THE THERMAL MAPPING PROGRAMME - DECISION SUPPORT CONCERNING SALT SPREADING

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SUMMARY

The Walloon territory is covered by fifty automatic weather stations. These stations permanently pick up parameters related to atmospheric conditions and road climatology. The network systematically sends these parameters to the PEREX centre (permanent station for network operation) and to the Air Force METEO WING which make short-term climatic forecasts for each of the main stations. More than 78000 climatic measures as well as 43000 measures coming from the road sensors are processed automatically each day.

At present, our aim is achieved : we receive a prediction curve concerning the road surface temperature nearby each main station – which means that 16 different forecasts are made for the next 18 hours.

A meteorological forecast information valid for periods of three hours specifies certain parameters such as cloud cover, precipitation risks and wind force.

The Walloon Region's climatology is very complex as a result of its variable geographic features, the very weak influence of maritime airstreams and an exposure to southwest prevailing winds. That is why road surface temperature forecasts are not sufficient to assess the danger over the whole length of the road network. To compensate for the spatial inaccuracy of road surface temperature forecasting, a thermal mapping programme was set up to enable the decision-makers to get a visual display of temperature evolution on the slow lane.

It is possible to generate surface temperature maps of the whole network of the Walloon Region's territory. The thus obtained thermal mapping can have either an instantaneous or forecasting character.

<u>The method is based on following principles :</u>

- Surface temperature measurements every 12.5 m over the whole network and in case of three weather types.
- Spatial relation analysis by the climatology laboratory of Liège University.
- Integration of temperature ranges taking account of 1-km long sections.
- Integration of the area of influence of all the main weather stations.
- Creation of routes by referring to the existing road database.
- Adaptation of a mapping software making it appropriate to each type of manager.
- User-friendly presentation of the results on the 54 local user terminals of the network managers.
- Training courses in software use.

The generation of thermal maps having an instantaneous or forecasting character completes the METEOROUTES decision support. Supplementary data provided by thermal mapping allow the co-ordinators to organise salt spreading which is better delimited in space and has a more suitable spread rate. These data also enable them to warn the users via the PEREX centre and radio broadcasts by "Radio Trafic".

Each country, each region is aware of the difficulty of maintaining minimal traffic conditions on its own road and motorway network.
The managers put considerable energy, in human and financial terms, into ensuring winter serviceability on their territory.

The Walloon Region is not an exception to the rule and it can be considered that nearly half of the annual road maintenance budget is allocated to spread melting agents on the network.

After analysis, it appears that these important costs can be mainly ascribed to three causes :

1. In winter, the Walloon Region's climate is often characterised by alternating night frost and positive day temperatures.
2. Wallonia's variable relief does not benefit much from maritime influence. The prevailing winds come from the southwest.
3. The winter maintenance organisation plan invites the road managers to keep the roads "black", that is to say completely clear.

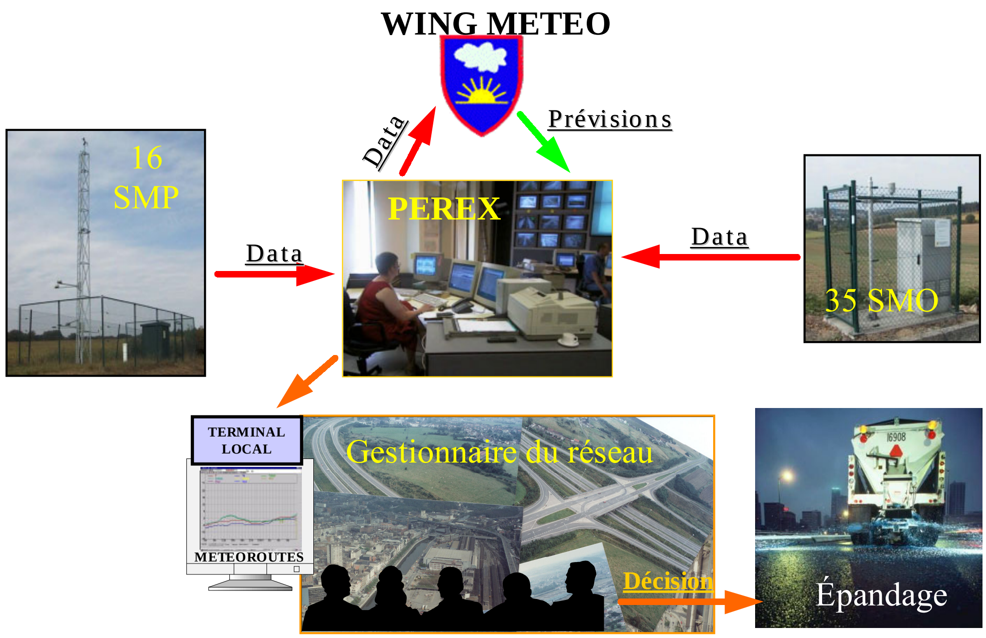
This last point is the subject of a more administrative approach and we are rather going deeper into the analysis of more scientific aspects.

