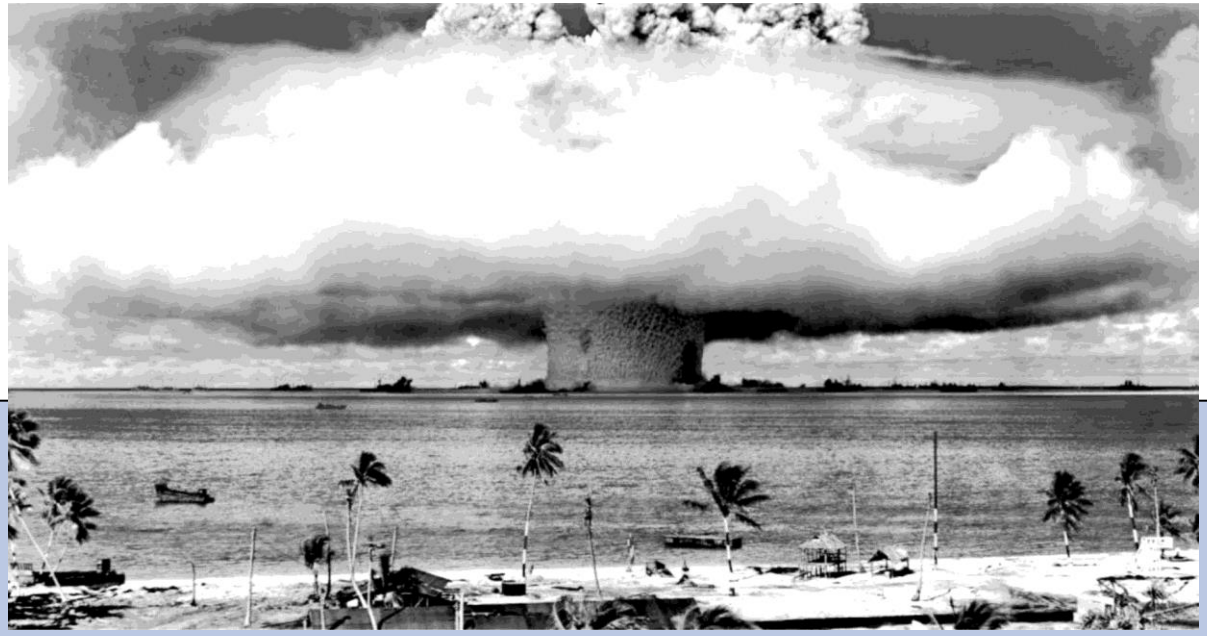
An introduction to the optical and thermal properties of building surfaces

- **Chaire « Architecture et Physique Urbaine »**
- **Urban Physics Joint Laboratory**
- **ISA BTP – Nobatek – Arkinova (Anglet)**

Benoit Beckers

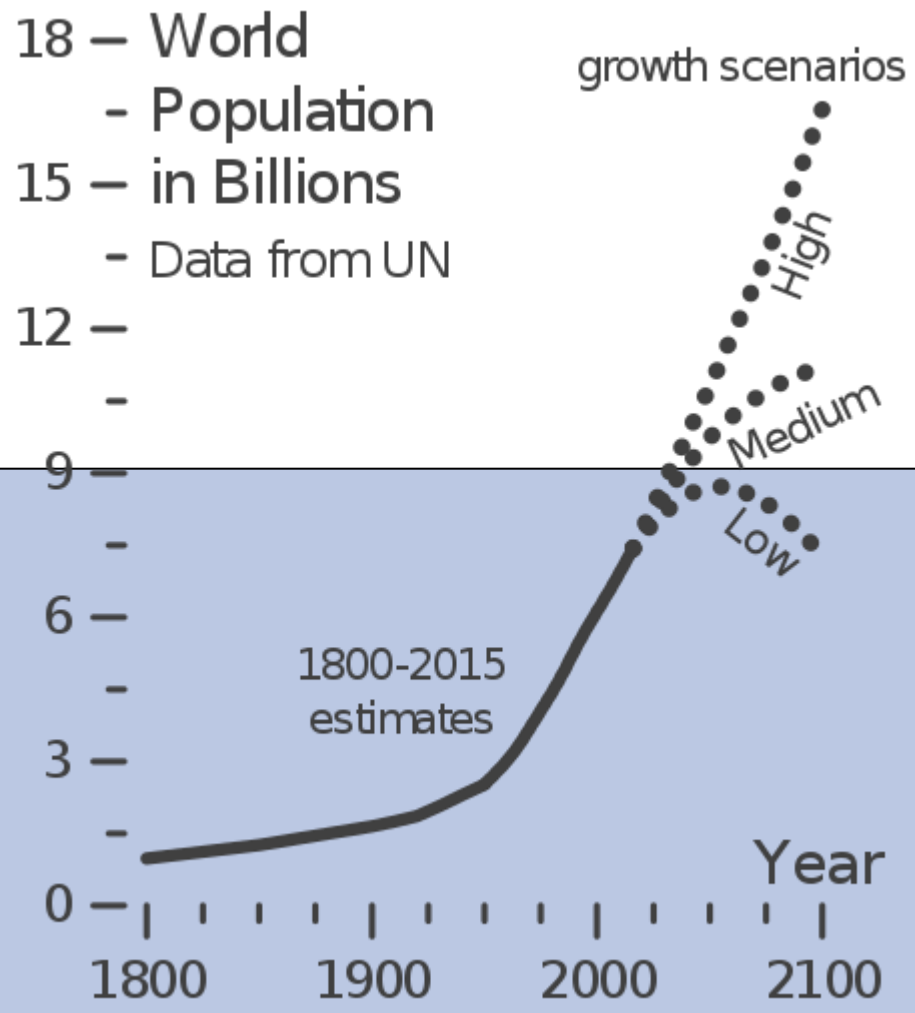
September 2017

What is the worst threat to the survival of our civilization?



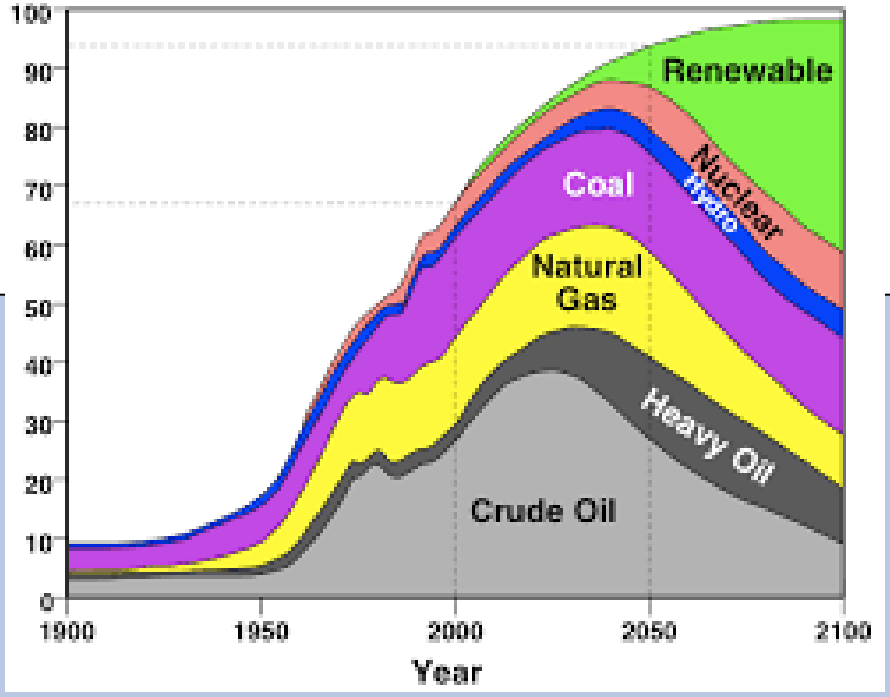
The Third world war?

What is the worst threat to the survival of our civilization?



the growth of the world's population?

What is the worst threat to the survival of our civilization?



The Peak oil?

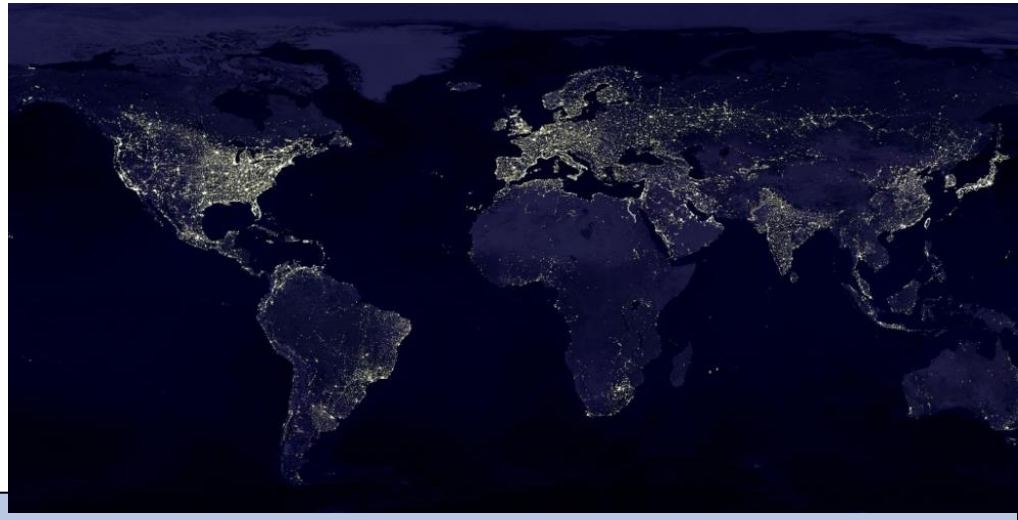
What is the worst threat to the survival of our civilization?

Climate change?

What is the worst threat to the survival of our civilization?

Urban sprawl !

Urban sprawl



1970 © NASA GSFC 2000

" … If current trends in population density continue and all areas with high probabilities of urban expansion undergo change, then by 2030, urban land cover will increase by 1.2 million km2, nearly tripling the global urban land area circa 2000."

Seto K. C., Güneralp B. & Hutyra L. R., "Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools", Proceedings of the National Academy of Sciences of USA,2012 October 2; 109(40): 16083–16088.

Urban sprawl

"The combination of an increasing number of human beneficiaries of ecosystem services and increasing competition for the land that provides these services is a worldwide phenomenon for which **the policy implications are only now beginning to be considered**."

Eigenbrod V.F., Bell A., Davies H.N. et al. (2011), "The impact of projected increases in urbanization on ecosystem services", Proceedings of the Royal Society B. 278:3201-3208.

"The heat generated **by everyday activities in metropolitan areas** [of Northern Asia and North America] has a significant enough warming effect to **influence the character of the jet stream** and other major atmospheric systems during winter months."

