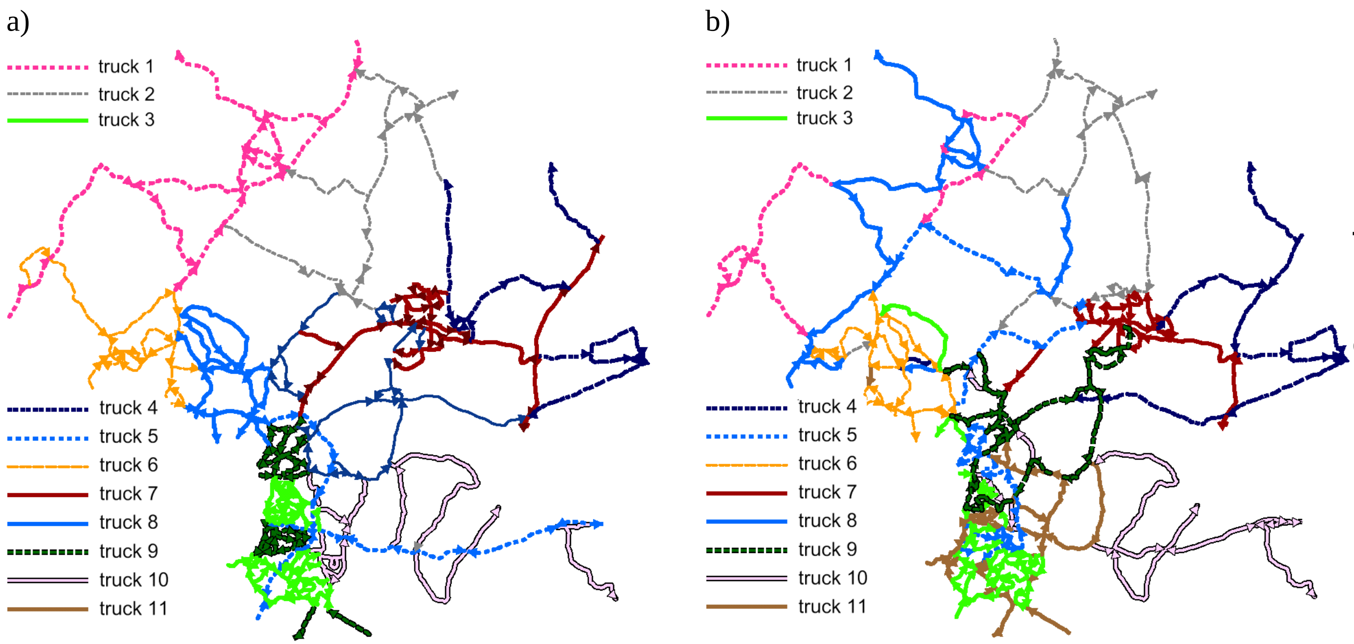
- Use a single temperature distribution to optimise routes (e.g. extreme thermal map)
- Road surface temperature is commonly classified into six different classes:

Over 2.5°C 1.5 to 2.5°C 0.5 to 1.5°C -0.5 to 0.5°C -1.5 to -0.5°C Under -2.5°C

- Each class is a CARP instance and optimised individually.
  - For efficiency, some movement between adjoining classes is needed
- The end result is salting routes optimised on thermal characteristics.
- Is a single temperature distribution representative?

A Robust Solution (post RBF)

- Uses a number of temperature distributions to optimise routes (i.e. a season of daily route based forecasts)
- Uses evolutionary computation and assumes all vertices require treatment



In this example, robust routes are 10% more efficient than the existing traditional routes with respect to distance travelled.

A Dynamic Solution

- Uses the daily temperature forecast from a route based forecast model.
- Routes optimised on a daily basis
- Selective salting is used with only vertices requiring treatment (e.g. under 0°c) are included on the routes
- Requires a leap of faith. Confidence needed in:
  - Satellite Navigation
  - New generation network forecast products (XRWIS)
  - Staff!
- A sophisticated MDSS is needed to keep track of what has been salted and when.

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Limitations (Part 2)

- High resolution ice prediction models now exist and have been around for 10+ years
- If combined with dynamic routing, then salting use is optimised.
- However, this hasn't happened.

- In an age of litigation, users are very wary about relying on model output to this level.
- Hence, a lack of sufficient technologies to verify / supplement route based forecasts is a big problem:
  - Thermal mapping = good spatial resolution, but poor temporal resolution
  - Outstations = good temporal resolution but very site specific

- Solve the verification problem and the savings and potential of all these approaches becomes unlocked:
  - Route based forecasting
  - Selective Salting
  - Dynamic Routing

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The Internet of Things

- A new ‘buzz’ word
- Literally means things that connect to the internet
  - Computers
  - Smart Phones
  - Sensors
  - Curtains, lights, central heating...
- Since 2008, these now outnumber users online

- Lots of potential via the smart cities agenda
  - Miniaturisation of technology
  - Decreasing cost of sensor networks
- Not without technological challenges
- How can winter road maintenance benefit?
  - Proprietary high resolution sensor networks
  - Connected gritters
  - Connected vehicles (mobile data and vehicle data translator)

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IoT and Winter Road Maintenance

A ROAD TRIP

Mobile data and the VDT: the long awaited solution?