Before the setting up of the METEOROUTES project, road and motorway districts based their interventions on the national weather forecasts, which were too imprecise in space and time to be able to organise efficacious preventive salting. This generally caused the salting operations to be decided upon well before the danger appeared. The salt was scattered by traffic and lost its efficiency.
In order to remedy this imprecision and to maintain the best possible traffic conditions, the Ministry of Equipment and Transport invested in a decision support tool : METEOROUTES.

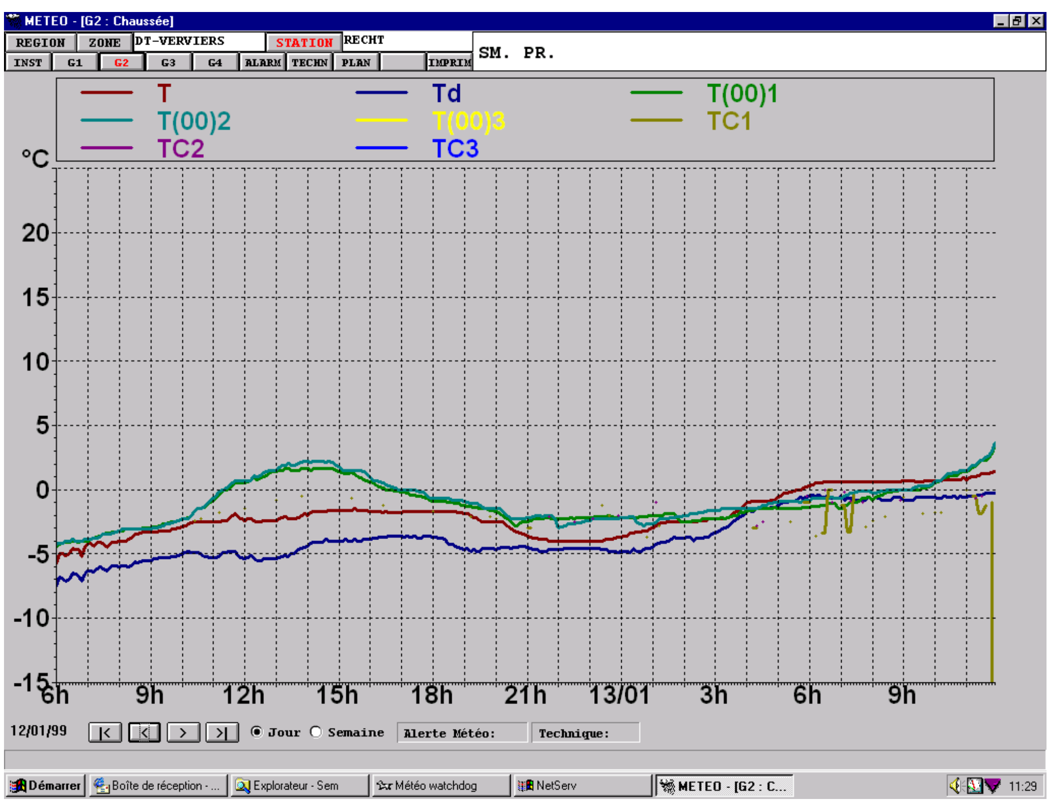
Following the advice of Professor ERPICUM of Liège University, 16 weather stations were set up so as to frame the region and warn about the arrival of cold fronts wherever they come from. Nearly all of them are located along the motorway network where we can make use of our own electrical power and communication network.
Thirty-five secondary stations give complementary information specific to road climatology.
These stations are different in the sense that they do not measure radiation, wind and rainfall.

