IMPROVEMENTS AND LIMTS IN THE USE OF AN INFRARED CAMERA FOR PAVEMENT THERMAL MAPPING

M. Marchetti, M. Moutton, S. Ludwig
CETE de l'Est – LRPC Nancy-ERA 31
L. Ibos, J.-P. Monchau, V. Feuillet
Université Paris Est-CERTES
J. Dumoulin
Université Paris Est-IFSTTAR-MACS division

AITA - 2011, 9th-11th of September - Florence

Summary

1- Objectives

2- Implementation of infrared camera

3- Results - Winter risk estimations

4- Conclusion - Perspectives

1- Objectives

Context:

- Instrument on a vehicle to establish road susceptibility to ice
- Measurements on one lane at a time ⇒ tests too long
- Measurements on a small spot *(radiometer FOV 20°)*
- No appreciation of road radiative environment

Objectives:

- Implement an IR camera on a vehicle,
- Analyze several lanes simultaneaously,
- Compare results from the IR camera and a radiometer,
- Improve winter risk definition

2- Implementation of IR camera

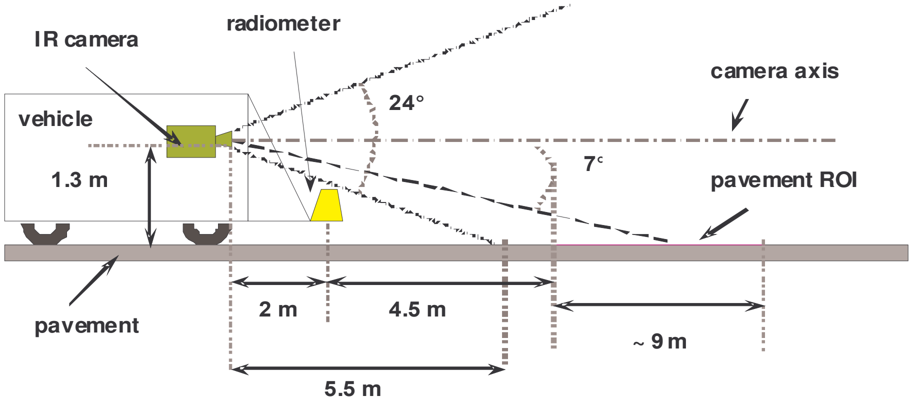
Radiometer PRT5 (BARNES Pyrometer) *(reference)*:

Detector type: bolometer
Spectral band: 9.5 - 11.5 µm
Temperature range: -40°C to + 70°C
Sensitivity: 0.1°C below 0°C, 0.05°C above 0°C
Accuracy: ± 0.5°C
FOV: 20°
Response time: 50 ms
NET : 0.005 for a time response of 50 ms on a body at 25°C

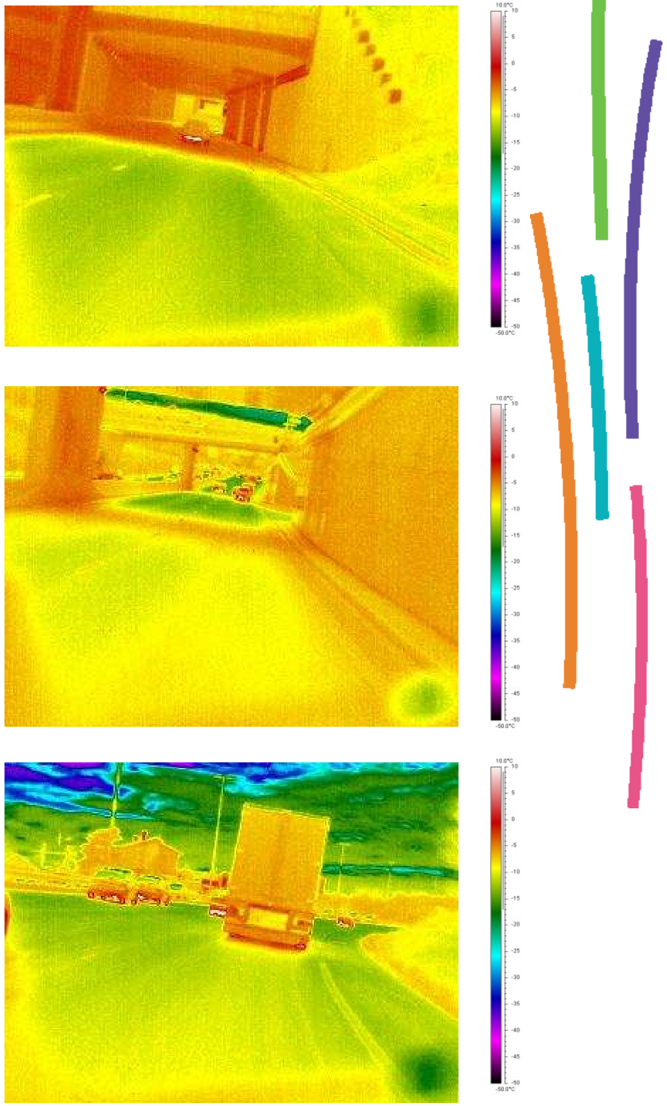
IR Camera FLIR S65 :

