Multivariate Data Analysis. A new Insight for Thermal Mapping

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laboratoire régional des ponts et chaussées de Clermont-Ferrand

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Summary

1- Context and objectives

2- Thermal mapping, what for?

3- A dose of multivariate data analysis instead of salt

4- Conclusion - Perspectives

1- Context and objectives

associated texts: verglas, risque de verglas, verglas fréquent

icy road, risk of ice, frequent ice

criteria of installation of road signs and/or RWIS?

1- Context and objectives

atmosphéric probes

IR radiometer

distance trigger

thermal mapping procedure
- vehicle with onboard instruments,
- mesurements embedded into the traffic

Context

- "static" ice susceptibility of road networks
- ice susceptibility built with specific weather conditions
- difficulty for the junction of itineraries monitored at different moments
- poor representativity with respect to the large variety of weather scenarii

1- Context and objectives

Objectives

- to build a dynamic and representative ice susceptibilty index,
- to be less dependent on weather conditions,
- to obtain a global and consitent overview of networks,
- to forecast $T_{surface}$ evolution along itineraries,
- to be less dependent on numerical models.

2- Thermal mapping, what for?

Thermal mapping

- mesurements of $T_{surface}$, T_{air}, relative humidity, calculation of $T_{dew\ point}$

- road environment monitoring *(bridges, tunnels, wood areas, urban areas, ...)*

- identification of zones with $T_{surface} < T_{dew\ point}$
(condensation risk, and possible occurrence of ice if $T_{surface} < 0°C$)

- correlation with field information and known accidents

- elaboration of an ice susceptibility index

→
- installation of road signs *(according to law rules)*
- installation of RWIS
- optimization of de-icer applied *(when $T_{surface} < 0°C$)*

3- A dose of multivariate data analysis instead of salt

Main question:

what is $T_{surface}$ evolution with time all over winter?

no answer ⇒ no dynamic ice susceptibility index

... but no possibilty to measure $T_{surface}$ all day long during winter time on all road networks
(French road network on eastern part ~ 3200 km)

Idea:

measurements in relevant conditions to build thermal fingerprints covering all weather situations

Itinerary

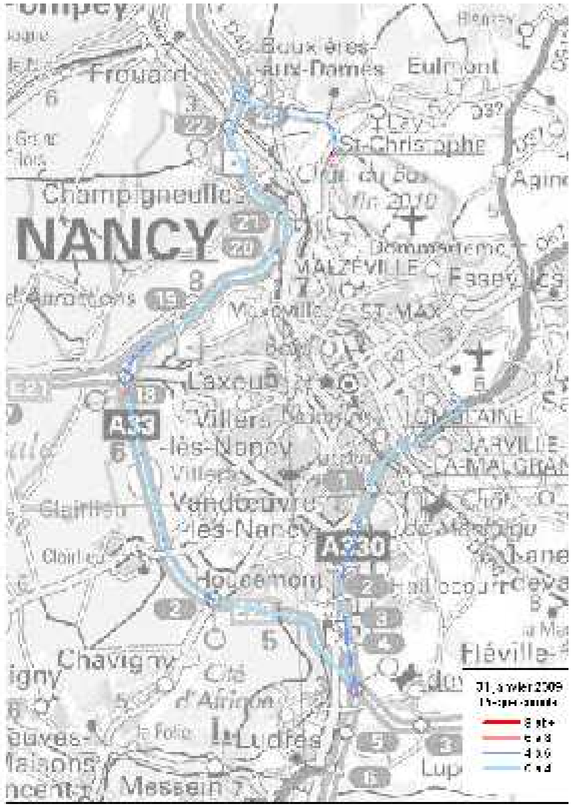
- 30 km long
- local and main roads, highways

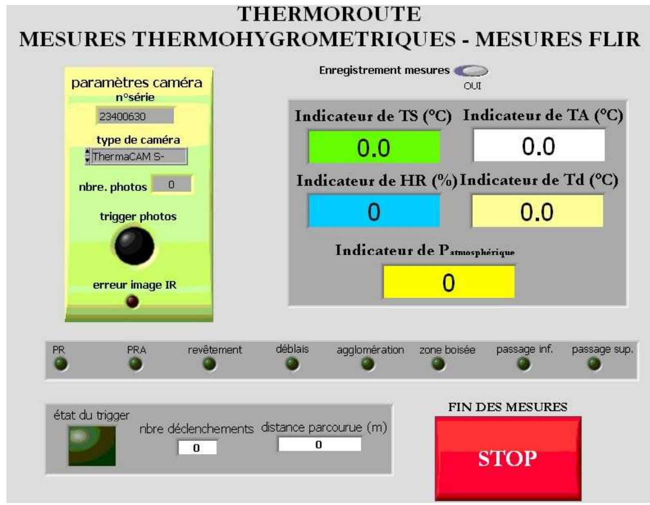
Data acquisition

- atmospheric parameters every 3 m
- maximum speed 110 km/h (~70 mph)
- LabVIEW® interface