The aim pursued is to create a system for road surface temperature forecasting nearby each main station.

The project was worked out under the guidance of an accompanying committee composed of specialists from the M.E.T. (Road, Telecommunications and Electromechanics Directorates), Liège University and the forecasting unit of the Air Force METEO WING.
The communication exchange diagram takes account of a well worked out hierarchical structure.



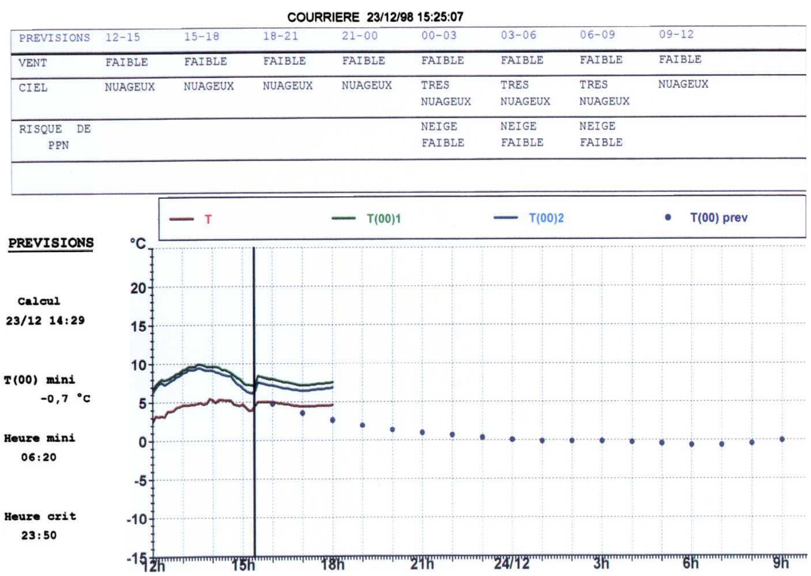
The programme's aim is to allow the road managers to access the values measured by the sensors every 6 minutes, via the local district terminal.
These values can be read either on an instantaneous table or on a graph where an historical account over the past 24 hours appears. The manager can also conduct historical queries.
All the values are stored for one month in the local unit and older values (up to two years back) can be downloaded via the network.



Every day around 16:00, a graph predicting road surface temperature can be displayed on the local terminal. This prediction curve is calculated by software installed at the Air Force forecasting centre.
The forecaster initialises its calculation basis for the 16 main stations by referring to the general meteorology centred on the 15:00 European data. He inputs local factors such temperature at the road surface and at 20 cm depth, wind speed and direction, radiation.
The forecaster also makes sure that the weather type complies with the forecasts for the night to come.
That is to say that a weather type has to be chosen according to cloud cover and wind observations. The chosen weather type is going to influence the pavement cooling curve appearance.

- Clear (cloudless) and calm (windless) weather will generate a very steep cooling curve.
- Overcast (cloudy) and windy weather will generate a fairly flat cooling curve.
- Intermediate weather, either calm and cloudy or clear and windy, will generate a moderately steep cooling curve.

Nowadays road and motorway managers analyse forecasts made for road surface temperature at 16:00 and can organise watch rotations or salt spreading operations in order to optimise service to the road user.



Yet one essential question remained to be solved. It would indeed be very useful to be able to predict road surface temperature evolution over time. These temperatures only concern 16 locations spread over a network of more than 8500-km roads and motorways.
That is why a programme for measuring the temperature profiles on the road network (thermal fingerprints) was launched. This programme solved the problem of road temperature in space by generating a thermal map.

Thermal mapping

The objective pursued by thermal mapping is to extrapolate from the road surface temperature and the weather type nearby the main stations and to apply these data to the whole road network through thermal fingerprints processing.