Detector type: uncooled microbolometer 320x240 matrix IRFPA
Spectral band: 7.5 - 13 µm
Temperature range: -40°C to + 120°C
Sensitivity: 0.08°C
Accuracy : ± 2 % of the measurement
FOV: 24°x18° (HxV) (35 mm focal lens)
IFOV : 1,3 mrad

Thermal mapping vehicle



Scheme of the camera installed on the vehicle



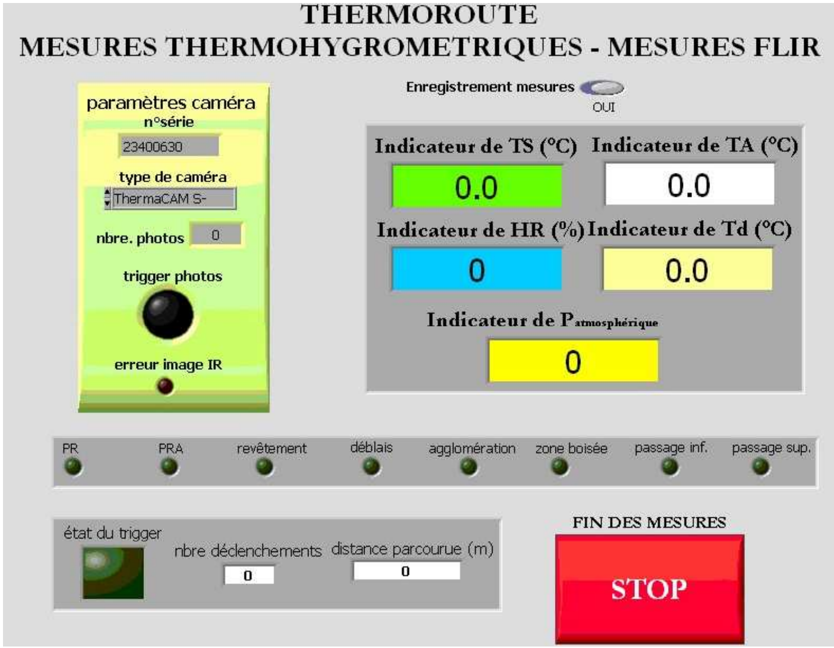
IR images *(-50°C<T<+10°C)*

Itinerary characteristics

- 30 km long
- local & main roads, highways

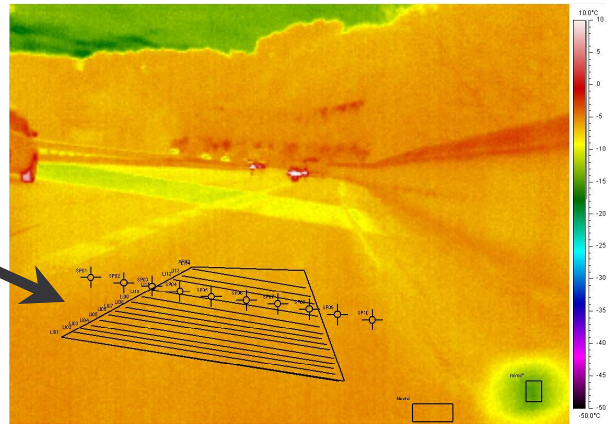
Data acquisition

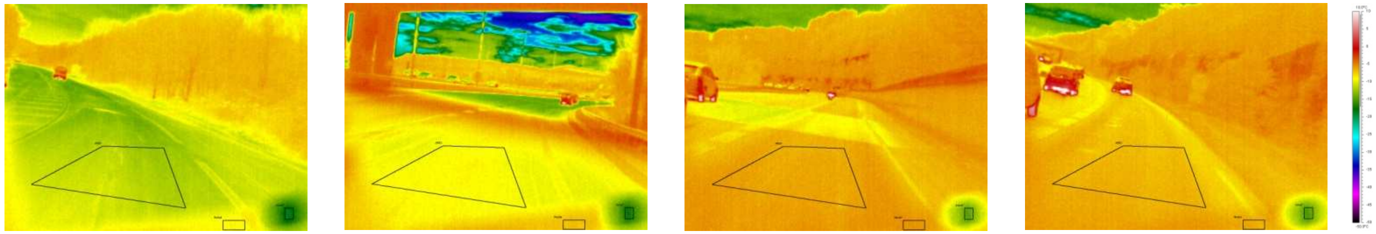
- atmospheric parameters every 3 m
- thermal images every 12 m *(native format)*
- maximum speed 70 km/h ≈ 44 mph
- LabVIEW® interface



Choice of an appropriate data analysis areas
(not directly affected by traffic)

- for emissivity correction
- for evaluation of transverse winter risk





IR images ***(-50°C<T<+10°C)***

Use of several regions of interest (ROI):

- ROI dedicated to road pavement

- Introduction of a "mirror" for environment correction (ε=0.063)

- Introduction of Nextel Velvet 811-21 as an emissivity reference (ε=0.97)

Distance offset betwen data from the radiometer and data from the IR camera (offset ≈ 12 m)