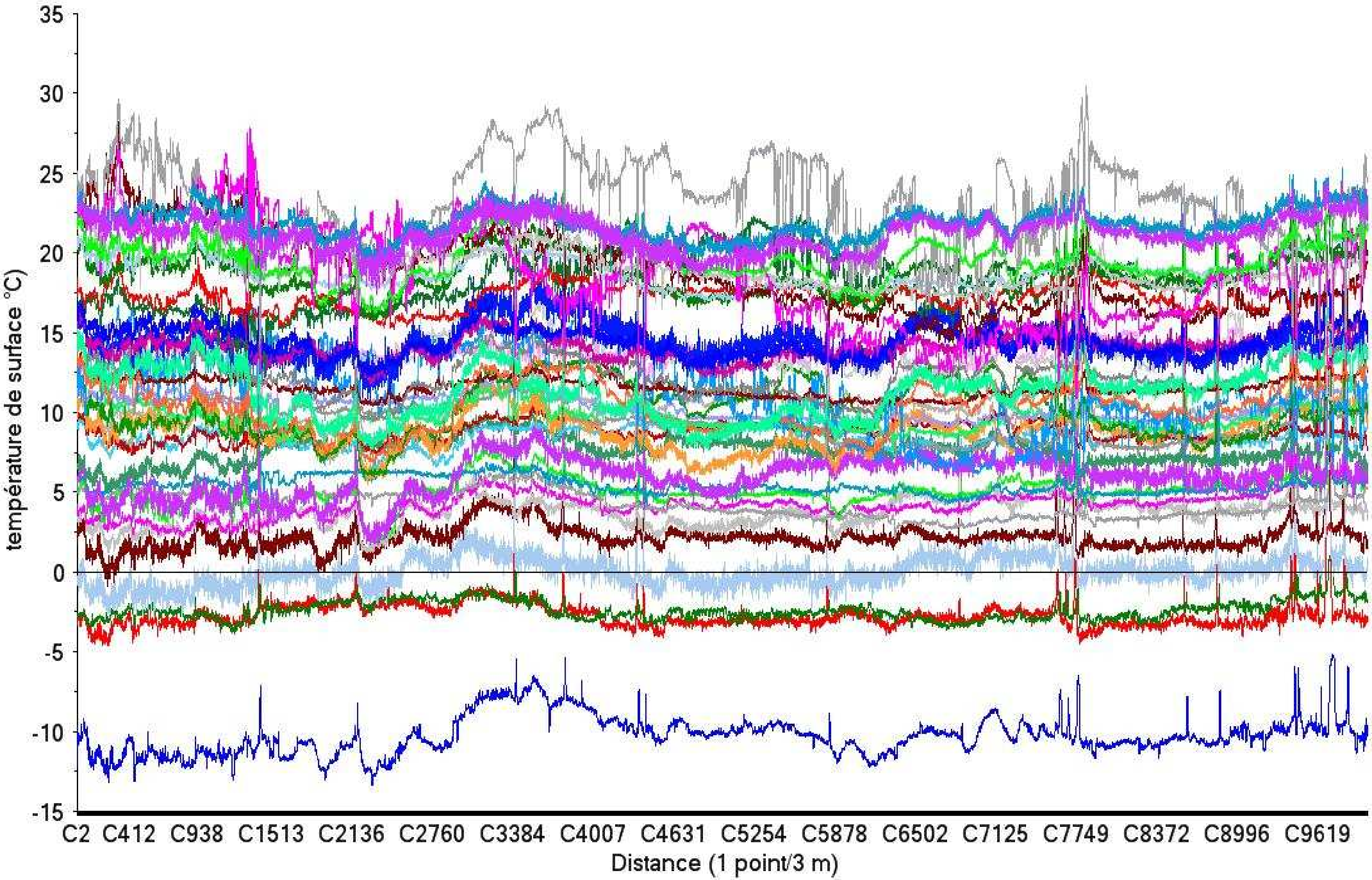
tens of thermal fingerprints since january 2009
(one or twice a month)

various measurements conditions
(various moment of the day and various weather situations except rainy and snowy ones, ...)
same departure and arrival points





$T_{surface}$ measurements over several months



Similar profiles with local distorsions and offsets
Existence of a generic profile to be adapted with seasons and weather conditions?