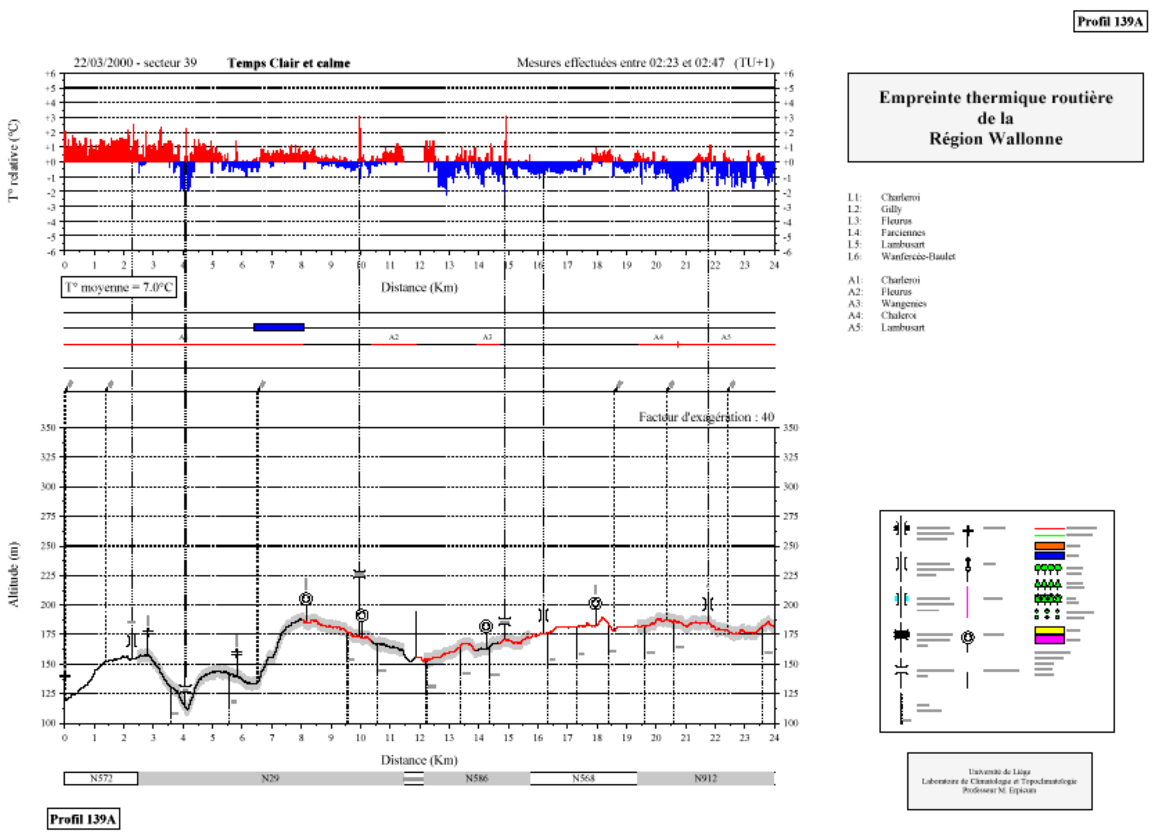
Thermal fingerprints

The topo-climatology laboratory of Liège University developed the thermal fingerprints.

They were taken during the second part of the night so as not to be influenced by solar energy and in order to avoid too important temperature variations during the measurements. The three following weather types were taken into consideration :

- clear and calm
- intermediate
- overcast and cloudy

Thermal fingerprint surveys were carried out in both traffic directions on the road network.
As far as roads are concerned, only one survey was done per dual carriageway.
The measurements consist in recording road surface temperatures by means of a sophisticated radio-thermometer that is fitted to a vehicle and records the values after processing the picked up signals. The location of the hectometre posts is used in order to ensure that the marks correspond to the central road database. Thermal fingerprints are always taken on a dry road surface to avoid disruptions of the infrared signal picked up by the radiometer.



The average surface temperatures are recorded every 12.5m along 24 km long road sections. The marking of the engineering structures, the inhabited or woody areas, the crossroads… brings the distinctive features of each circuit to the fore. These data are analysed and then sent to CAP GEMINI ltd whose task consists in integrating these values in the « ARCVIEW GIS » software and to provide the winter serviceability co-ordinators with a usable tool.
1-km long road sections were taken into consideration because there is no point in referring to a smaller scale that would prove useless in reality.

Measurement processing

1. Validity of the measurement campaign.

This operation consists in confirming the validity of the measurement campaigns by eliminating the abnormal measurements (missing data, dissimilarities concerning the distances, …)

2. Homogeneity of cloud cover.

The measurement campaigns best corresponding to a constant weather type during the whole measurement period are selected on the basis of the atmospheric balance. This is possible thanks to the data measured during the campaign by means of a pyrgeometer.