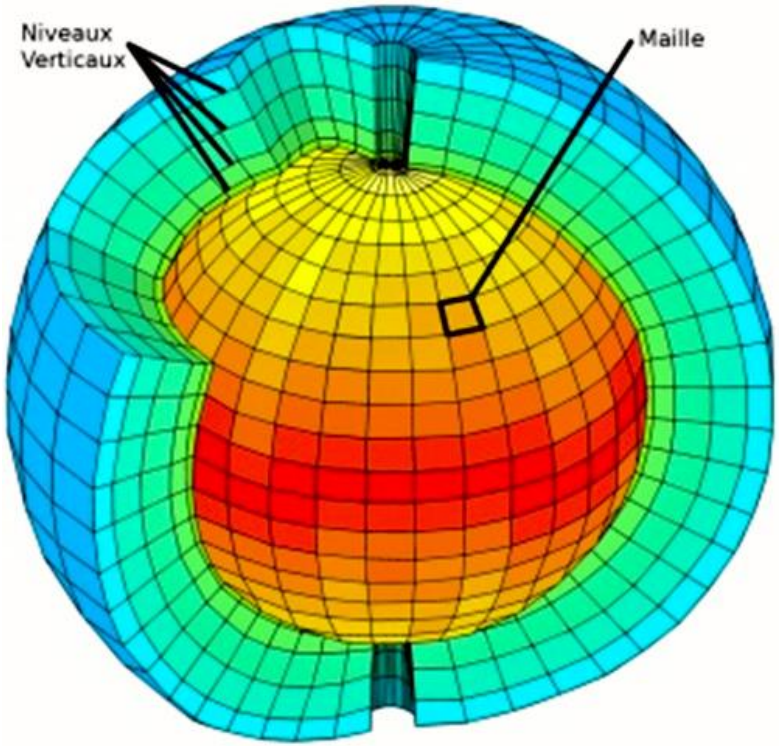
Guang J. Zhang, Ming Cai & Aixue Hu, Energy consumption and the unexplained winter warming over northern Asia and North America, *Nature Climate Change* (January 27, 2013)

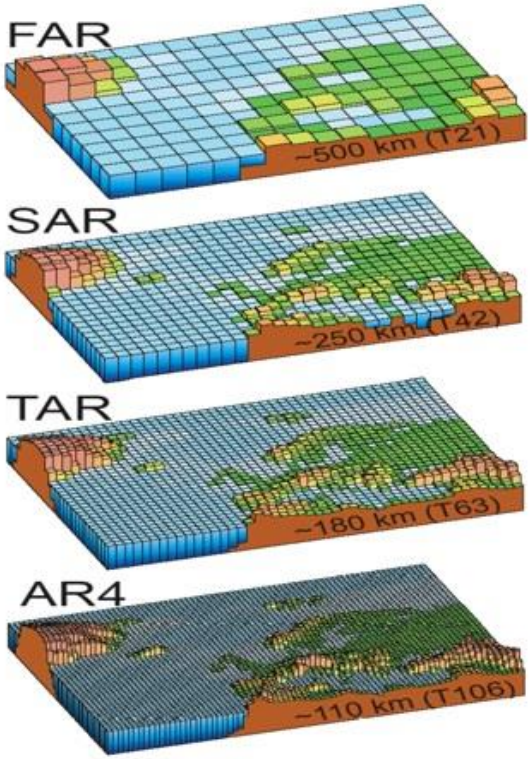
"Urban Physics is a well-established discipline, incorporating relevant branches of physics, environmental chemistry, aero-dynamics, meteorology and statistics. Therefore, **Urban Physics is well positioned to provide key-contributions to the existing urban problems and challenges**."

Moonen P., Defraeye T., Dorer V., Blocken B., Carmeliet J., "Urban Physics: Effect of the micro-climate on comfort, health and energy demand", Frontiers of Architectural Research (2012) 1, 197–228

The key challenges for Smart Cities and Communities are to significantly increase the overall energy efficiency of cities, to exploit better the local resource both in terms of energy supply as well as through the demand side measures. This will imply the use of energy efficiency measures optimizing at the level of districts, the use of renewables, the sustainability of urban transport and the needed drastic reduction of greenhouse gas emissions in urban areas - within economically acceptable conditions - while ensuring for citizens better life conditions: lower energy bills, swifter transport, job creation and as a consequence a higher degree of resilience to climate impacts (e.g. urban heat islands effects) etc.

CALL Smart cities and communities
(http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/2148-scc-01-2015.html)

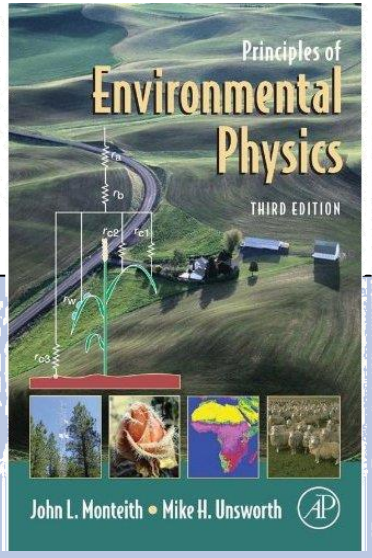


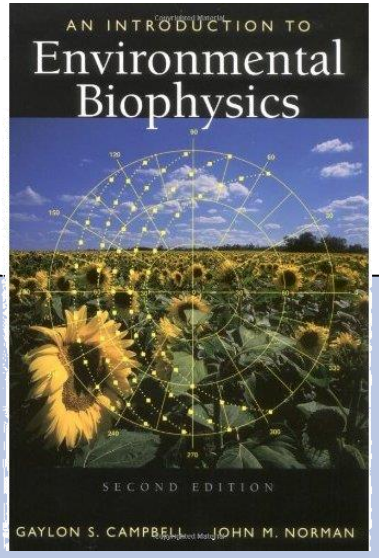


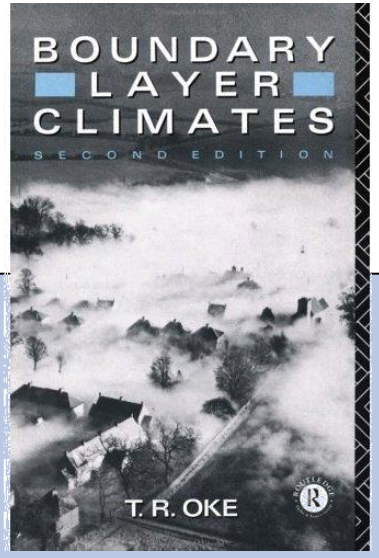
GIEC 2007

La physique urbaine - références

La **Physique Environnementale** se développe dans les années 1970 (rendement des cultures), 1980 (forêts et pluies acides), 1990 (trou dans la couche d'ozone), 2000 (changement climatique). Parmi ses méthodes : le bilan local des flux d'énergie (conductif, radiatif, sensible et latent).



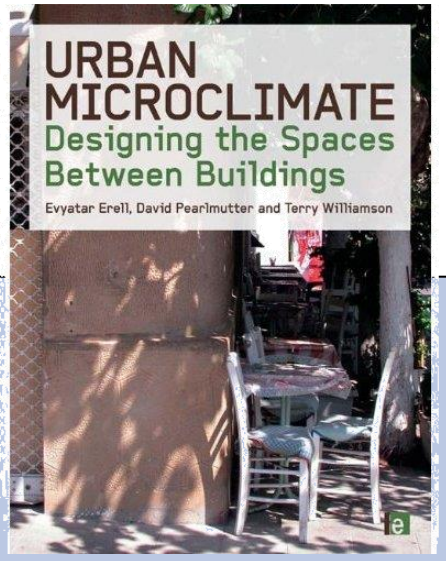


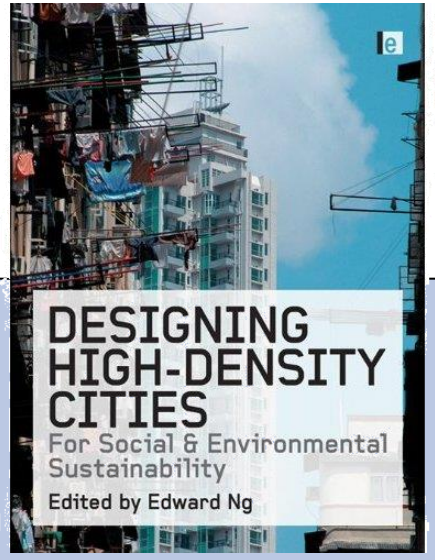


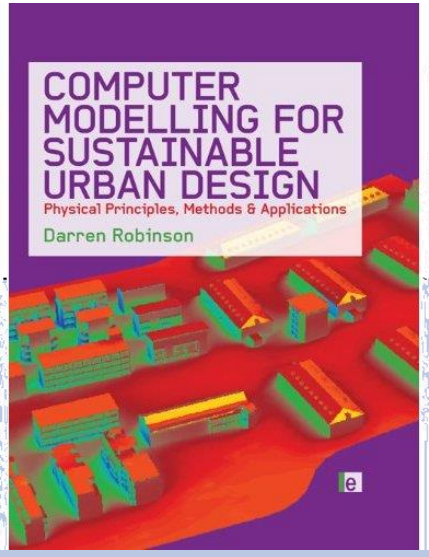
L'application des mêmes méthodes aux structures urbaines est proposée dès les années 1970 par T. R. Oke, autour de la problématique de l'Ilot de Chaleur Urbain. On peut dès lors parler de **Physique Urbaine**.

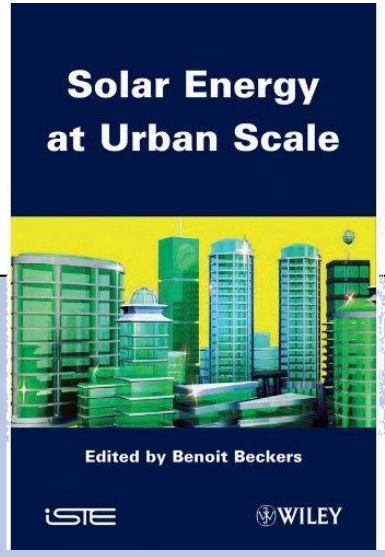
La physique urbaine - références

Ces dernières années, des progrès considérables dans plusieurs domaines annexes: systèmes d'information géographique, standardisation du niveau de détail des modèles 3D (BIM et CIM), mesures terrestres et satellitaires, puissance de calcul des ordinateurs,…



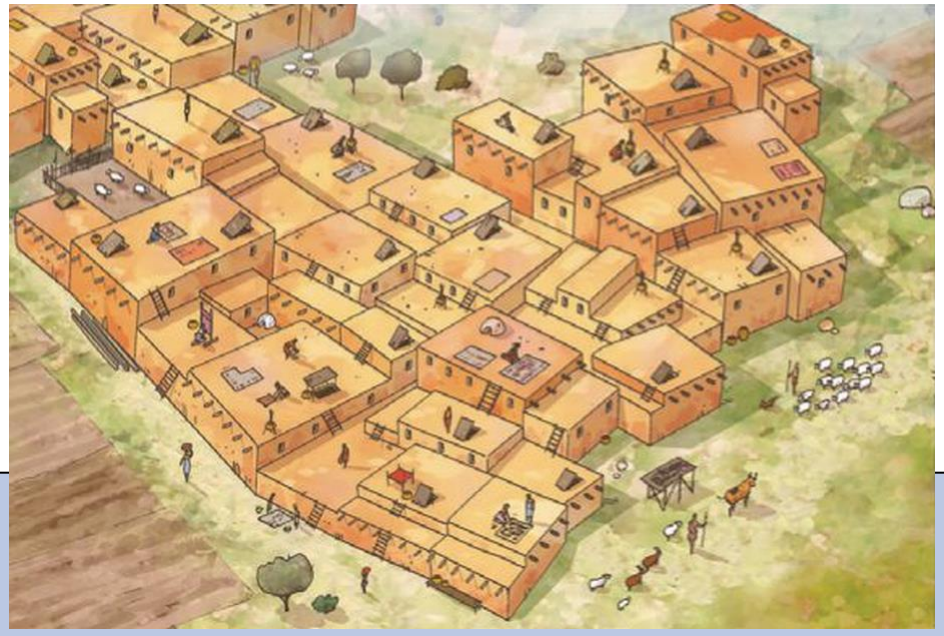


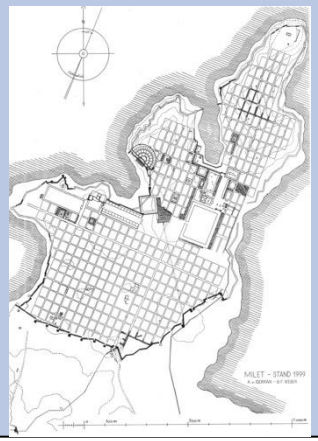




…permettent une première appréhension de la physique urbaine par la simulation numérique.
Cadre: "smart", "safe" and "sustainable" city.
Emergence de la **thermique urbaine** (climat urbain, flux thermiques bâtiment-ville-territoire, efficience énergétique, production locale d'énergie renouvelable).