"Route-based forecasts represented a paradigm shift in winter maintenance decision making"

making process is slowly being passed from engineer to forecaster, although this is a crucial step towards uniform decision-making across jurisdictions.

Latest forecast systems

The pace of development of decision support systems and route-based forecasts over the past decade has almost been too quick for users to fully adopt them with the required confidence. Securing the winter roads can be a matter of life and death, and therefore decision makers need to be convinced of the accuracy and reliability of new forecasting systems. For this reason, one of the main barriers to the universal uptake of route-based forecasts is the non-trivial matter of how such high-resolution forecasts can be verified.

Winter maintenance is presently dealing with a legacy of outstations with poor spatial coverage and thermal mapping with poor temporal coverage for verification. The answer can only be an increased number of sensors for monitoring. However, these will have to be low-cost to be realistically deployed in the numbers required for the task, which immediately raises concerns regarding the quality of the data being returned. However, there appears to be a gradual shift in the meteorology community on this issue and that perhaps it is actually better to have some data – even if there are compromises – than no data at all.

Mobile data collection

A few rogue readings should not detract from the bigger picture should the sensor network be sufficiently large enough. It is for this reason that the advances in mobile data collection and the vehicle data translator developed by the Federal Highway Administration are so timely.

Such technology potentially brings a paradigm shift in forecast verification and is probably the only means in which a route-based forecast can be verified in detail. However, ongoing concerns about data quality would suggest that this technology is a long way from being suitable for data assimilation in forecast models and even if it was, there would need to be considerable research effort to ensure that it actually added anything to the forecast. ▮

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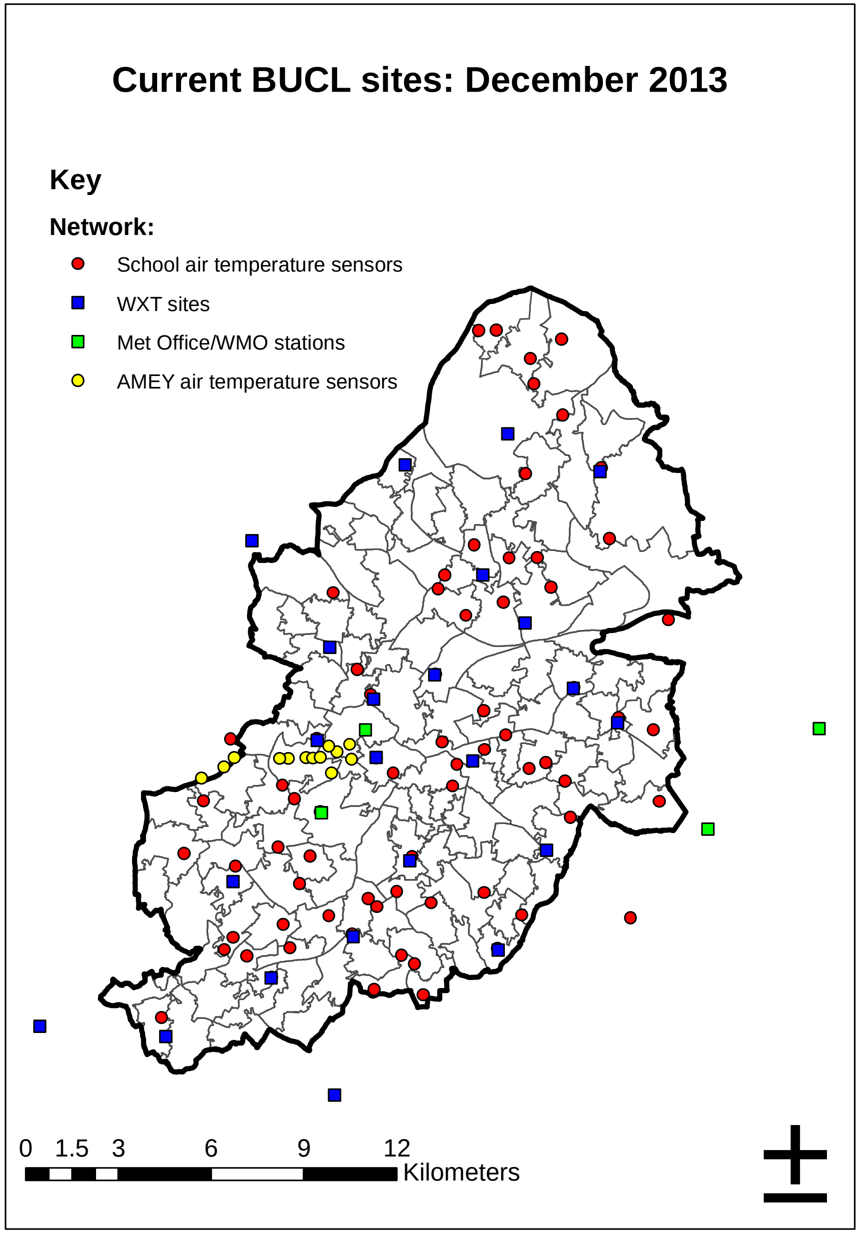
Response box taken from Drobot & Chapman (2012) Heading down the highway. *Meteorological Technology International* August 2012