3.1. Principal components analysis - very short overview

Multivariate statistical data analysis = set of descriptive techniques based on matrix algebra
Statistical tool used = correlations or the variance-covariance matrix

Data-analytic technique: linear transformations of a group of correlated variables ⇒ optimal conditions
Most important condition = transformed variables are uncorrelated

Principal Component Analysis (PCA): statistical sensitivity analysis method
PCA = descriptive method, based on a NIPALS algorithm
In PCA, the physics generating variations "lost" for a mathematical one = linear combination of current physical factors
Data transposed in another space build on real physical factors.
Calculations conducted to identify the space leading to the lower variance, meaning axis along which data tend to gather

3.2. Principal components analysis - whole itinerary

Objectives

- Search of a minimum thermal fingerprints to build new relevant ones
- Measurements validation
- PCA interpolation to build new ones ("including" several weather situations)

Software

Unscrambler X 10.1, 32 bits

3 approaches/calculations:

- all data set (53 cases),
- all measurements below 5°C (8 cases)
- 5 measurements below 5°C (5 cases)

3.2. Principal components analysis - whole itinerary - Results

Case study	Case 1 All measurements (53)	Case 2 All measurements under 5°C (8)	Case 3 5 selected measurements under 5°C
Number of principal components (PC) used	10	6	3
Percentage of explained variance (with 1st PC)	98%	99%	99%
Outliers detected (number of data points)	1000	91	94

Good fit with the first principal component (PC)

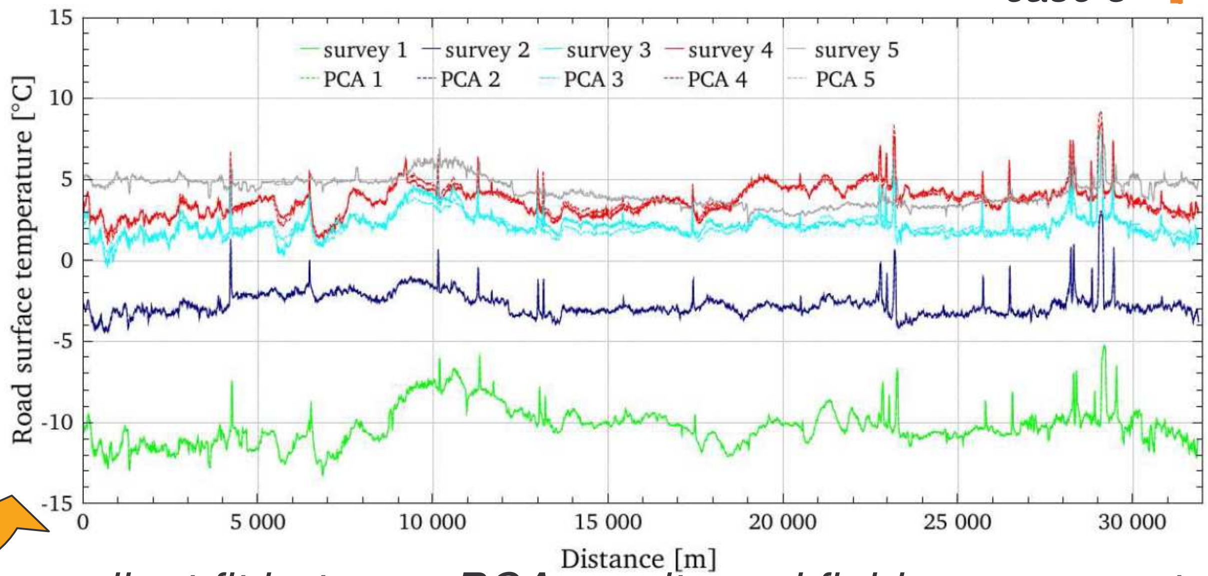
(statistically associated with the average)