ARCHITECTURE ET PHYSIQUE URBAINE





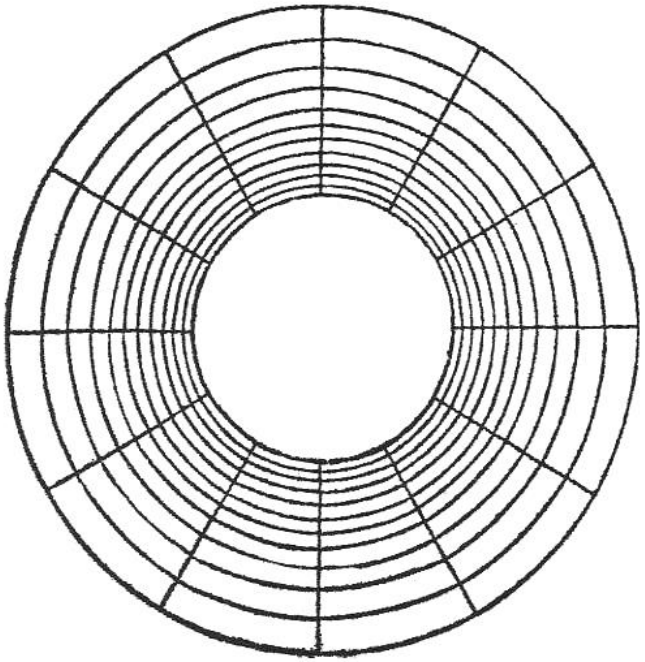
A city has to be Smart, Safe and Sustainable

Ιππόδαμος ο Μιλήσιος (c. 498- c. 408 BC)

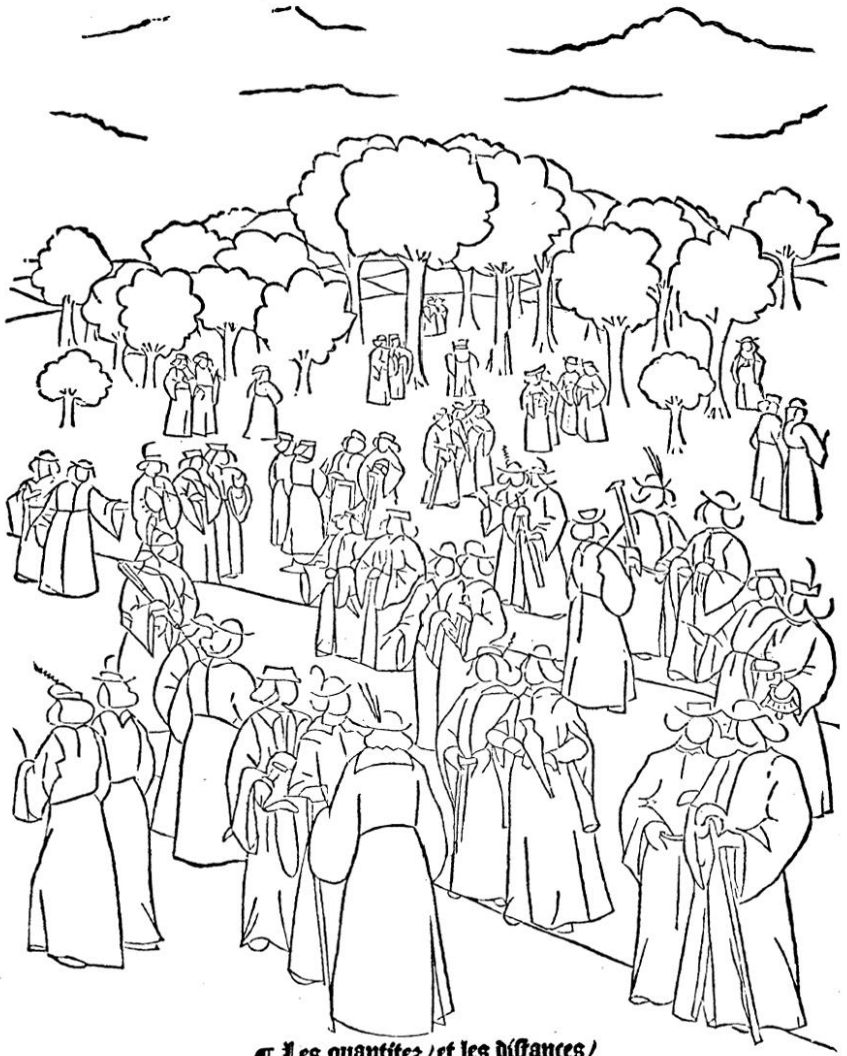
Benoit Beckers ***ISA BTP – Université de Pau et des Pays de l'Adour***