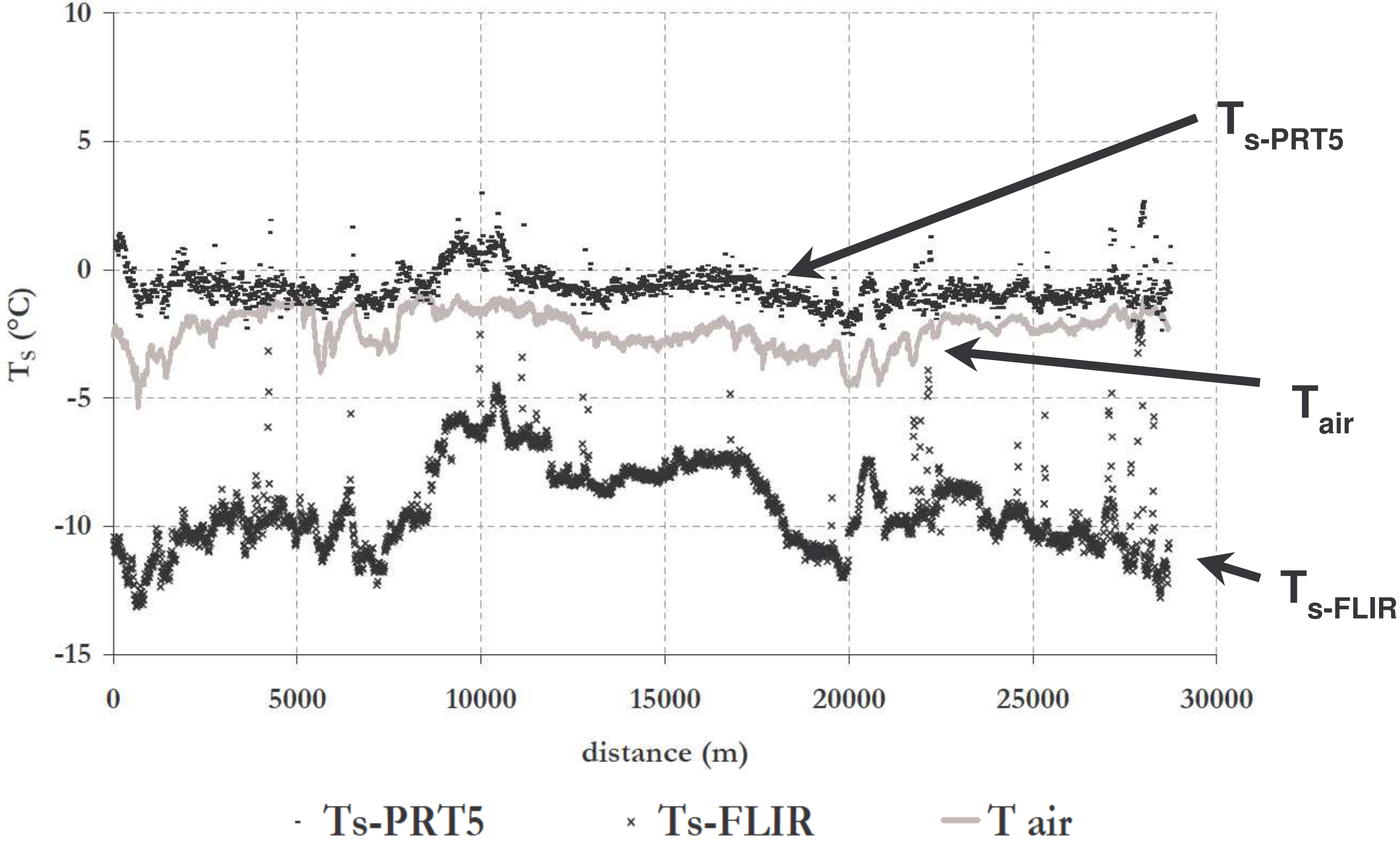
Thermal images triggered in "snapshot" mode every 12 m

- integration time of a few ms ⇒ slight blur in the images over 2 pixels
- compensation with ROI size >> blur size