98% of variance explained with 1st PC

Possibility to build thermal fingerprints with PCA results including several weather conditions

average +(scores)x(loadings)

case 3



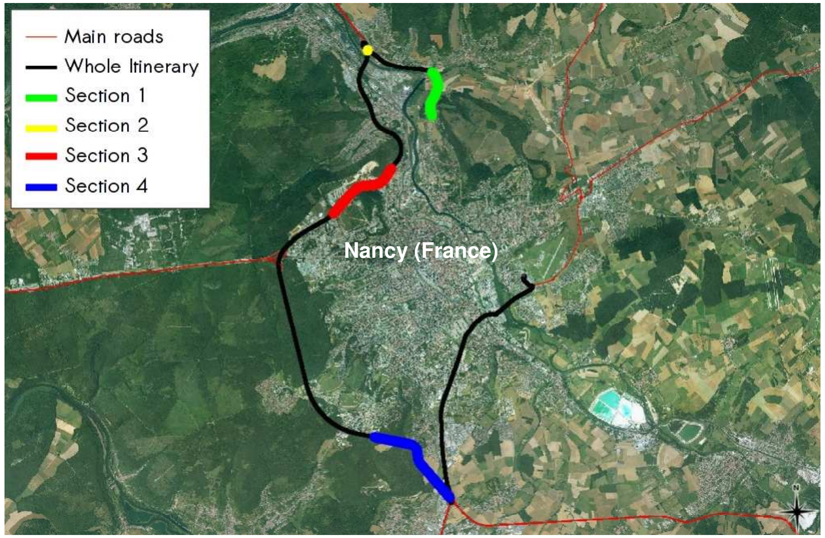
excellent fit between PCA results and field mesurements

3.2. Principal components analysis - itinerary sections

Objectives

- Search of a minimum thermal fingerprints to build new relevant ones
- Measurements validation
- PCA interpolation to build new ones
("including" several weather situations)
- Obtain an homogeneity with the road infrastructure,
or to isolate specific climatic phenomenon ***(land occupation, ...)***
- Identify winter maintenance specific needs.

Section 1: a slope (1500 m)
Section 2: a bridge (40 m)
Section 3: a hill (2400 m)
Section 4: a hill (3200 m)

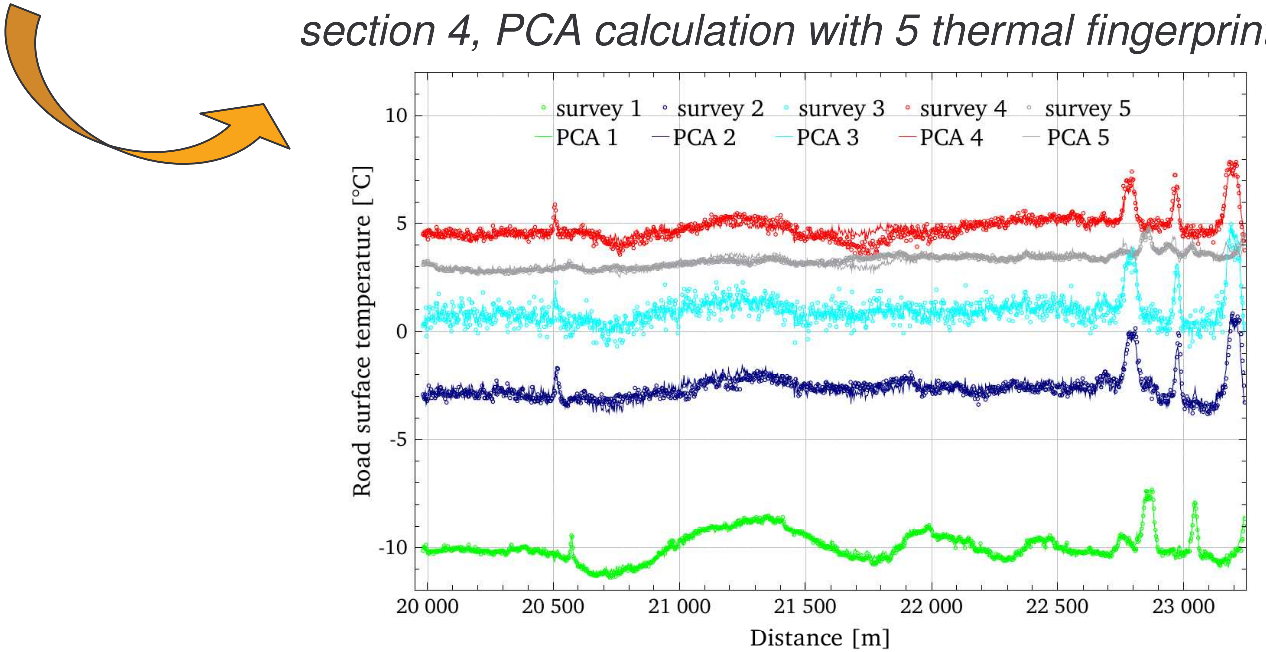


3.2. Principal components analysis - itinerary sections - Results

Possibility to build thermal fingerprints from PCA results

average +(scores)x(loadings)