ARCHITECTURE ET PHYSIQUE URBAINE

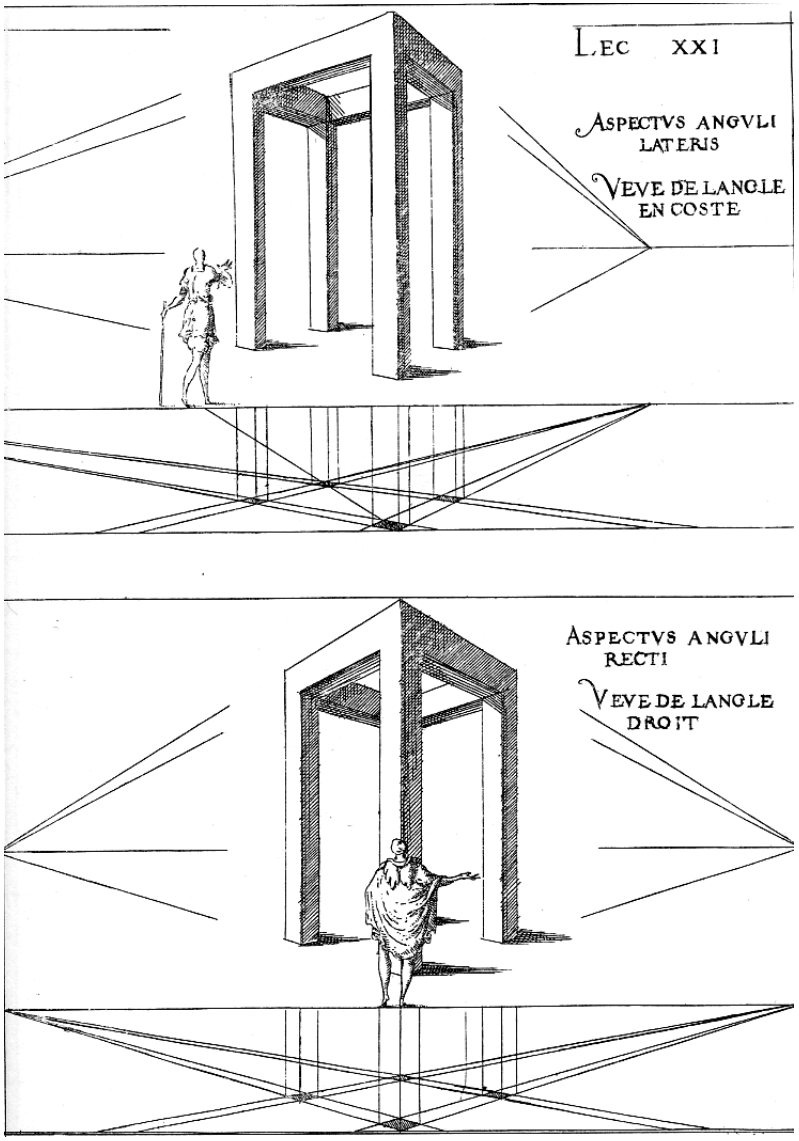
DE·ARTIFICIALI·PSPECTIVA·

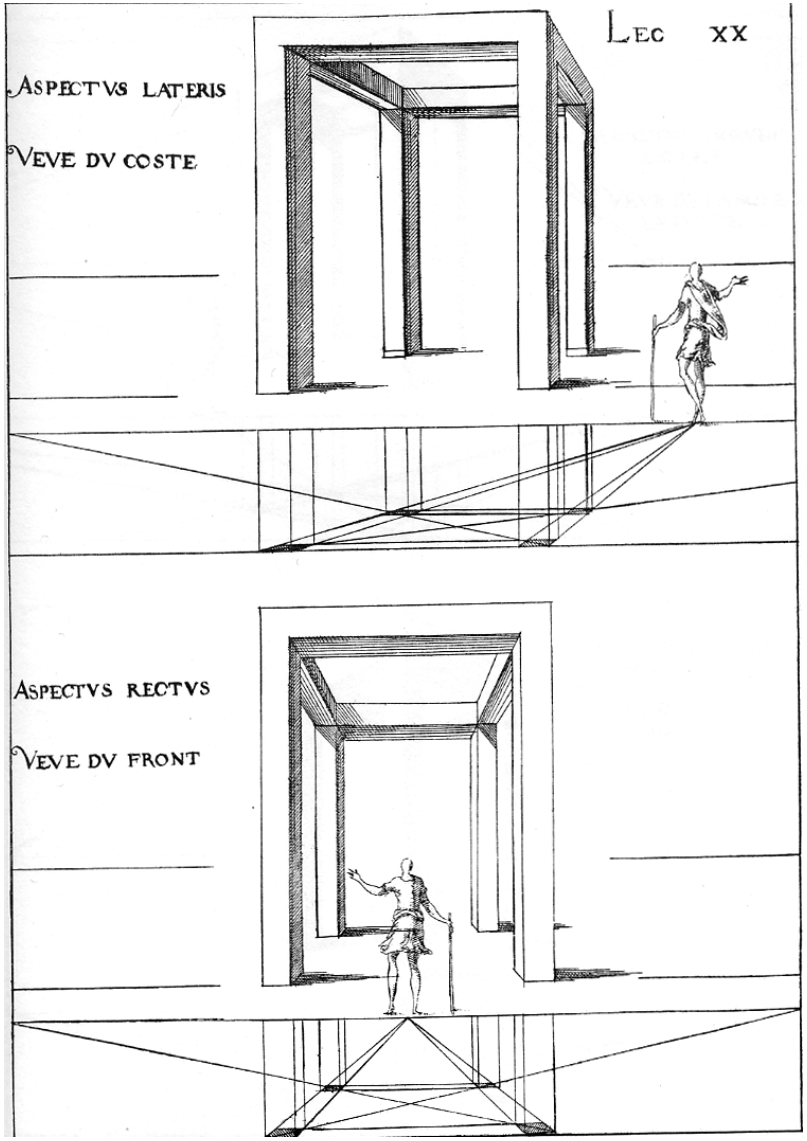


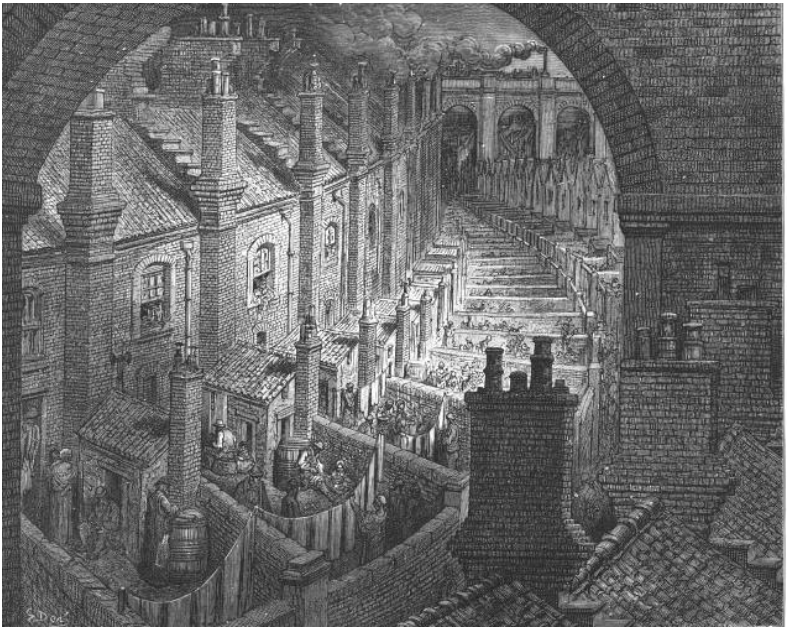
VIATOR



¶ Les quantitez / et les distances /
Ont concordables differences.


LEC XXI
ASPECTVS ANGVLI LATERIS
VEVE DE LANGLE EN COSTE
ASPECTVS ANGVLI RECTI
VEVE DE LANGLE DROIT


LEC XX
ASPECTVS LATERIS
VEVE DV COSTE
ASPECTVS RECTVS
VEVE DV FRONT



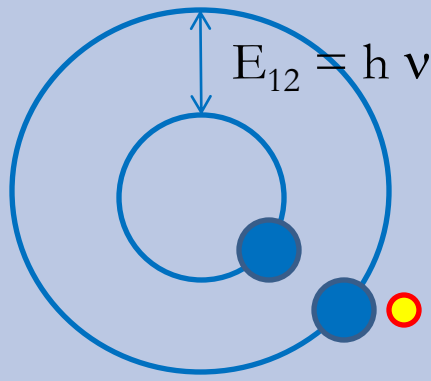
Corps noirs et corps gris

- Absorptivité α
- Réflexivité ρ
- Transmissivité τ

$$\alpha + \rho + \tau = 1$$

Photon

$E = h \nu = h c / \lambda$



$E_{12} = h \nu_{12} = h c / \lambda_{12}$

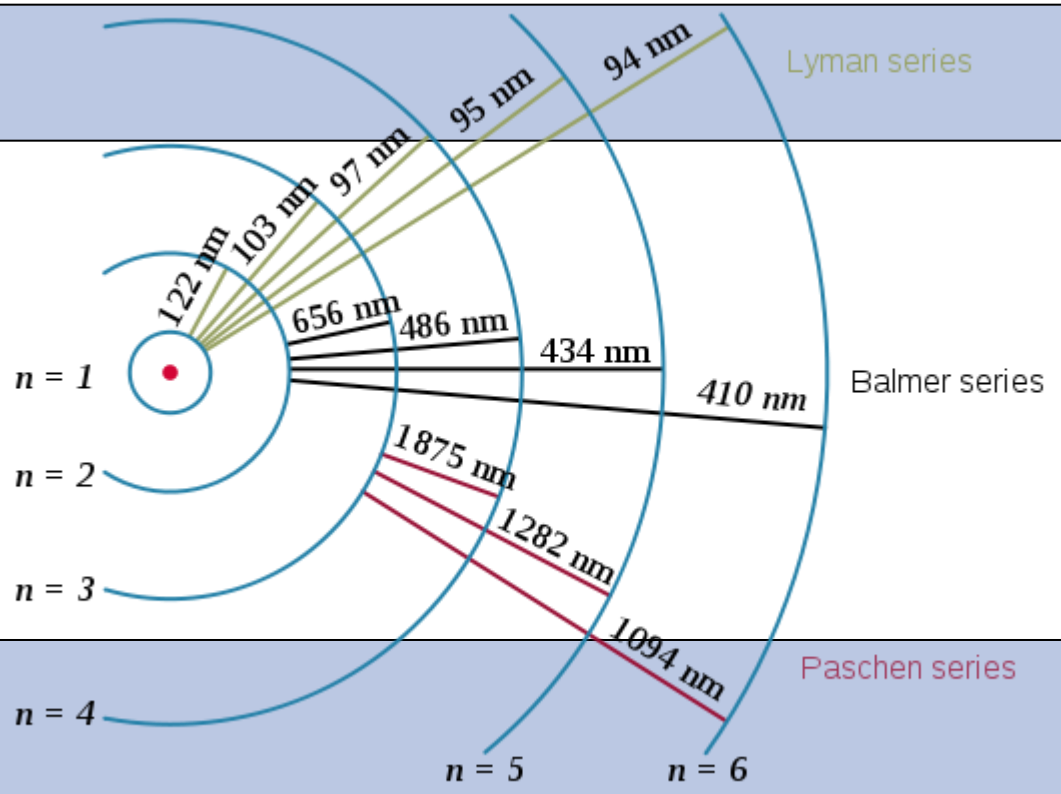
Emissivité ε

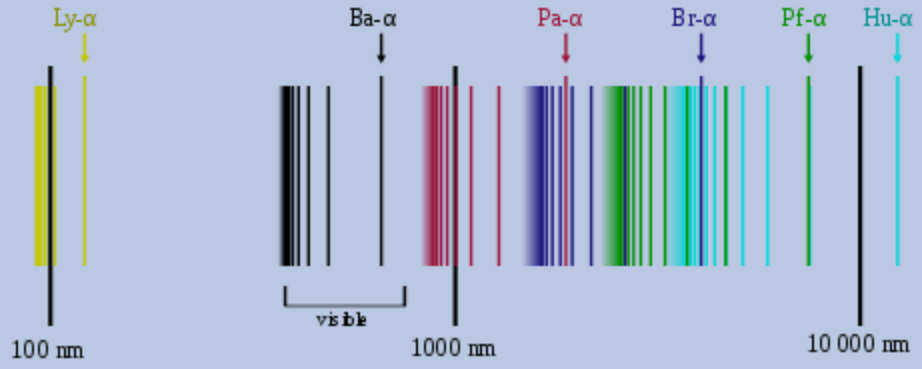
Pour tout λ, on a:

$$\alpha (\lambda) = \varepsilon (\lambda)$$

Loi de Kirchhoff

$$\alpha + \rho + \tau = 1$$





Pour tout λ, on a:

$$\alpha(\lambda) = \varepsilon(\lambda)$$

Loi de Kirchhoff

http://en.wikipedia.org/wiki/Hydrogen_spectral_series

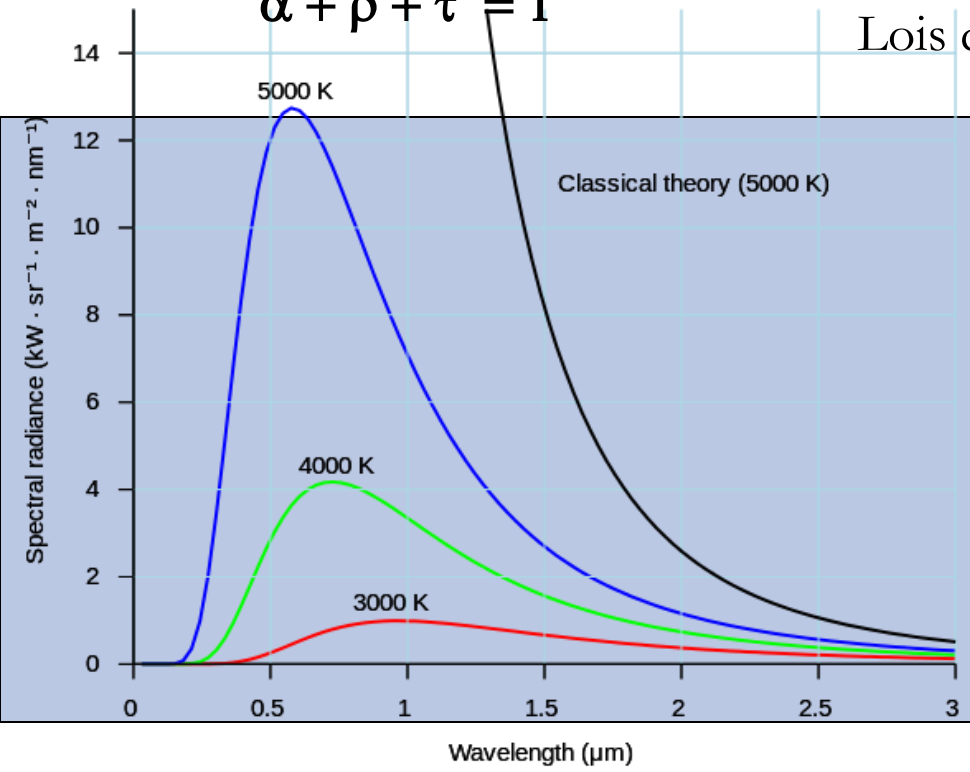
$$L_\lambda = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{k\lambda T}}-1}$$

$$\lambda_{\max} T = 2.898 \times 10^{-3}\, mK$$

$$Q\left(Wm^{-2}\right) = \sigma\left(T_r^4 - T_i^4\right)$$

$$\alpha + \rho + \tau = 1$$

Lois de Planck, Wien et Stefan-Boltzmann



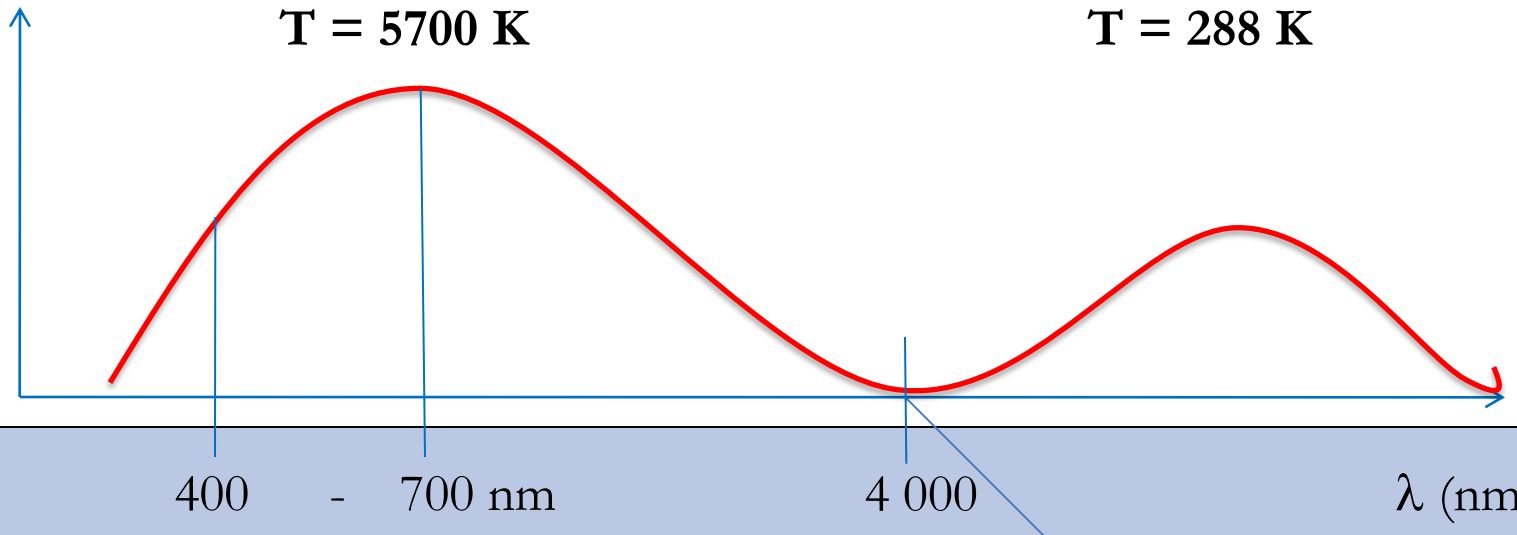
Pour tout λ, on a:

$$\alpha(\lambda) = \varepsilon(\lambda)$$

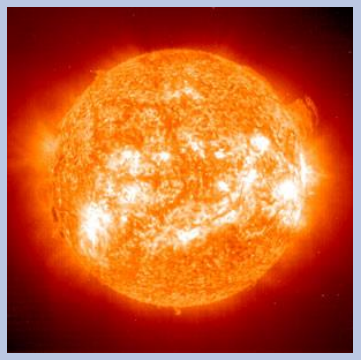
Loi de Kirchhoff

http://en.wikipedia.org/wiki/Black_body

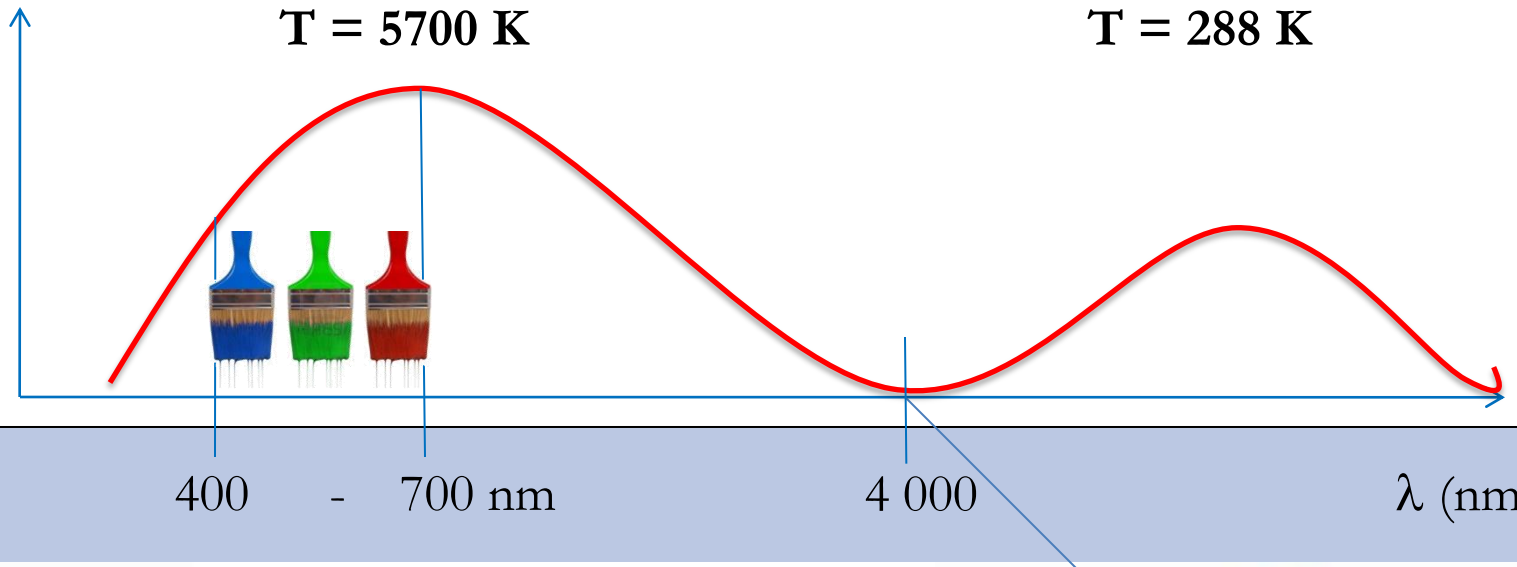
Ondes courtes et ondes longues

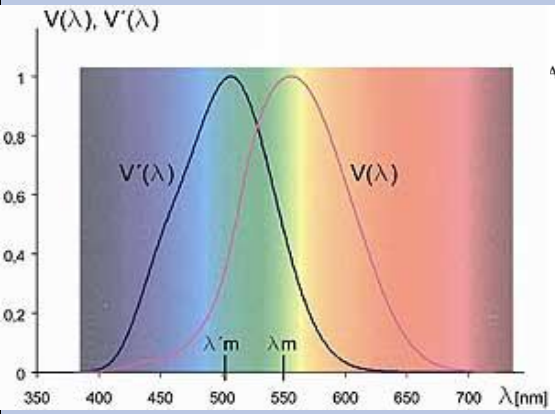


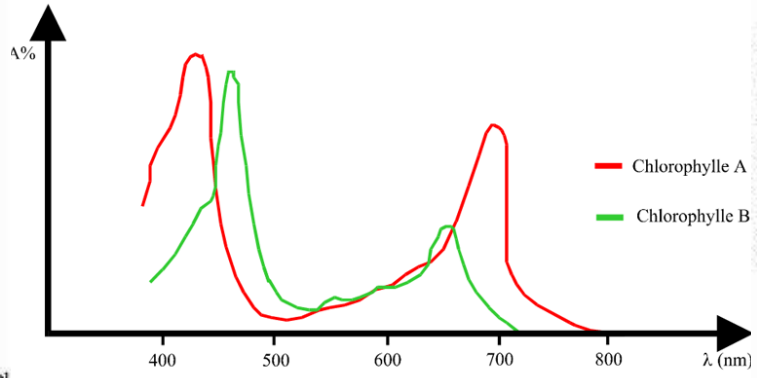
UV visible IR proche IR thermique

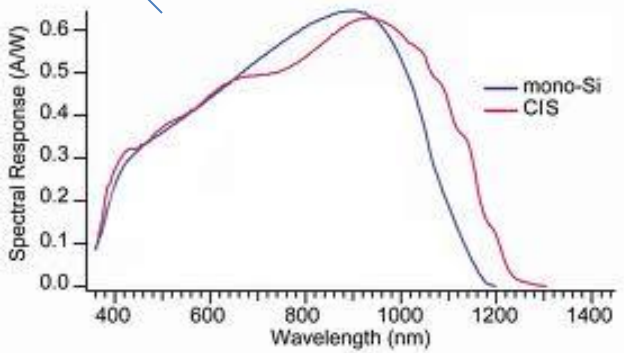


Sensibilité spectrale









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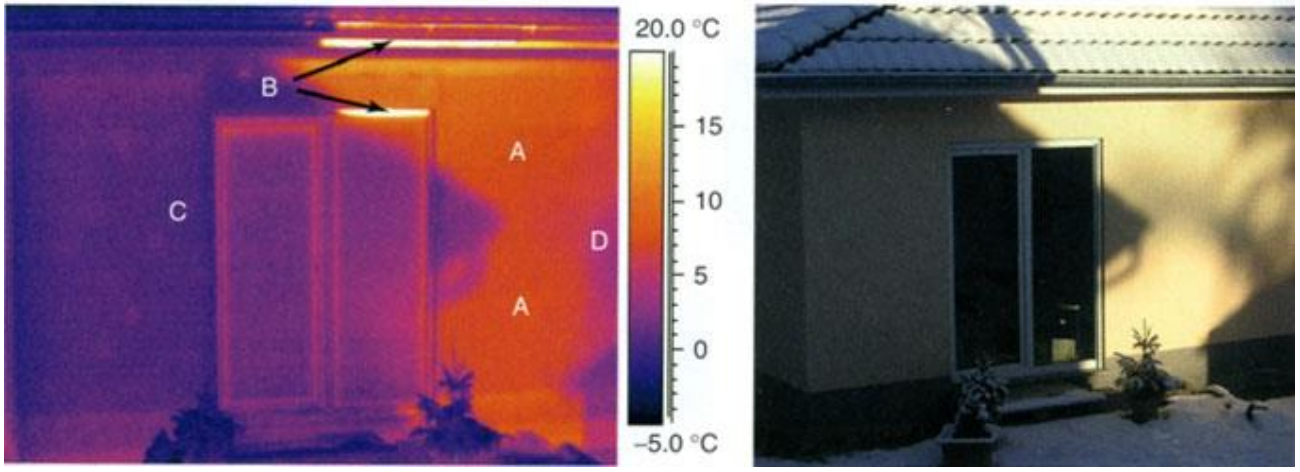
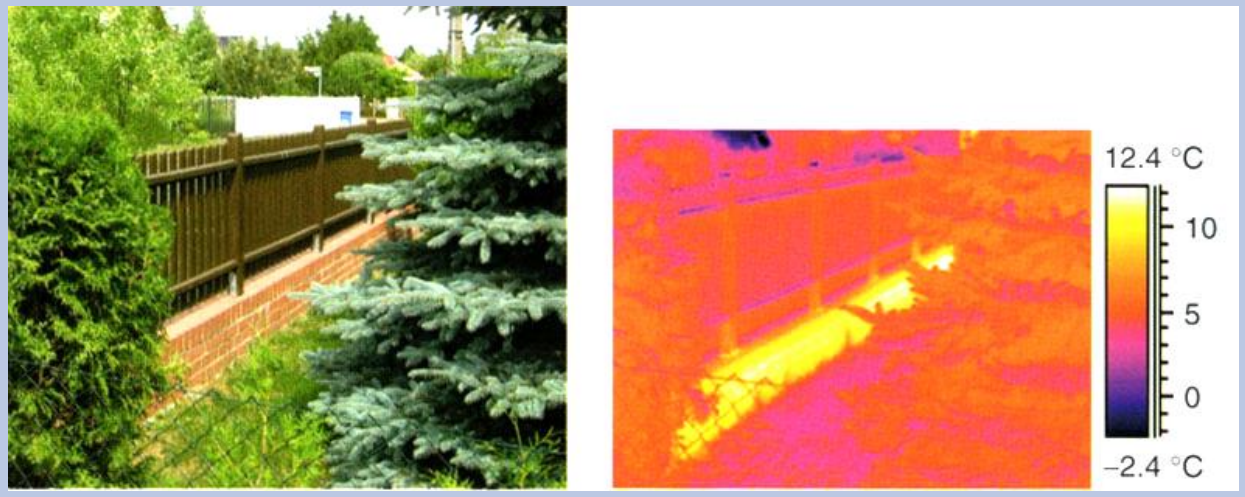
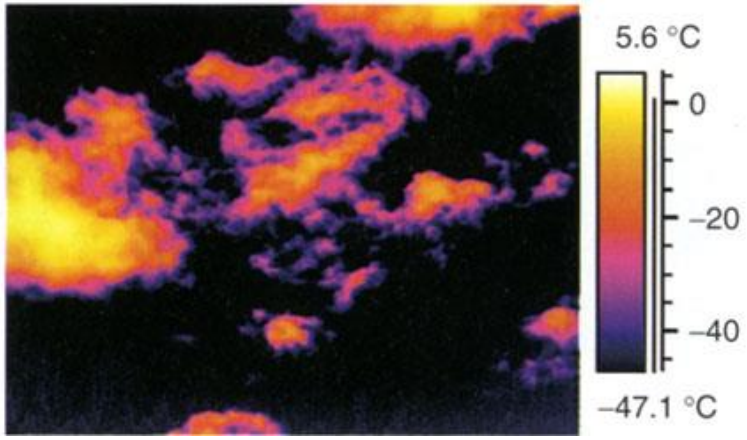
Thermographie