Atmospheric parameters (T_{air}, relative humidity) as inputs in the IR camera

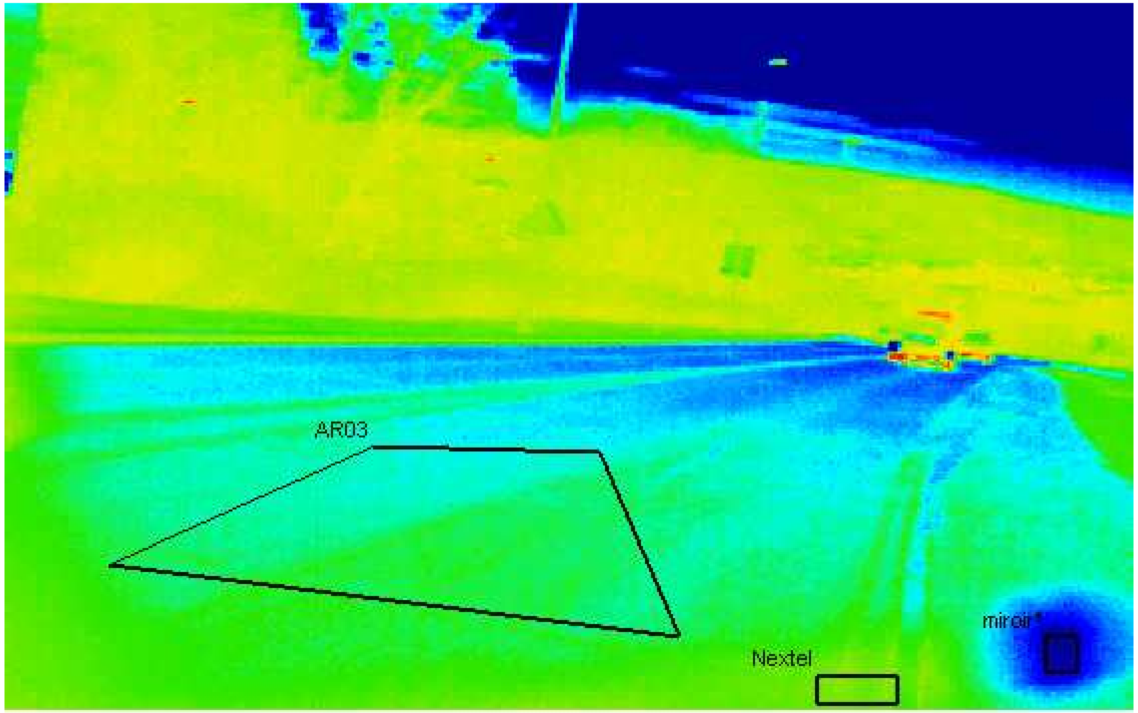
3- Results. Winter risk estimations

3.1. Temperature and radiative corrections



Results before any correction

Thermal images sequence of the Itinerary



Radiometric balance

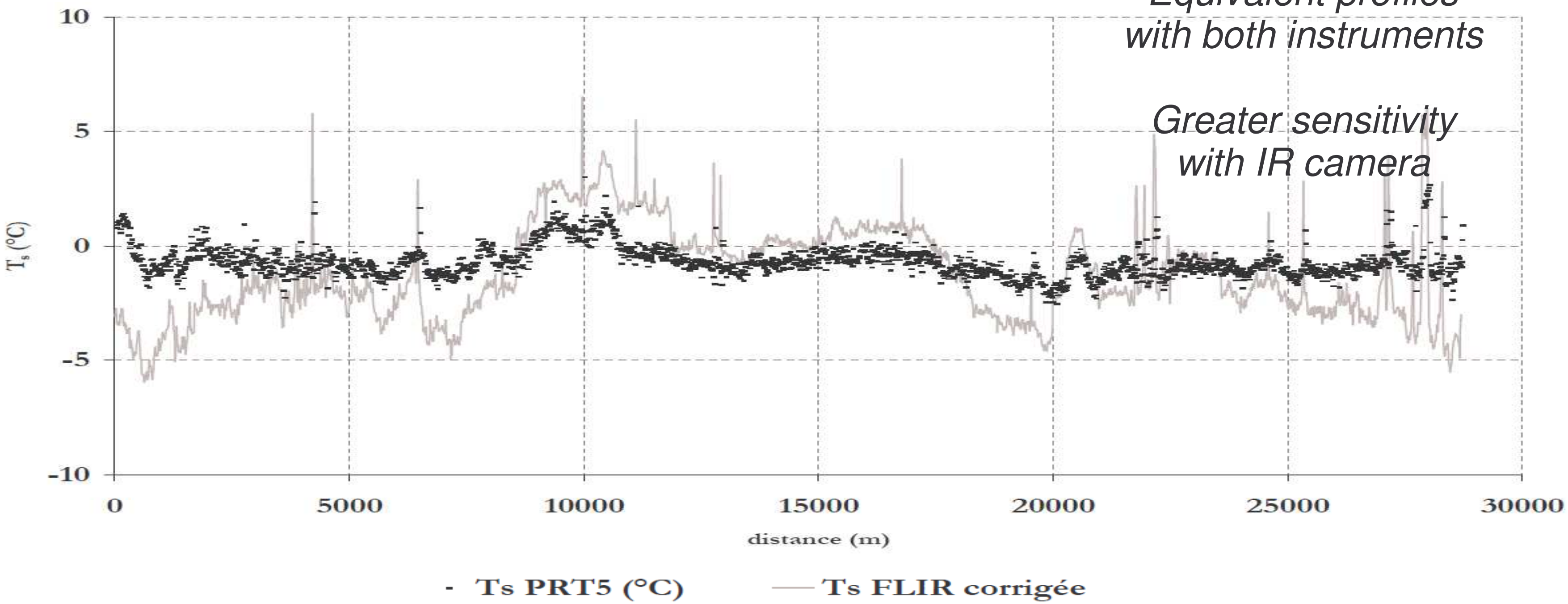
$$L_{measured} = \tau_{atmosphere}.\varepsilon_{pavement}.L_{pavement} + \tau_{atmosphere}.(1-\varepsilon_{pavement}).L_{environment} + (1-\tau_{atmosphere}).L_{atmosphere}$$

Radiometric corrections

- low distance and clear atmosphere: $\tau_{atmosphere} \sim 1$
- no specularity: Stefan law $L=\sigma T^4$
- emissivity correction over the pavement ROIs