section 4, PCA calculation with 5 thermal fingerprints, Ts < 5°C



excellent fit between PCA results and local field mesurements

3.2. Principal components analysis - itinerary sections - Results

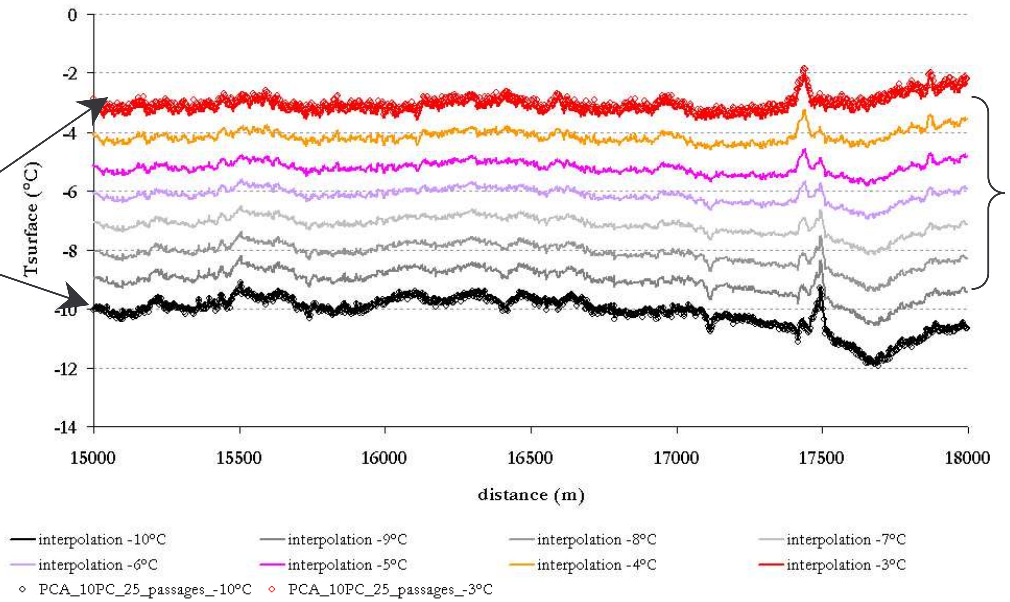
Field measurements and PCA results covering a given range of $T_{surface}$ but only for given values *(examples: data around -12°C, around -5°C)*

Idea: use of linear inerpolation between PCA results to obtain thermal fingerprints at other temperatures

data: PCA results PCA_1, PCA_2, ... PCA_n

interpolated: $PCA_{interpolated} = kPCA_i + (1-k)PCA_{i+1}$ *(with $0 \leq k \leq 1$)*

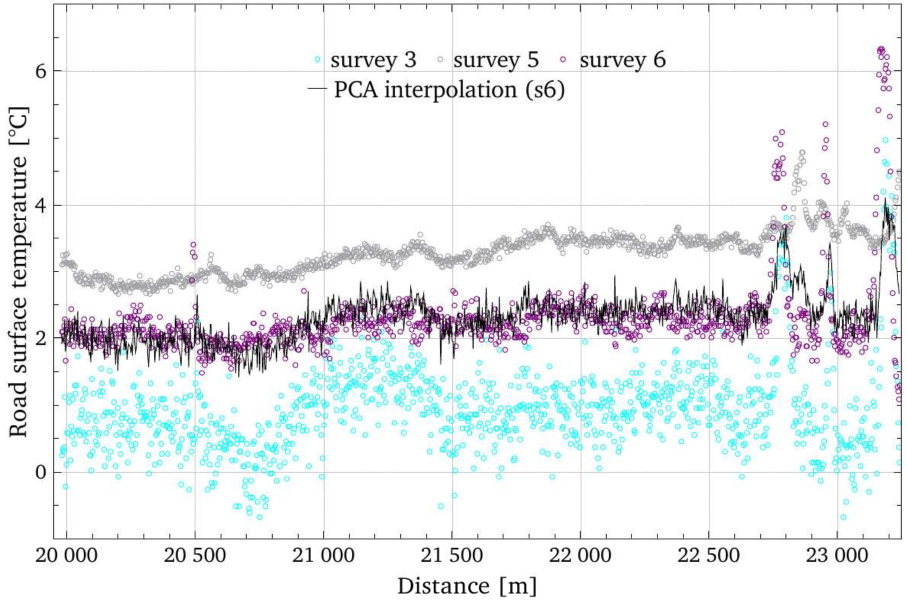
PCA results



interpolated

3.2. Principal components analysis - itinerary sections - Results

section 4, interpolation between PCA results, Ts < 5°C



excellent fit between interpoated PCA results and local field mesurements

4- Ice susceptibility occurrence maps

one possible definition of ice susceptiblity

$$\text{ice susceptibility} = 2.\text{susceptibility}(T_{surface}) + \text{susceptibility}(T_d),$$