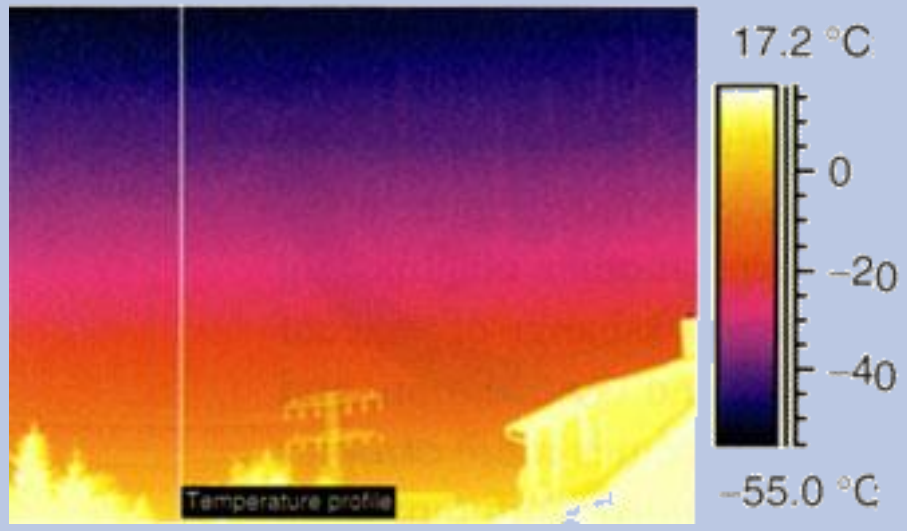


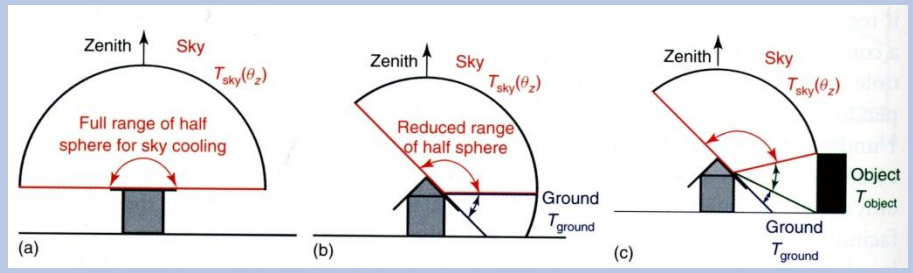


M. Vollmer & K.-P. Möllmann "Infrared Thermal Imaging: Fundamentals, Research and Applications", Wiley-VCH, 612 pages, 2010.

Thermographie







M. Vollmer & K.-P. Möllmann "Infrared Thermal Imaging: Fundamentals, Research and Applications", Wiley-VCH, 612 pages, 2010.

Campagne de mesures 23/04/2017

Températures superficielles urbaines dans la ville dense

Urban Physics Joint Laboratory
Elena García Nevado ETSAB (UPC)
Benoit Beckers ISA-BTP (UPPA)

https://apua.urbanistes.fr/2016-37e-rencontre-national-des-agences-durbanisme-a-bayonne-et-pau-audap/

CAMPAGNE DE MESURES

CHARACTERISTIQUES

- **Rue des Tonneliers**
- **19 heures** (6am – 1am)
- **Jour dégagé**

MOYENS TECHNIQUES

- **Caméra FLIR B200**
- Station Météo NOBATEK
- Thermo-anémomètre datalogger

Nobatek

PARAMÈTRES ENVIRONNEMENTAUX MESURÉS

- **Température superficielle** → **PARAMÈTRE D'ETUDE**
- Rayonnement solaire → **CONDITIONS AUX LIMITES**
- Température de l'air → **CONDITIONS AUX LIMITES**
- Vitesse du vent → **CONDITIONS AUX LIMITES**

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Rue des Tonneliers vue de la Nive

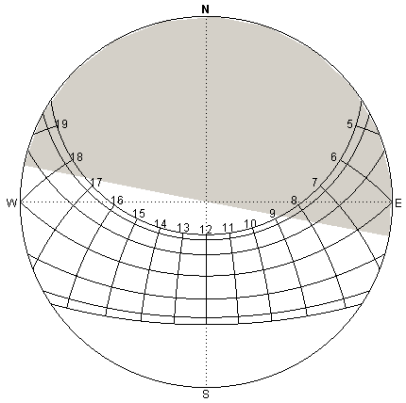
1] Façade Sud

2] Façade Sud et Nord

3] Arceaux

SIMULATIONS DANS HELIODON *sans obstacles*

FAÇADE SUD

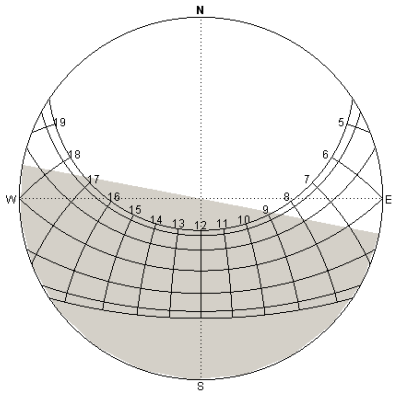


Heure solaire

Lever du soleil 5:12

Coucher du soleil 18:48

FAÇADE NORD



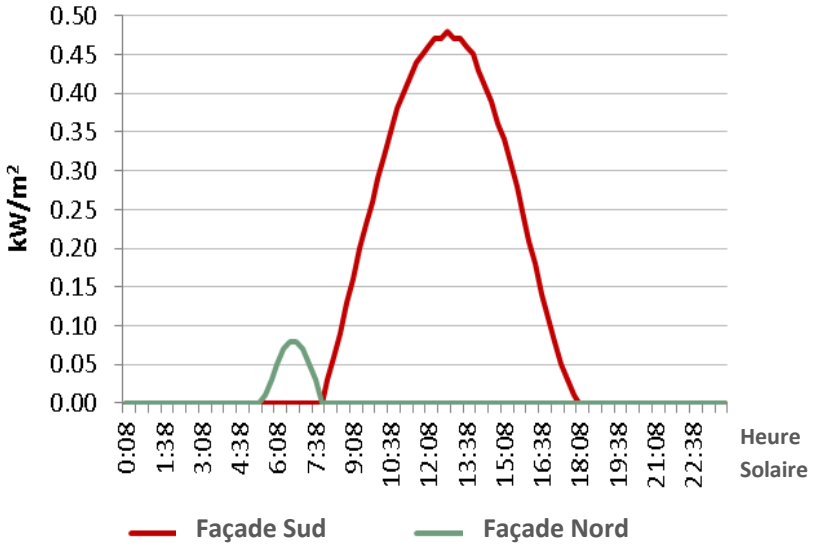
Heure officielle

Lever du soleil 7:12

Coucher du soleil 20:48

RAYONNEMENT SOLAIRE DIRECT SUR LES FAÇADES

23 avril



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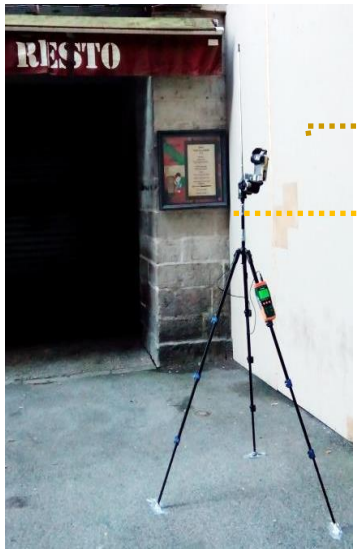

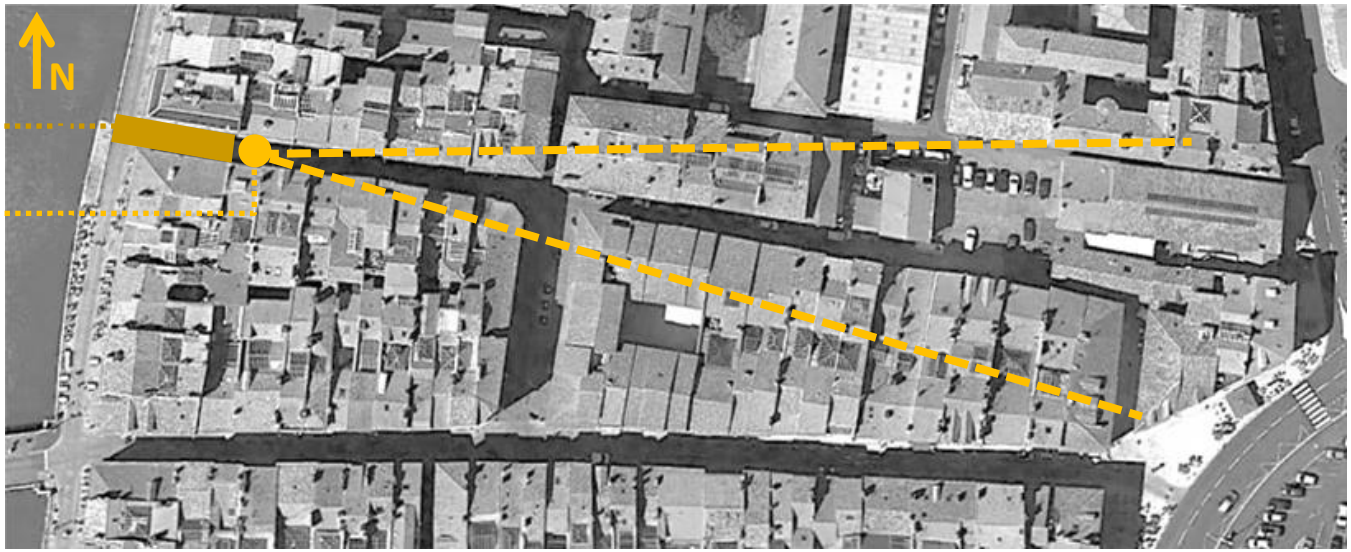

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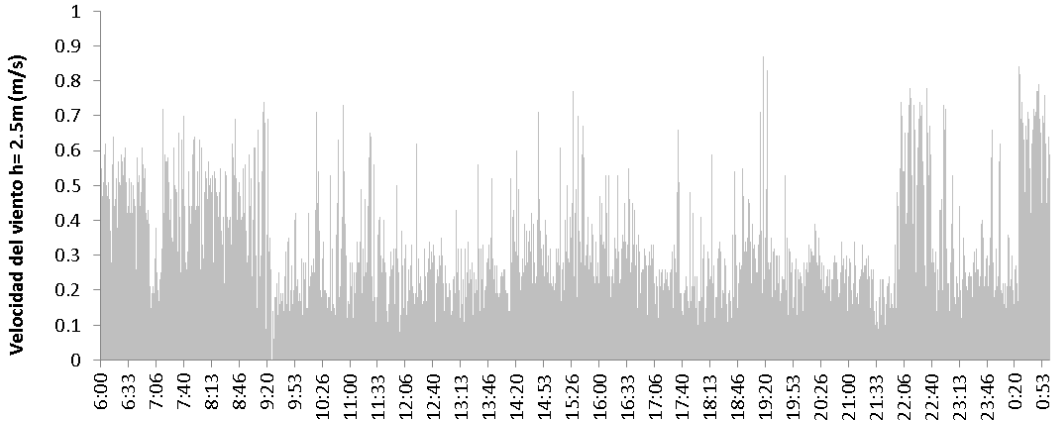

