Urban heat island and inertial effects: analyse from field data to spatial analysis

Jérémy BERNARD(1), Marjorie Musy, Isabelle Calmet, Erwan Bocher, Pascal Kéravec

(1) IRSTV / CRENAU
Observation: behaviour differences between several temperature signals ⇒ Inertial effects
Context

Observation: behaviour differences between several temperature signals ⇒ Inertial effects
Observation: behaviour differences between several temperature signals ⇒ Inertial effects
Context

Observation: behaviour differences between several temperature signals ⇒ Inertial effects
Study area and equipment
Study area and equipment

Data are recorded for 4 years
Study area and equipment

Data are recorded for 4 years

2 Meteo-France (MF) stations

8 TRH stations
Study area and equipment

2 Meteo-France (MF) stations

8 TRH stations

Data are recorded for 4 years

<table>
<thead>
<tr>
<th>Station</th>
<th>location</th>
<th>sampling time</th>
<th>sensor accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRH</td>
<td>mostly on walls</td>
<td>15 mins</td>
<td>+/- 0.3 K</td>
</tr>
<tr>
<td>MF</td>
<td>open sites</td>
<td>1h – linear interpolation every 15 mins</td>
<td>+/- 0.1 K</td>
</tr>
</tbody>
</table>
Climate indicators calculation

| Symbol | Indicator name               | Unit   | Time period                        | Equation                                                        |
|--------|-----------------------------|--------|------------------------------------|                                                               |
| Δt     | Time shift                  | mins   | sunset+4h → sunset+8h              | Index when the cross-correlation function is maximum           |
| Cr     | Cooling rate                | °C/h   | sunset → sunset+4h                 | mean temperature derivative difference                        |
| UHIn   | Night-time Urban Heat Island| °C     | all day                            | mean temperature difference                                    |
Climate indicators calculation

A reference is used for each indicator calculation: "MF_Boug"

Calculations are performed for each day

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Indicator name</th>
<th>Unit</th>
<th>Time period</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δt</td>
<td>Time shift</td>
<td>mins</td>
<td>sunset+4h → sunset+8h</td>
<td>Index when the cross-correlation function is maximum</td>
</tr>
<tr>
<td>Cr</td>
<td>Cooling rate</td>
<td>°C/h</td>
<td>sunset → sunset+4h</td>
<td>mean temperature derivative difference</td>
</tr>
<tr>
<td>UHIn</td>
<td>Night-time Urban Heat Island</td>
<td>°C</td>
<td>all day</td>
<td>mean temperature difference</td>
</tr>
</tbody>
</table>
Season / weather conditions filtering

data

daily distinction
Season / weather conditions filtering

Filtering

- data
  - daily distinction
    - rain
    - no rain
Season / weather conditions filtering

Filtering
- rain
  - spring
  - summer
  - autumn
  - winter

Sorting
- no rain

Data
- daily distinction
Season / weather conditions filtering

- Filtering
- Sorting
- Filtering

Data

Daily distinction

Rain

- Spring
- Summer
- Autumn
- Winter

No rain

Time range for UHIn

Time range for Cr

Time range for Δt
Season / weather conditions filtering

- Filtering:
  - rain
  - no rain

- Sorting:
  - spring
  - summer
  - autumn
  - winter

- Filtering:
  - time range for UHIn
  - time range for Cr
  - time range for $\Delta t$

- Calculation:
  - UHIn
  - mean wind
  - mean nebulosity
Season / weather conditions filtering

Filtering:
- Rain
- No rain

Sorting:
- Spring
- Summer
- Autumn
- Winter

Calculation:
- UHIn
- Mean wind
- Mean nebulosity

Sorting:
- Wind and nebulosity sorting
Season / weather conditions filtering

Data
- Daily distinction
  - Rain
    - Spring
      - Time range for UHIn
    - Summer
      - Time range for Cr
    - Autumn
      - Time range for Δt
    - Winter
      - Wind and nebulosity sorting
Geographical indicators calculation

- Sensor location
- Reference unit for analysis (100m radius)
- Buildings surface
- Mineral ground cover
- High vegetation surface
- Low vegetation surface
Geographical indicators calculation

BD TOPO - IGN - 2013

SPOT image - 2.5 m resolution - 2004

Sensor location
Reference unit for analysis (100m radius)
Buildings surface
Mineral ground cover
High vegetation surface
Low vegetation surface
Geographical indicators calculation

Calculated indicators:
- Average building height
- Linear of facade density
- Open space area
- Building volume density
- Facade density
- Vegetation density
- Equivalent admittance
Geographical indicators calculation

Calculated indicators:
- Average building height
- Linear of facade density
- Open space area
- Building volume density
- Facade density
- Vegetation density
- Equivalent admittance

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_{Flin}</td>
<td>Linear of facade density</td>
<td>( \frac{\sum_i p_i}{A_{ref}} )</td>
</tr>
<tr>
<td>ADM</td>
<td>Equivalent admittance</td>
<td>( \mu_a (D_{Flin} h_w + \frac{a_{vh}}{A_{ref}} + \frac{a_{vh}}{A_{ref}} + \frac{a_{vl}}{A_{ref}}) )</td>
</tr>
</tbody>
</table>