Meteorological Sensor Networks



- Potentially a more reliable form of high resolution data collection than that crowd-sourced from vehicles
- Examples of sensor networks now evident worldwide (particularly in urban areas)
- For example, the Birmingham Urban Climate Laboratory

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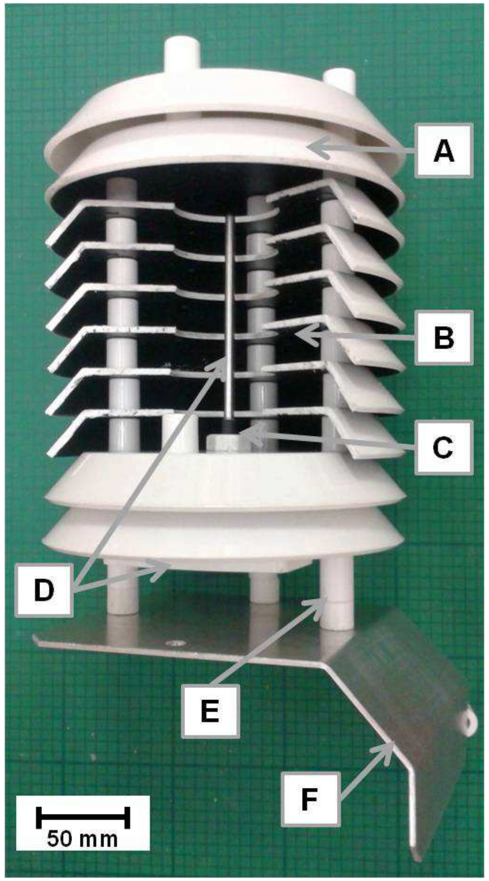
Low Cost Air Temperature Sensors

- Vaisala WXT520 are a perfect solution for Meteorological Networks, but are expensive:
  - Requires datalogger and hardwired / GSM / GPRS communications
  - Power can also be an issue
- Bespoke sensor was designed to fill in the gaps of the coarse network:
  - 10kΩ Negative Temperature Coefficient Thermistor
  - Bespoke radiation shield
  - Comms provided via a wireless communication card
  - Power provided from a Lithium-Thionyl Chloride battery which last for 3 years under ideal conditions
  - Very cheap - £87!
  - Tested at UKMO calibration lab with an absolute error of ±0.22°C
- Can be deployed anywhere where there is a WiFi network (e.g. Schools in BUCL)
- A good example of a low cost thing in the IoT
- No ongoing costs for communication / power
- Cheap to install in a large network



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Winter Maintenance Demonstrator

- Wifi is becomingly increasingly available
- Many cities / major roads now have proprietary communication networks
- A range of sensors based on the ‘low cost’ IoT principle can now be rapidly deployed

- As part of a TSB funded IoT project working with partners InTouch and Amey plc, a winter maintenance demonstrator has been deployed in Birmingham.
- Amey have installed a WiFi based roadside communications mesh which covers all major roads in the city
- It is used to control:
  - Traffic signals
  - Variable message signs
  - Car park counters
  - CCTV
  - and Air Temperature Sensors!