$\Rightarrow$ emissivity distribution over pavement ROI

$$T^4_{measured} = \varepsilon_{pavement}.T^4_{pavement} + (1-\varepsilon_{pavement}).T^4_{environment}$$

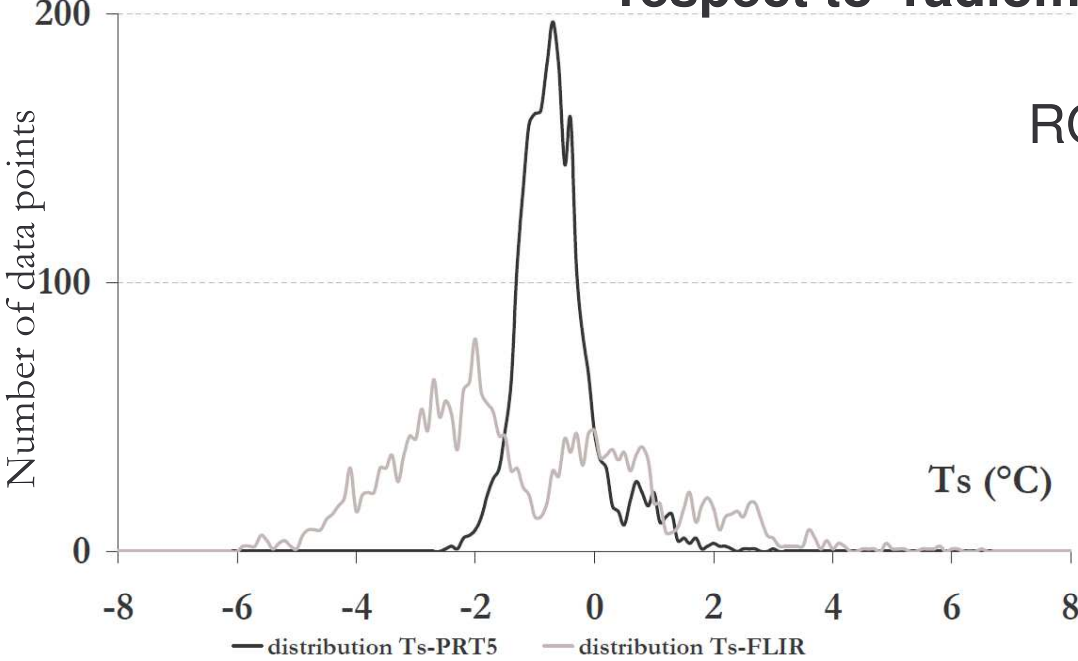


Equivalent profiles with both instruments

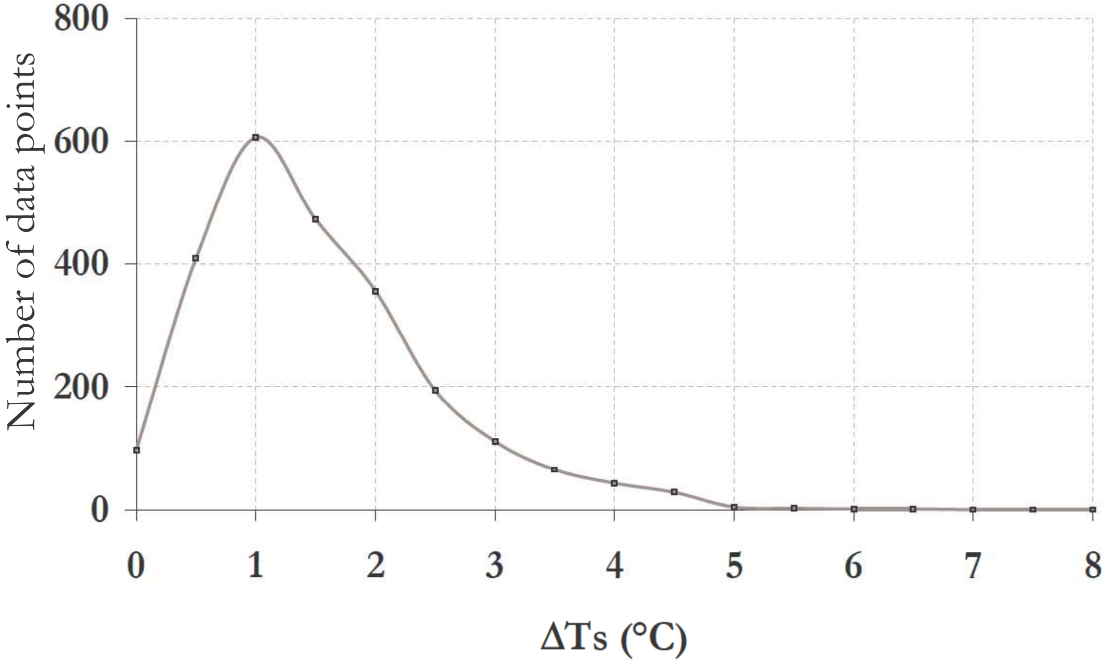
Greater sensitivity with IR camera

Results after radiometric corrections

Data dispersion in pavement ROI from the IR camera with respect to radiometer

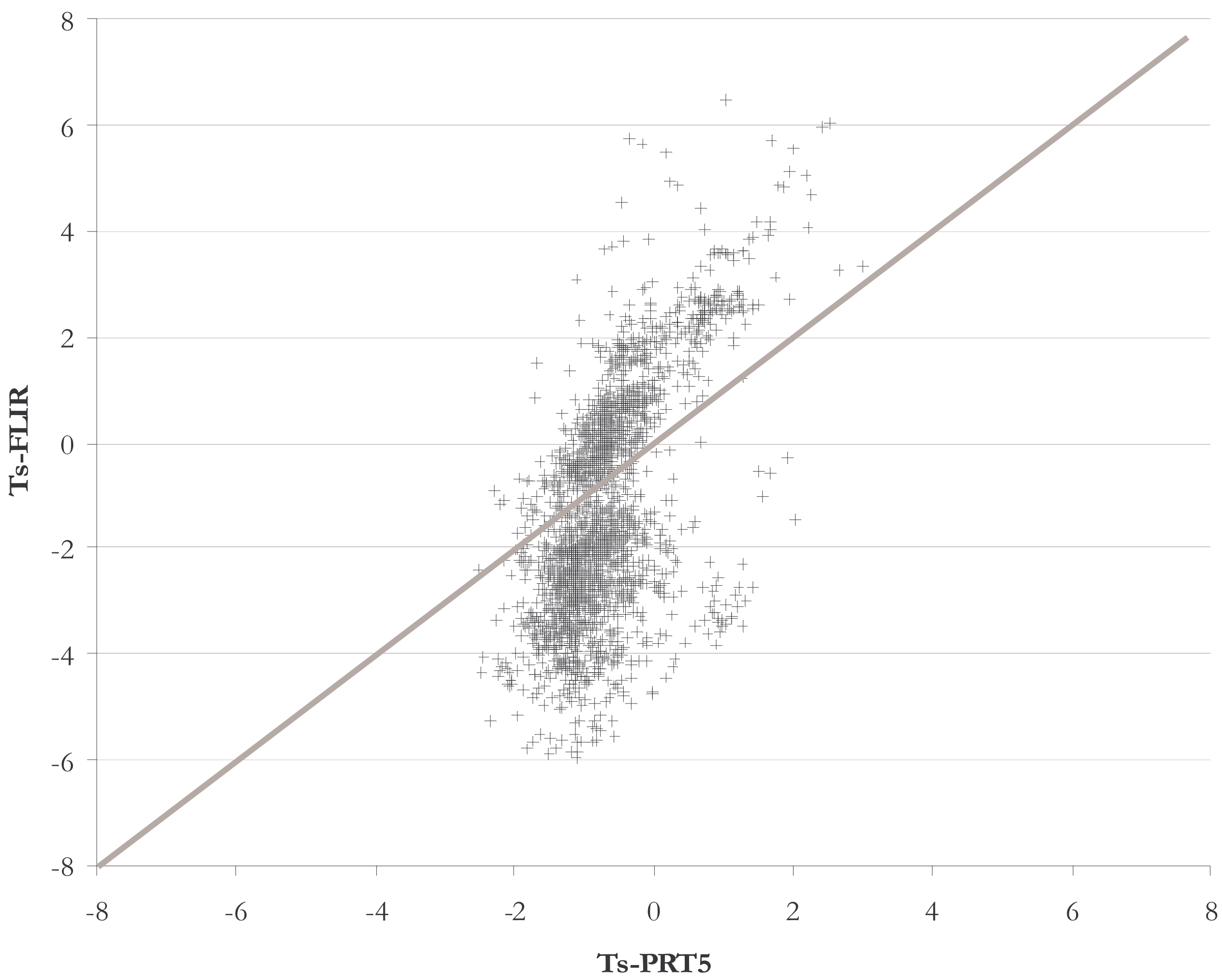


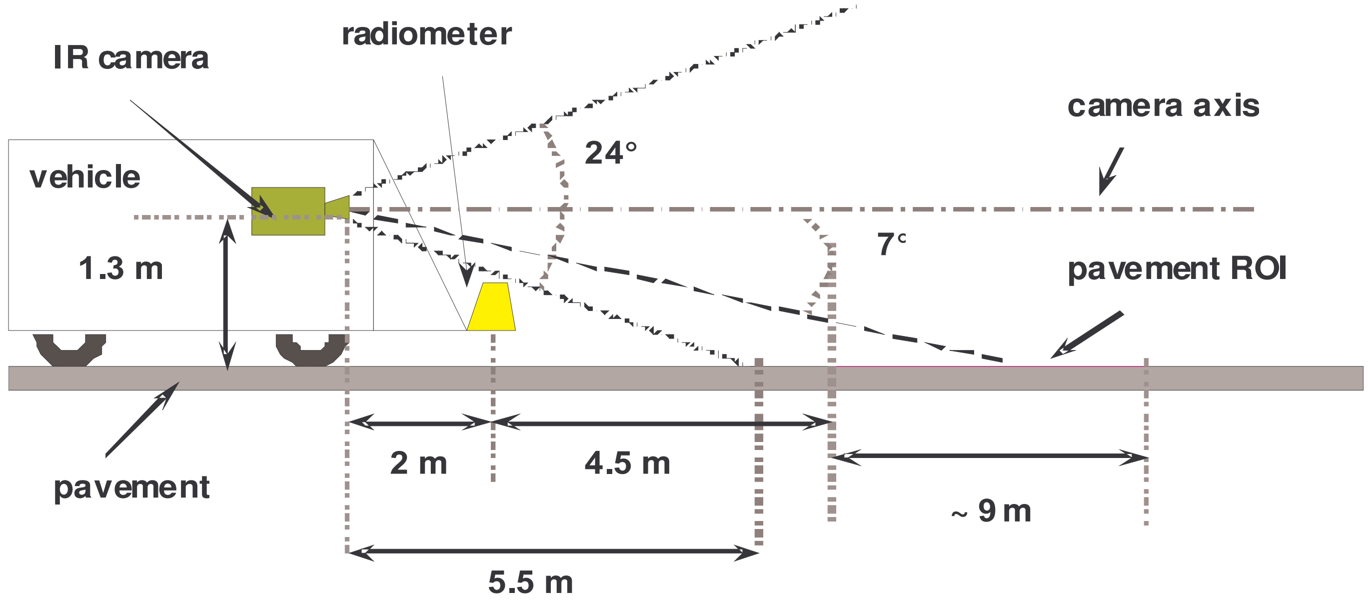