$$\text{with susceptibility}(T_{surface}) = 0 \text{ if } -0.5°C \leq T_{surface} - T_{surface,average} < 0°C; 1 \text{ if } -1°C \leq T_{surface} - T_{surface,average} < -0.5°C; \ldots$$

$$\text{and susceptibility}(T_d) = 0 \text{ if } 0°C \leq T_d - T_{d,average} < 0.5°C; 1 \text{ if } 0.5°C \leq T_d - T_{d,average} < 1°C; \ldots$$

Main issue:

T_{air} and relative humidity known over a large area, or sometimes along itineraries

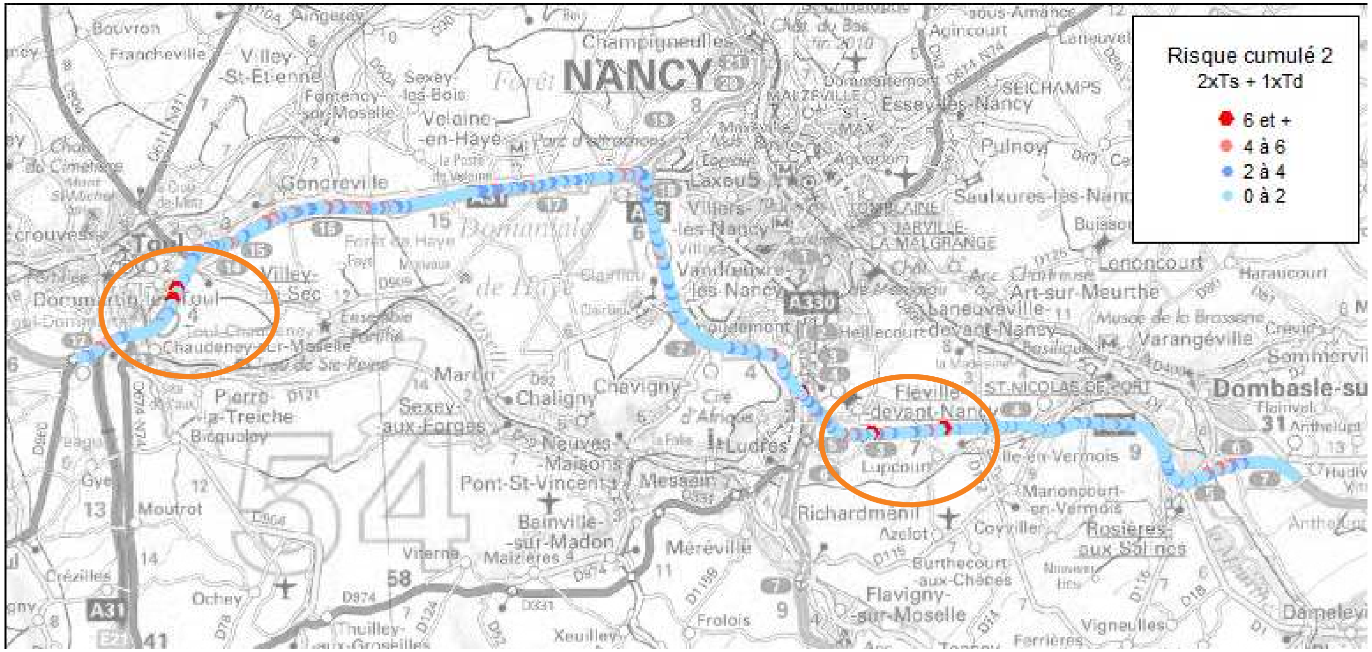
$T_{surface}$ known locally (RWIS), or "old" static data (thermal fingerprint)

Idea:

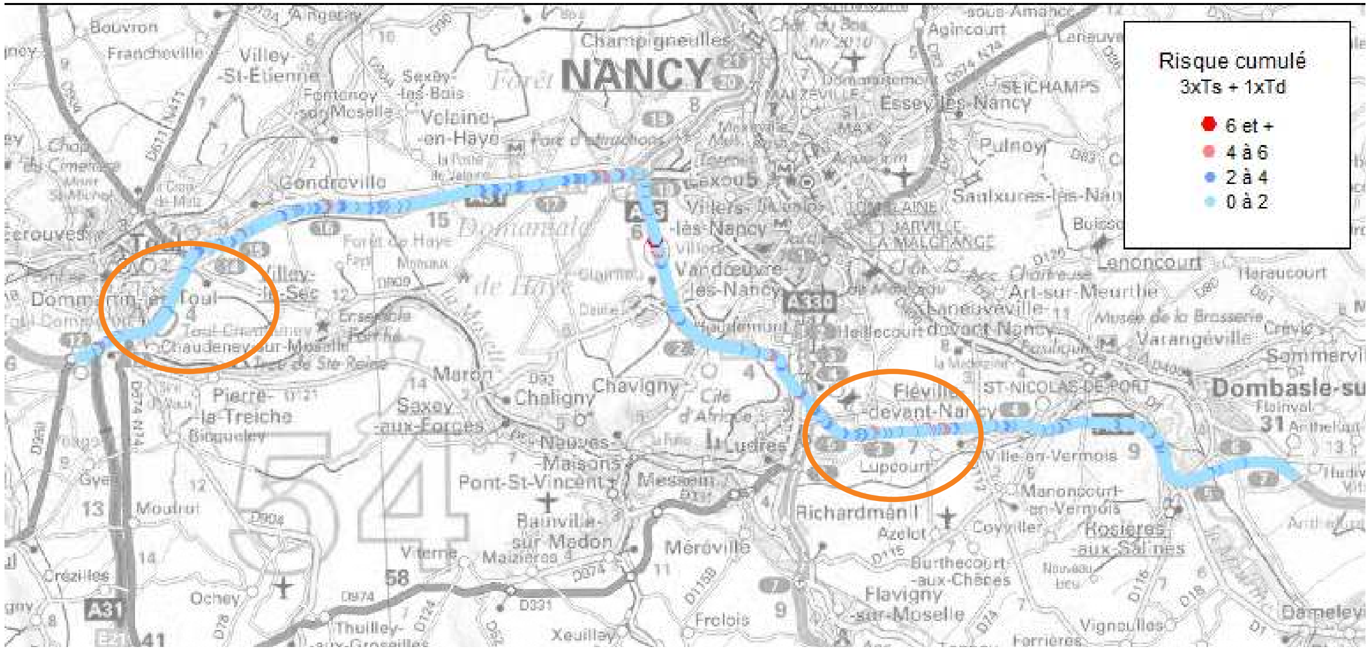
dew point temperature T_d: calculated with T_{air} and relative humidity data

surface temperature $T_{surface}$: extracted from PCA calculations

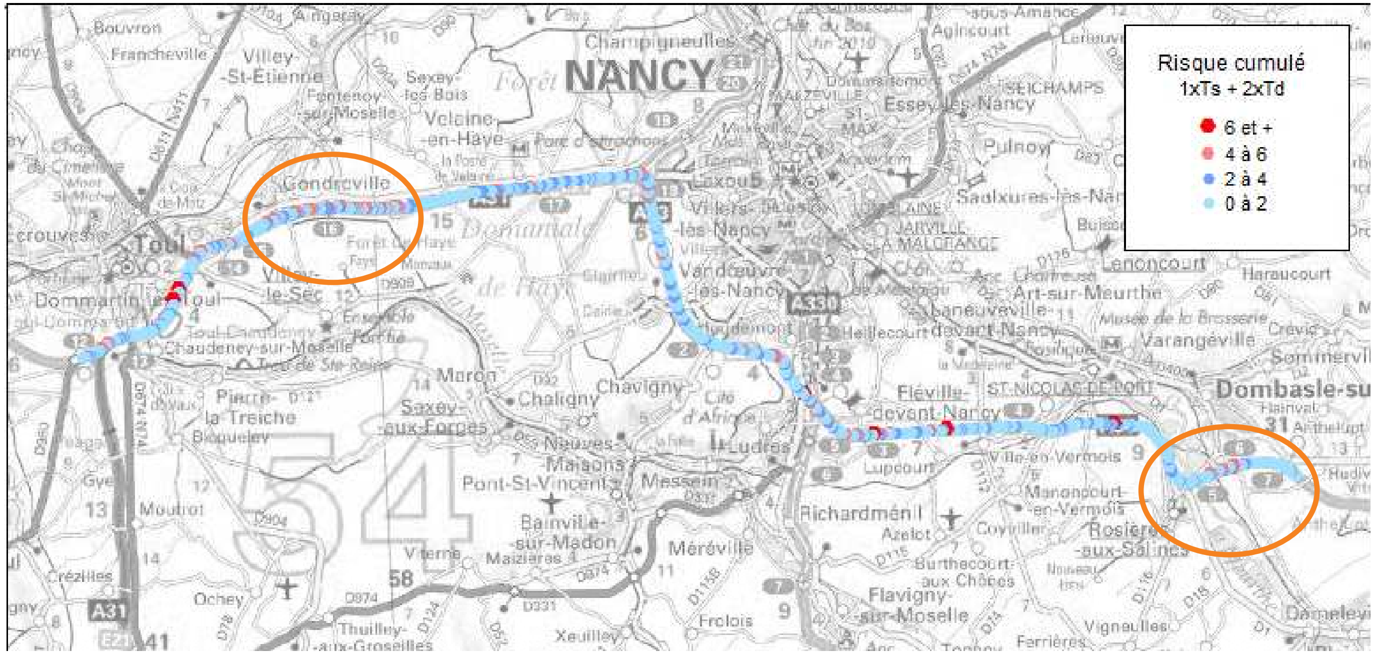
$\Rightarrow$ forecast of ice susceptibility occurrence