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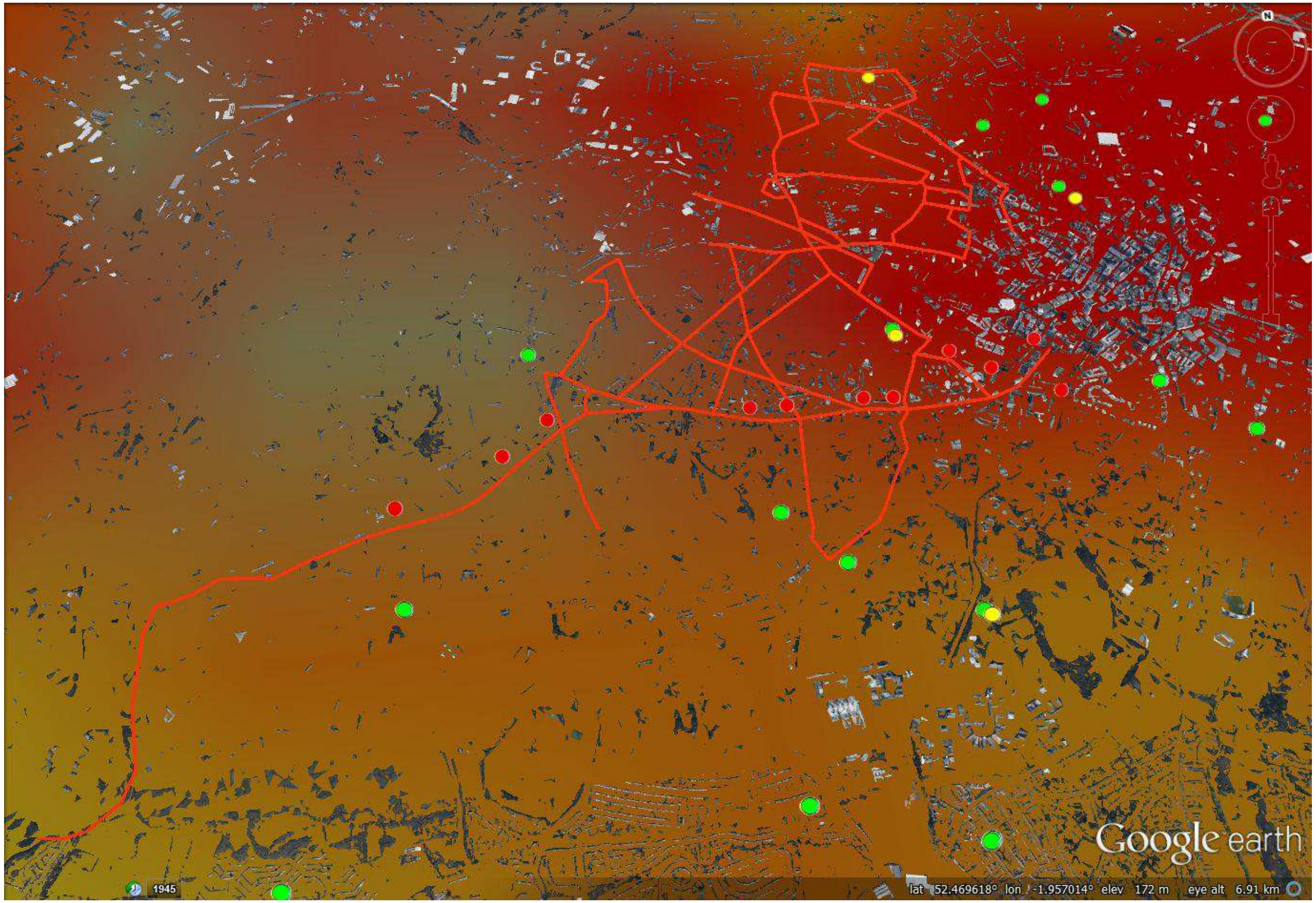
Winter Maintenance Demonstrator



Consists of:

- 11 sensors nested within BUCL
- Connected gritter:
  Vaisala DSP111 temperature probe +
  forward facing camera

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Limitations (Part 3)

- Relatively small scale study. Thousands of sensors are realistically required to resolve the road network.
- Numerous, significant challenges identified at this scale...

- Technology doesn't stand still! WiFi protocols change…
  - Backward compatibility exists
  - What if you don't own the network?
  - Communications become expensive if you do...
- If winter maintenance was to use the IoT, is there sufficient coverage across the network for communications anyway?
  - Alternatives – Zigbee, connected vehicles, hybrid approach??
  - Cost effective?
- Power
  - Batteries not 100% reliable
  - Drain quickly if communications are poor
  - Other forms of energy harvesting needed
  - Cost effective?
- Maintenance
  - Potentially enormous task!
  - Annual calibration of 1000s of sensors would be fun.

- The aim of a new EPSRC project is to overcome those challenges!
- New generation of IoT technology being used to develop a bespoke infra-red sensor
- Will be fitted on every other lamp-post on the demonstrator corridor to verify route based forecasts at 50-100m resolution

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Summary

- Numerous new options for further improving road ice prediction and optimising salt usage.

- The gold standard is an MDSS consisting of:
  - Route Based Forecast
  - Evolutionary salting route optimisation tool
- This will enable dynamic routing and selective salting
- What about residual salt detection?

- The IoT appears to be the facilitating technology to solve many problems:
  - Connected gritters
  - Verification data from connected vehicles and low cost sensor networks
- The IoT is just one answer...
  ...but can the challenges be overcome?
- Are there other more disruptive technologies on the horizon (e.g. road nanocoatings?)

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Questions?

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