ROI IR camera more extended than the one of radiometer
⇒ greater temperature variations



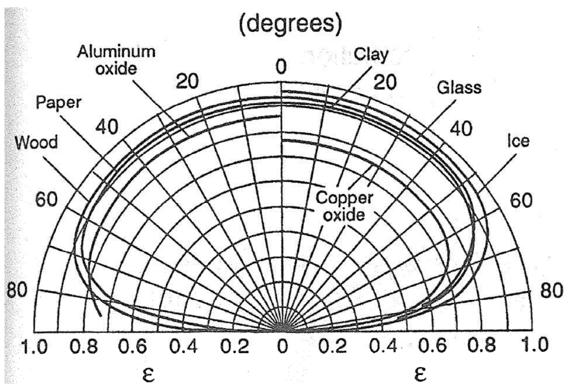
Absolute values of temperature differences between the two instruments

correlation between $T_{s\text{-}FLIR}$ and $T_{s\text{-}PRT5}$





emissivity correction to be improved over the pavement ROI
⇒ emissivity distribution over pavement ROI



Gaussorgues, 1981

Observation angle:

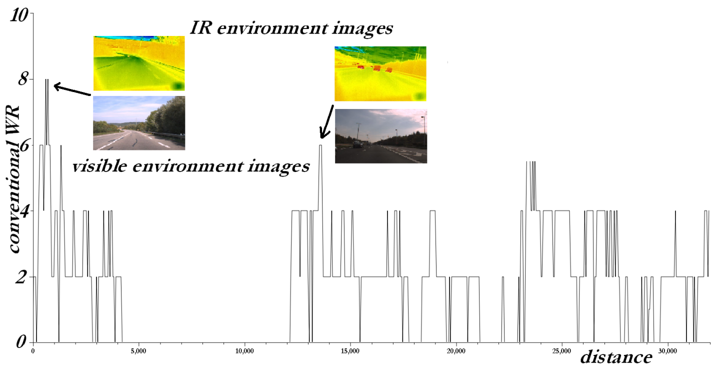
$\alpha_{average} \approx 7°$
$\alpha_{min} \approx 4°$
$\alpha_{max} \approx 11°$