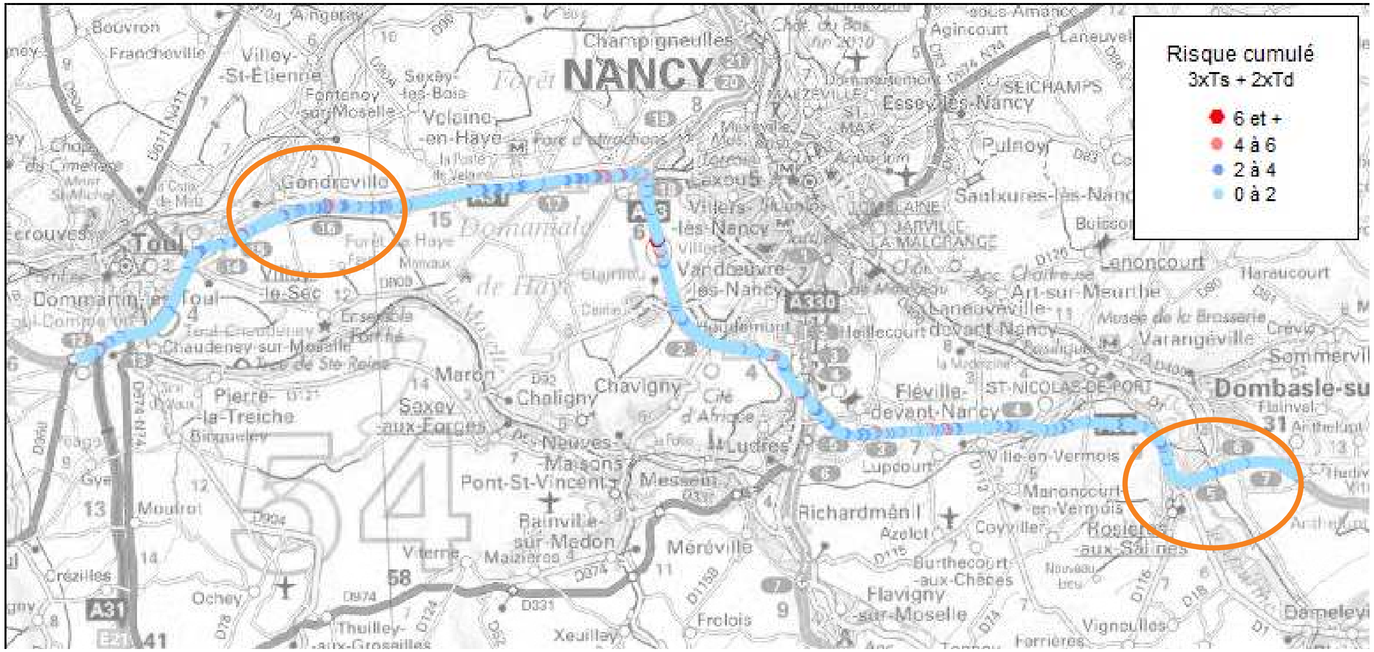
obtained with surface temperature measurement



obtained with PCA surface temperature



obtained with PCA surface temperature



obtained with PCA surface temperature

5- Conclusion. Perspectives

PCA: appropriate and relevant tool to build
- dynamic local thermal fingerprints,
- dynamic ice susceptibility risks maps

Results of PCA and interpolated ones containing the influence of various weather situations

Best results obtained on specific zones
(~ a few hundreds of meters)

Errors due to instruments and trajectories variations

Perspectives

- use of PLS *(forecast of $T_{surface}$ with a given parameter)*
- application to infrared thermal images
- emphasis to give a statistical weight to some specific sets of weather conditions

Thanks for your attention

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