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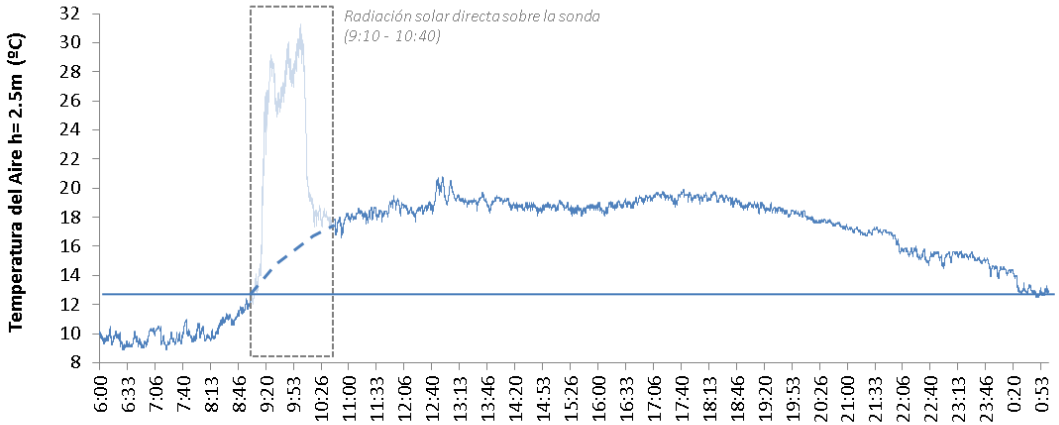
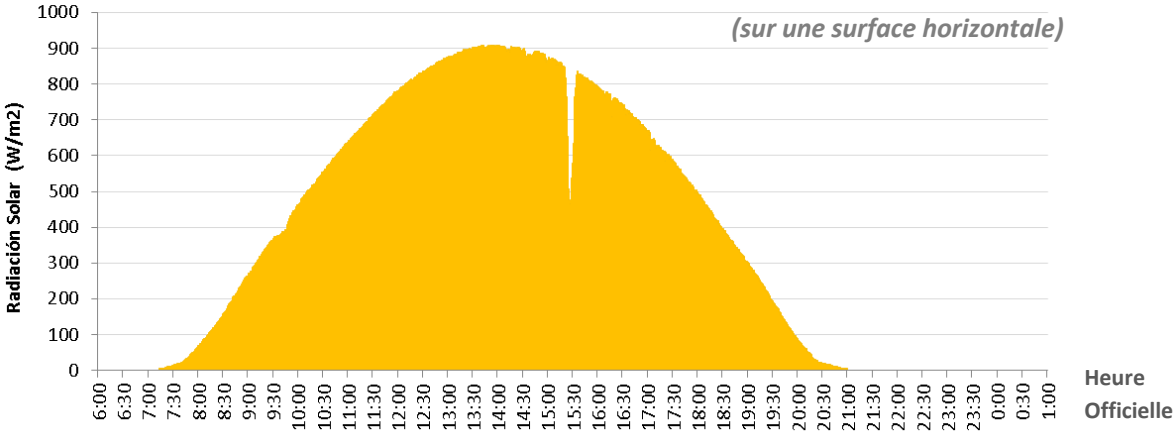


TEMPÉRATURES DE L'AIR DOUCES



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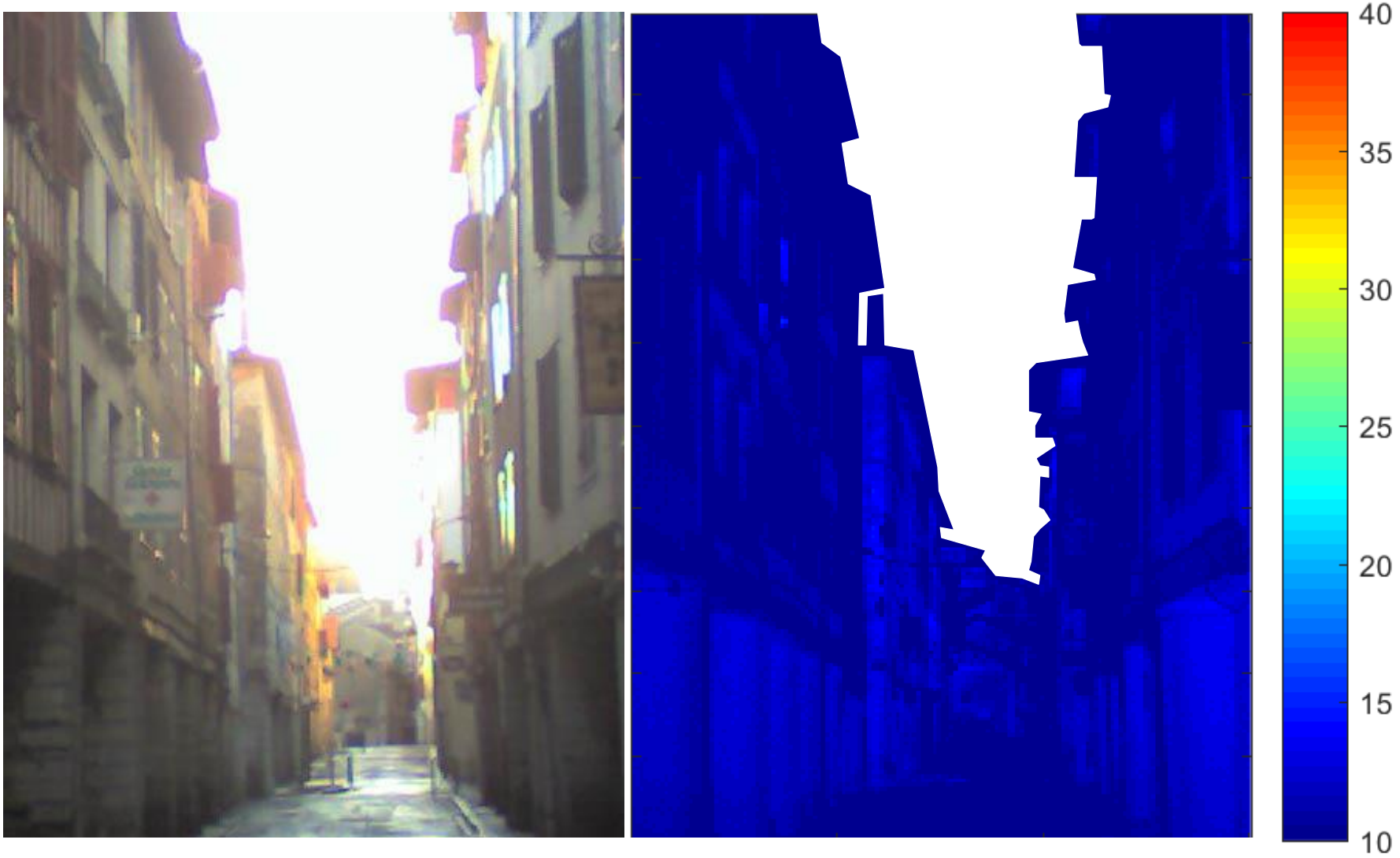

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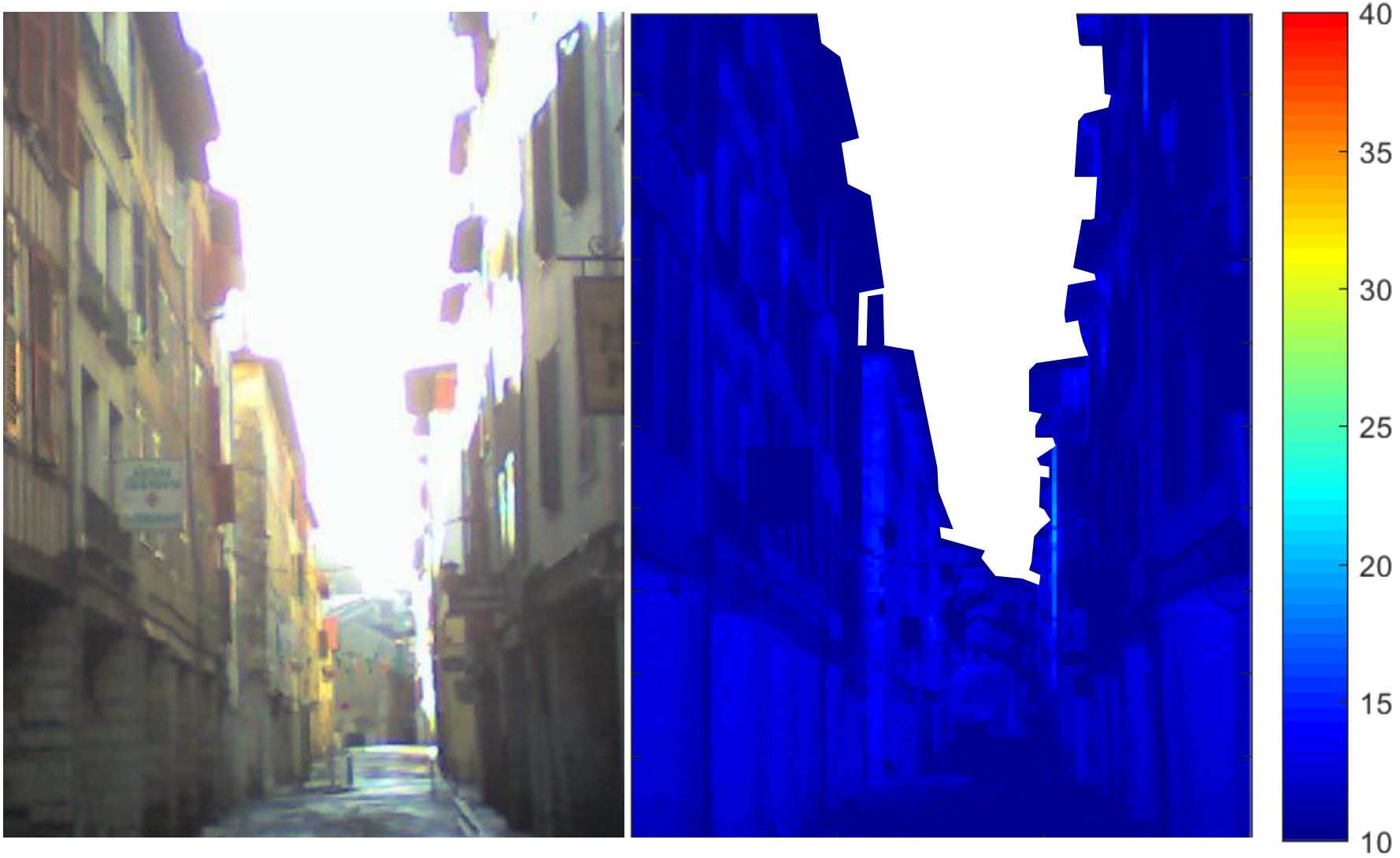