Small angle reduction or increase = large emissivity change

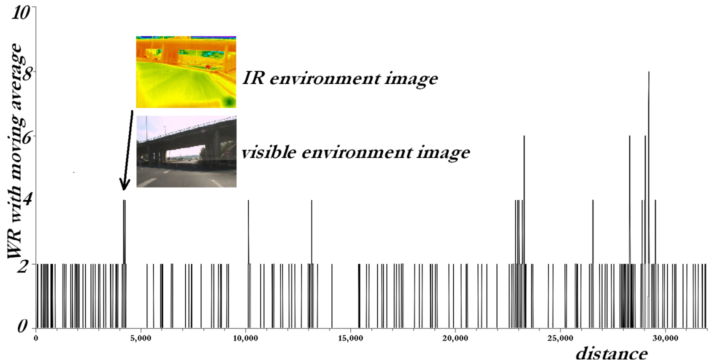
3.2. Winter risk index.
Consistency with seasons and infrastructure

Approach based on a moving average

$$WR = 2.WR(T_s) + WR(T_d),$$
$$\text{with } WR(T_s) = 0 \text{ if } 0°C \le T_{s,\text{moving average}} - T_s < 0.5°C; 1 \text{ if } 0.5°C \le T_{s,\text{moving average}} - T_s < 1°C; \ldots$$
$$\text{and } WR(T_d) = 0 \text{ if } 0°C \le T_{d,\text{moving average}} - T_d < 0.5°C; 1 \text{ if } 0.5°C \le T - T_{d,\text{moving average}} < 1°C; \ldots$$