3. Selection of the most representative campaign.

After winter, the most reliable measurement campaign corresponding to each weather type is selected. This selection results in three real-time thermal fingerprints.

4. Data transfer at the same time.

This operation consists in copying out all the data measured at 6:00 a.m. in order to obtain a temperature variation curve independent of the time factor. This means that the temperature curve represents values that would all have been measured at the same time, at 6:00 a.m. To that end, a weighting factor, which takes account of the distances to the three closest main stations, is applied according to the hereafter defined rule.

5. Association with road sections.

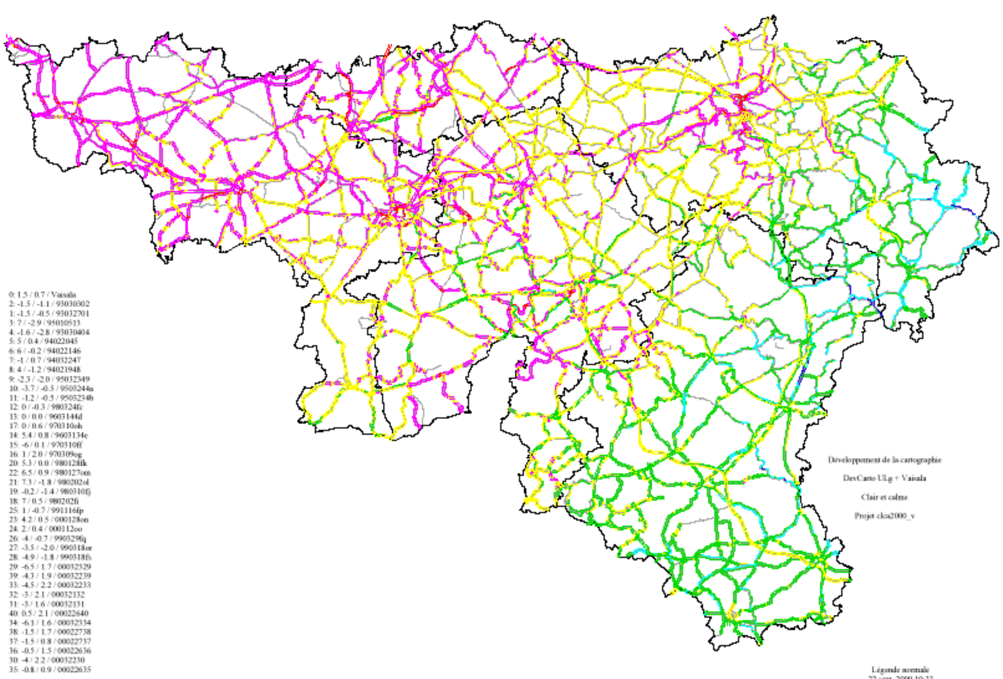
The road and motorway network has been divided into 1-km long sections (situated between 2 kilometre posts). The average temperature resulting from 80 values recorded every 12.5 m and generated by the thermal fingerprints is associated with each section.

6. Correspondence between sectors.

Each thermal fingerprint corresponds to a measurement area or sector. The data common to 2 or more adjoining sectors must obligatorily tally with each other. A tool was developed for making sector overlaps tally.

7. Creation of the reference thermal mapping.

The definitive measurement data can be displayed on a map representing the two extreme weather types. The arithmetic mean of the extreme values is taken into account for the intermediate weather type.