- \( A_{ref} \): buffer circle area (m²)
- \( p_i \): perimeter of the building i
- \( a_{vh} \): area taken by the high vegetation i
- \( a_{vl} \): area taken by the low vegetation i
- \( a_{bg} \): area taken by the bare ground i
- \( a_{as} \): area taken by the artificial surface i
- \( \mu_v = 700 \), \( \mu_d = 175 \), \( \mu_{vh} = 350 \): thermal admittance for artificial surfaces, low vegetation and high vegetation (J.m⁻².s⁻¹/².K⁻¹)
- \( h_w = 3 \): wall height to consider as influent on the air temperature at screen height
Wind speed classification
(Spring)

Wind speed (m/s)

UHln (°C)

Decile sup (q = 0.9) - clear
Decile inf (q = 0.1) - clear

20-24th July 2015
Wind speed classification

(Spring)

Wind speed (m/s)

Calm

Windy

Stormy

| Decile sup (q = 0.9) - clear |
| Decile inf (q = 0.1) - clear |

Introduction
Methods
Results
Discussion

20-24th July 2015
Nebulosity classification

(Spring)

UHIn (°C)

Nebulosity (octas)
Nebulosity classification

(Spring)

Nebulosity (octas)

Clear

Cloudy

Covered

UHln (°C)

Decile sup (q = 0.9) - calm
Decile inf (q = 0.1) - calm
Interclimatic indicators regression

![Graph showing UHIn (°C) vs. Time shift (mins)]
The slope of the regression is modified by the season and the weather conditions.

$R^2$ is good (most of the time $> 0.6$) – 0.94 and 0.90 between UHIn and Cr respectively for summer and autumn time (clear and calm conditions).

⇒ the 4 hours after sunset seem decisive for UHI formation.
UHIn versus geographical indicators

\[
\begin{align*}
\text{UHIn (°C)} & \quad \text{D}_{\text{Flin}} \\
\text{Autumn time - 9 days} & \quad y = 9.19 x, R^2 = 0.748 \\
\text{Spring time - 22 days} & \quad y = 8.36 x, R^2 = 0.654 \\
\text{Summer time - 30 days} & \quad y = 7.57 x, R^2 = 0.738 \\
\text{Winter time - 7 days} & \quad y = 6.27 x, R^2 = 0.791
\end{align*}
\]
UHIn versus geographical indicators

![Graph showing relationship between UHIn (°C) and ADM](image)

- Autumn time - 9 days
- Spring time - 22 days
- Summer time - 30 days
- Winter time - 7 days

Equations:
- $y = 0.00332x, R^2 = 0.851$
- $y = 0.003x, R^2 = 0.734$
- $y = 0.00273x, R^2 = 0.839$
- $y = 0.00213x, R^2 = 0.792$
Application of the results on Nantes

- < 0.75 °C
- 0.75 - 1 °C
- 1 - 1.5 °C
- 1.5 - 2 °C
- 2 - 3°C
- > 3 °C

Water surface
Application of the results on Nantes

[Map showing temperature zones and station locations]
Application of the results on Nantes

- < 0.75 °C
- 0.75 - 1 °C
- 1 - 1.5 °C
- 1.5 - 2 °C
- 2 - 3 °C
- > 3 °C

Water surface

---

Observed UHIn (°C)

Modelled UHIn (°C)

20-24th July 2015
Application of the results on Nantes

- < 0.75 °C
- 0.75 - 1 °C
- 1 - 1.5 °C
- 1.5 - 2 °C
- 2 - 3 °C
- > 3 °C

Water surface

Observed UHI\(\text{In}\) (°C)

MF_Boug

Goss

10

17

11

04

06

18

18

02

06
Application of the results on Nantes

Observed UHIn (°C)

- < 0.75 °C
- 0.75 - 1 °C
- 1 - 1.5 °C
- 1.5 - 2 °C
- 2 - 3°C
- > 3 °C

Water surface

Buffer 100 m

Modelled UHIn (°C) vs Observed UHIn (°C)
Further improvements

- **Climatic measurement:**
  - Increase the number of measurement sites (currently too low for good regression analysis)
Further improvements

- **Climatic measurement:**
  - Increase the number of measurement sites (currently too low for good regression analysis)
  - Use poles far from urban surfaces for sensor location
  - Improve the knowledge about shield issues
Further improvements

- **Climatic measurement:**
  - Increase the number of measurement sites (currently too low for good regression analysis)
  - Use poles far from urban surfaces for sensor location
  - Improve the knowledge about shield issues

- **Geographical part:** evaluate the influence on the results of:
  - The size and the shape (LCZ, buffer circle, city block defined from road network) choice of the spatial reference unit;
  - The accuracy of the data (remote sensing image resolution) and the errors led by the use of different sources of data
Acknowledgements

Thank you for your attention!

- **Work supported by**
  - French Environment and Energy Management Agency (ADEME)
  - AgroCampus Ouest (ACO) school
  - Region des Pays de la Loire

- **Special thanks to :**
  - OrbisGIS team for their technical support ([http://www.orbисgis.org/about/the-team/](http://www.orbисgis.org/about/the-team/))
  - Meteo-France for the availability of their measurement data
Wind speed classification

- Calm
- Windy
- Stormy

Wind speed (m/s)

UHln (°C)
Nebulosity classification

![Graph showing different nebulosity levels and their classifications.

Legend:
- Decile sup (q = 0.9) - calm
- Decile inf (q = 0.1) - calm
- Decile sup (q = 0.9) - windy
- Decile inf (q = 0.1) - windy
- Decile sup (q = 0.9) - stormy
- Decile inf (q = 0.1) - stormy

Nebulosity (octas):

- Clear
- Cloudy
- Covered

UHI (°C):

Range: -1.5 to 3.0