2009-01-31
former conventional WR as a function of distance (in m)

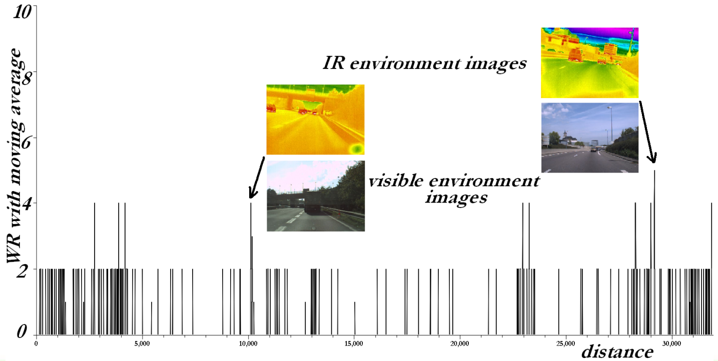


2009-01-31
moving average WR as a function of distance (in m)

greater consistency with the infrastructure ...

... and with seasons

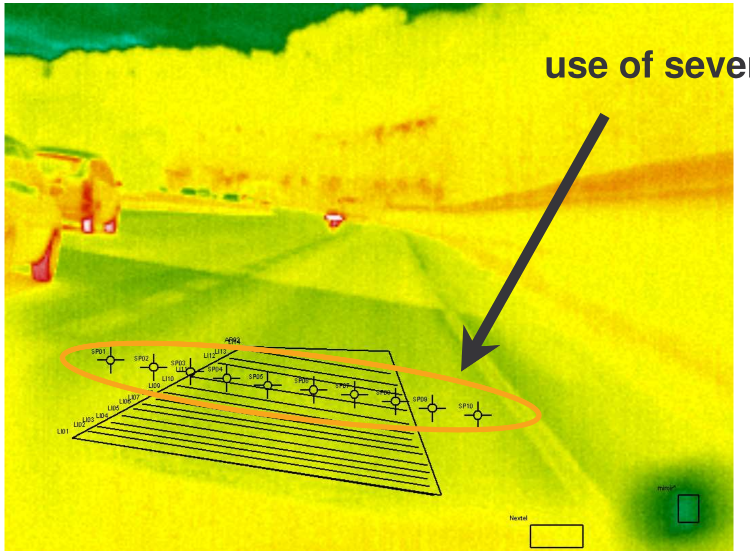
2009-08-19
moving average WR as a function of distance (in m)



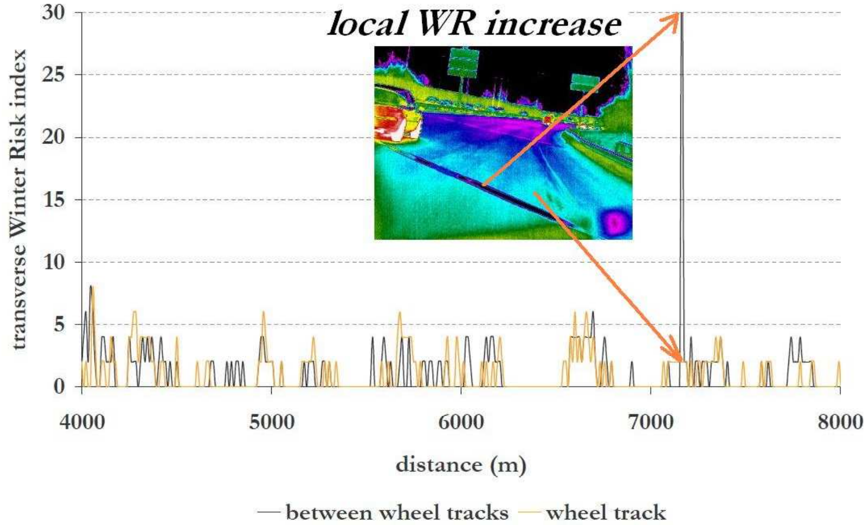
3.3. Evaluation of a transverse winter risk index

Continuous rolling of vehicles wheels ⇒ thermal specificity of wheel tracks

Additional investigation on the existence of a transverse winter risk (preferential wearing of the asphalt concrete in this part of pavement surface)



use of several points to identify transverse variations



No significant detected difference except for specific spots
Analysis very local ⇒ disappearance of WR in the wheel track with respect to the situation between the wheel tracks compensated by the occurrence of new WR elsewhere

4- Conclusion. Perspectives

Efficiency of the implementation of an IR camera for thermal mapping

Radiometric corrections :

- **emissivity corrections / grazing angle**
- **signal weakening / distance camera pavement**
- **detailed analysis of measured differences / radiometer**

(nature structures, radiative environment)

Improvements already implemented

- **better IR camera position (several lanes monitored)**
- **increased data acquisition frequency**

Thanks for your attention

additional contacts:

mario.marchetti@developpement-durable.gouv.fr
jean.dumoulin@ifsttar.fr
ibos@u-pec.fr

Ressources, territoires et habitats
Énergie et climat
Développement durable
Prévention des risques
Infrastructures, transports et mer

Présent pour l'avenir

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

CETE Est

IFSTTAR

UNIVERSITÉ PARIS-EST