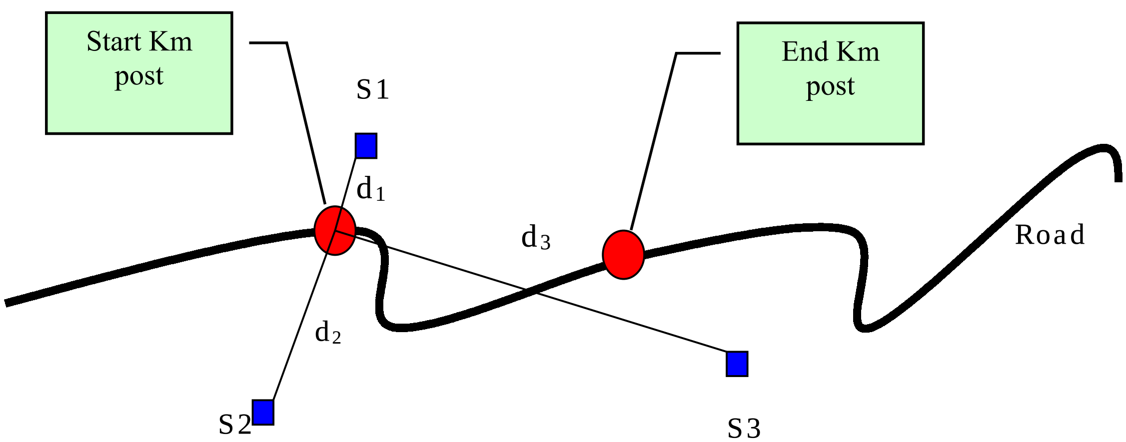


Calculation of the sections' temperature

In order to determine the temperature of a road section on the basis of the instant or predictive climatic conditions observed near the weather stations, the climatology laboratory of Liège University associated each road section with 3 main weather stations having an influence on it.

S1 Station = primary station (the closest)
S2 Station = secondary station (intermediate)
S3 Station = tertiary station (the remotest)

The sections' temperature is calculated by weighting the influence of each station according to the distance between the station and the beginning of the section under consideration.



The weighting factors associated with each weather station are calculated as follows :

$$p_1 = \frac{1/d_1}{1/d_1 + 1/d_2 + 1/d_3}$$

$$p_2 = \frac{1/d_2}{1/d_1 + 1/d_2 + 1/d_3}$$

$$p3 = \frac{1/d_3}{1/d_1 + 1/d_2 + 1/d_3}$$

$$T_{section} = \sum_{i=1}^{3} [\, ti + (\Delta \text{ section} - \Delta \text{ station i}) \,]*pi$$

where

- $T_{section}$ = road section temperature (instant or predictive)
- ti = temperature near station i
- Δ section = section temperature provided by thermal fingerprint
- Δ station i = section temperature near station i provided by thermal fingerprint
- pi = weighting factor associated with station i and applying to the section concerned

The weighting factors are applied according to following rule :

- If the primary weather station is defective (no temperature or weather type information), the weighting coefficients of the secondary and tertiary stations are calculated according to a rule of three considering that p2 + p3 = 1 .
  Calculation is only generated when the secondary and tertiary stations are operational. Otherwise no thermal mapping occurs for the road sections concerned.

- The same principle is applied when one of the other stations is defective.

The weather type observed near each of the main weather stations defines the weather type on the road section under consideration. If this weather type is not known, the system refers to the weather type of the secondary station.
The weather types are chosen according to following criteria :

<table>
<tr><td></td><td></td><td colspan="9">Low clouds</td><td colspan="9">Medium clouds</td><td colspan="9">high clouds</td></tr>
<tr><td>WIND in knots</td><td></td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td rowspan="10">calm and faint</td><td>0</td><td colspan="3" rowspan="10">1</td><td colspan="3" rowspan="10">3</td><td colspan="3" rowspan="21">2</td><td colspan="3" rowspan="10">1</td><td colspan="4" rowspan="10">3</td><td colspan="2" rowspan="21">2</td><td colspan="6" rowspan="10">1</td><td colspan="2" rowspan="10">3</td><td rowspan="21">2</td></tr>
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<tr><td rowspan="8">moderate</td><td>10</td><td colspan="2" rowspan="8">1</td><td colspan="4" rowspan="8">3</td><td colspan="2" rowspan="8">1</td><td colspan="5" rowspan="8">3</td><td colspan="4" rowspan="8">1</td><td colspan="4" rowspan="8">3</td></tr>
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<tr><td rowspan="3">windy</td><td>18</td><td colspan="6" rowspan="3">2</td><td colspan="7" rowspan="3">2</td><td colspan="8" rowspan="3">2</td></tr>
<tr><td>19</td></tr>
<tr><td>20</td></tr>
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1 = clear and calm weather type
2 = cloudy and windy weather type
3 = intermediate weather type

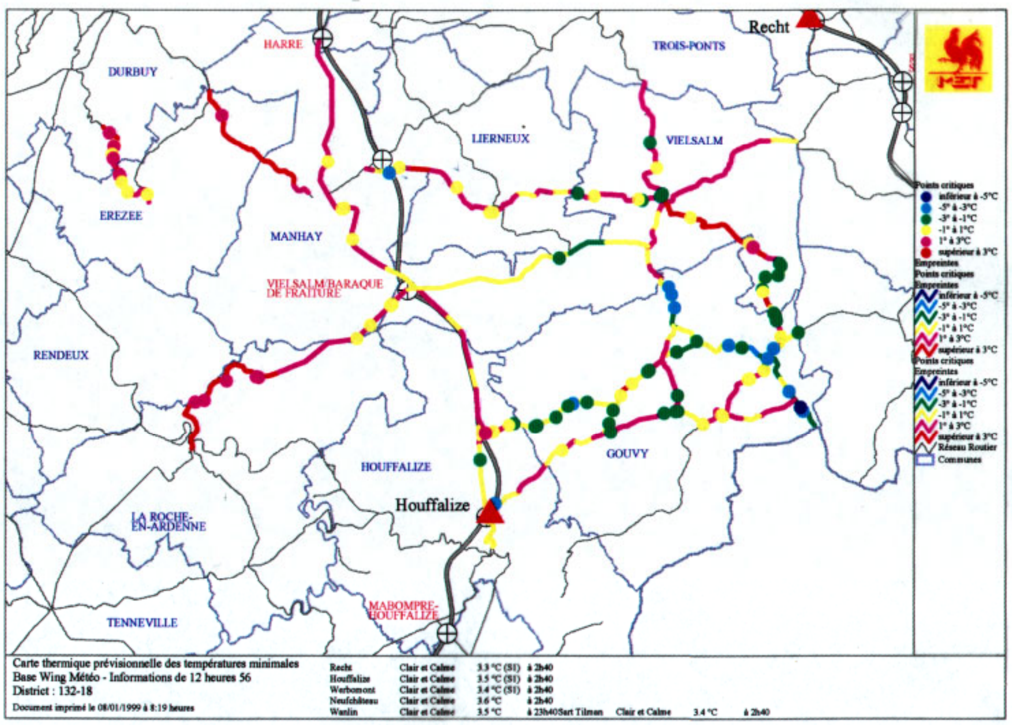
The scale of cloud cover is divided in eight according to « sky obstruction due to clouds » at low, medium and high altitude.

Visualisation.

Three types of thermal map configuration can be displayed :

- A view of the « district » for the local managers ;
- A view of the « territorial directorates » ;
- A view intended for « PEREX », the co-ordination centre for the whole of Wallonia.

The users can visualise instant maps. The road sections are coloured according to segments of 2°C. Critical points also appear on the screen. They correspond to a location where road surface temperature belongs to the temperature range just below the average on the section considered.
A predictive map that gives the predictions for the night to come can also be generated. Around 4:00 p.m., the managers have the opportunity to refer to surface temperature maps indicating the temperatures foreseen at 21:00, 24:00, 03:00, 6:00 and at the time when temperature will reach its minimum at the station.



Conclusions

This very accurate tool offers the following advantages to the to the managers :

- Planning the watch rotations of the co-ordinators and the network controllers.
- Planning the time of optimal salting just before danger appears.
- Planning more localised salting operations and making savings on salt quantities.

Nevertheless, the drawbacks are not inconsiderable :

- Because of the accumulation of errors in measurements carried out near the stations, weather forecasts, thermal fingerprints, choice of weather type and cartography, thermal maps sometimes do not reflect reality any more. This can be noticed particularly when using thermal maps predicting temperatures at the end of the night in case of an intermediate weather type.
- Although thermal mapping proves very accurate, it does not always confirm the decision to spread salt. The winter serviceability co-ordinators very often face situations where road surface temperature on a given circuit makes them have doubts as to the necessity of spreading salt.

- Thermal mapping only shows road surface temperatures. It goes without saying that relative air humidity and precipitation risks must be taken into account. That is why the local terminal data are analysed and the network is subjected to control.

This tool still has to be perfected and its predictions made more useful. It should also integrate levels of service in support of a legal decision-making methodology.