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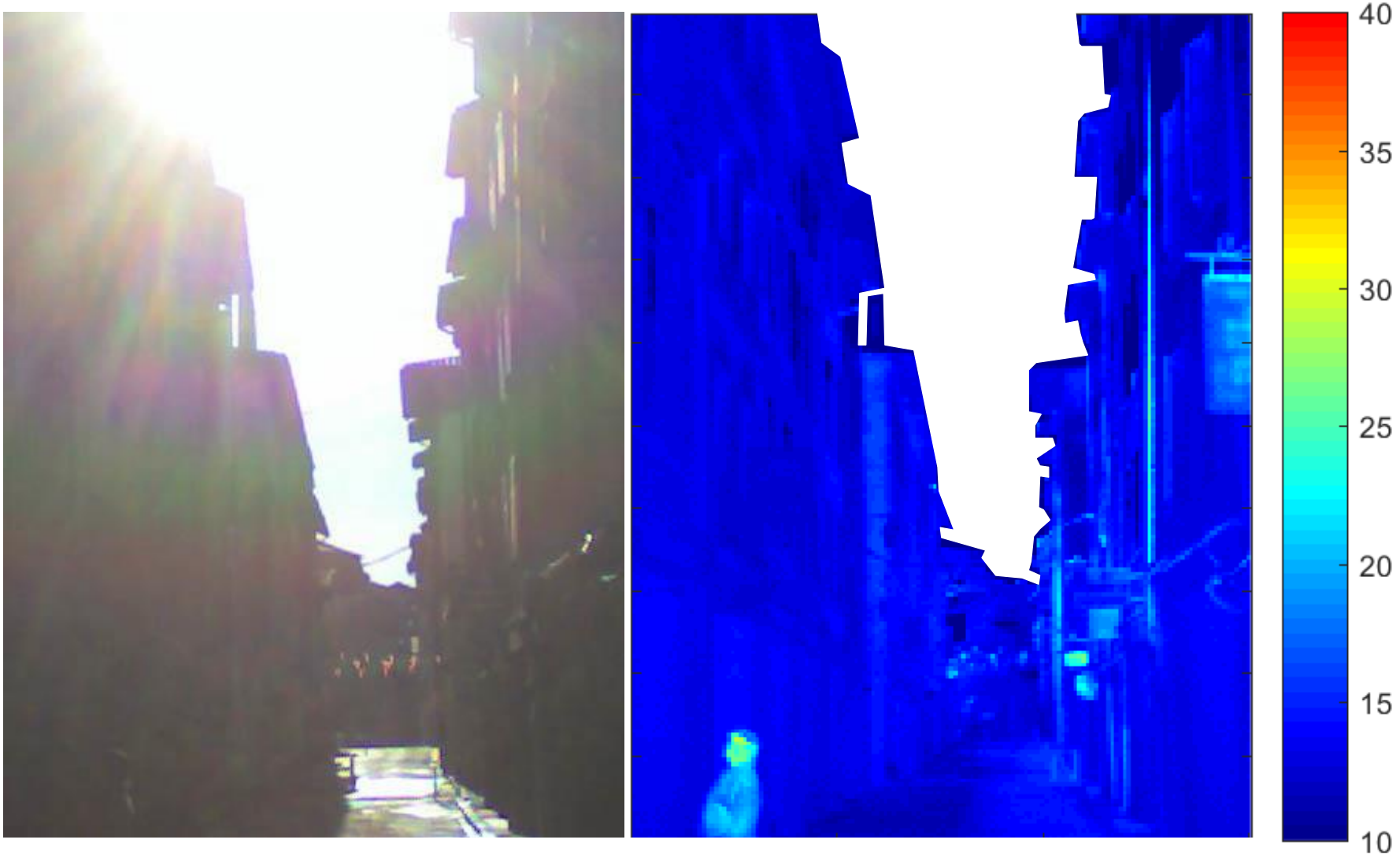

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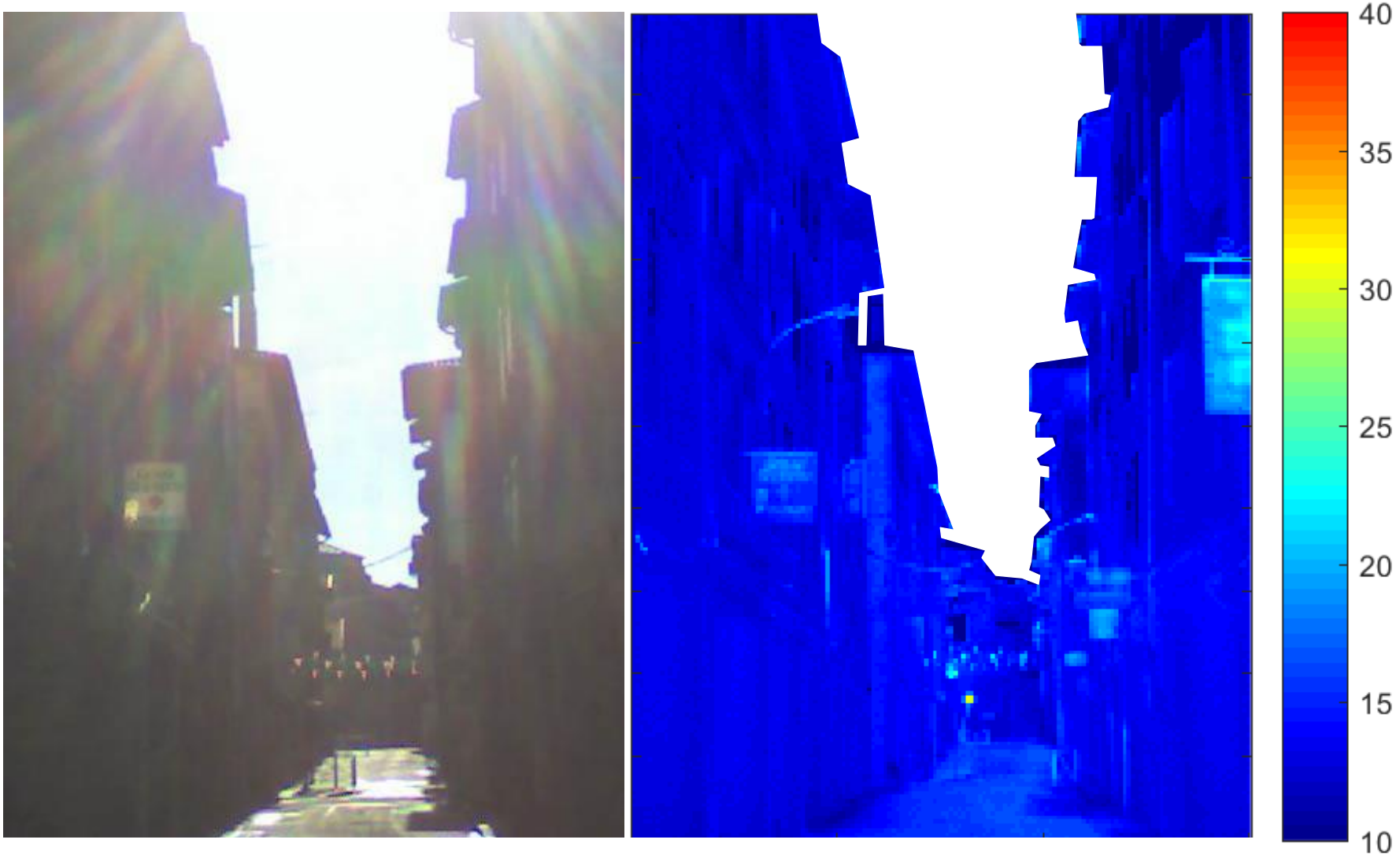

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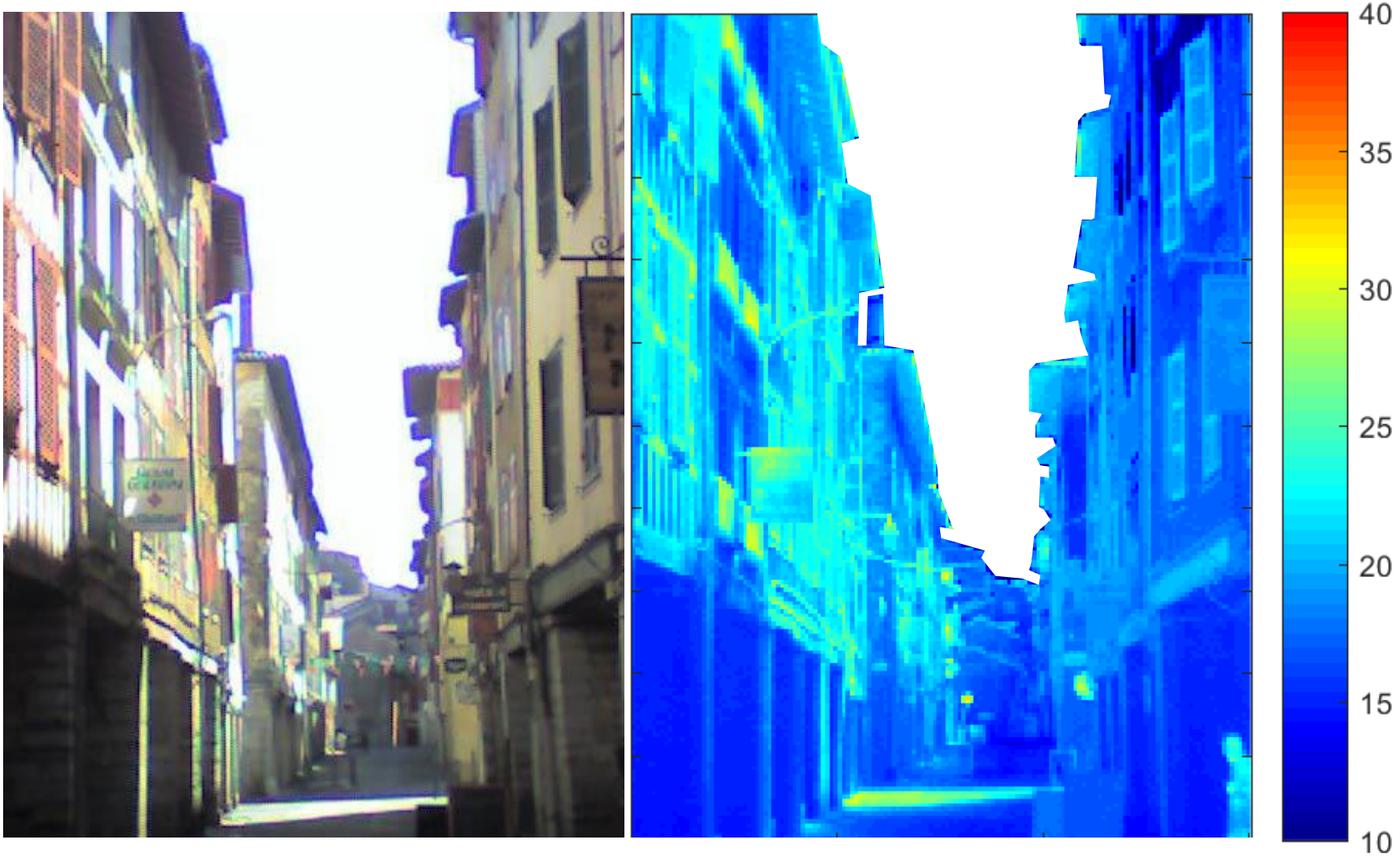

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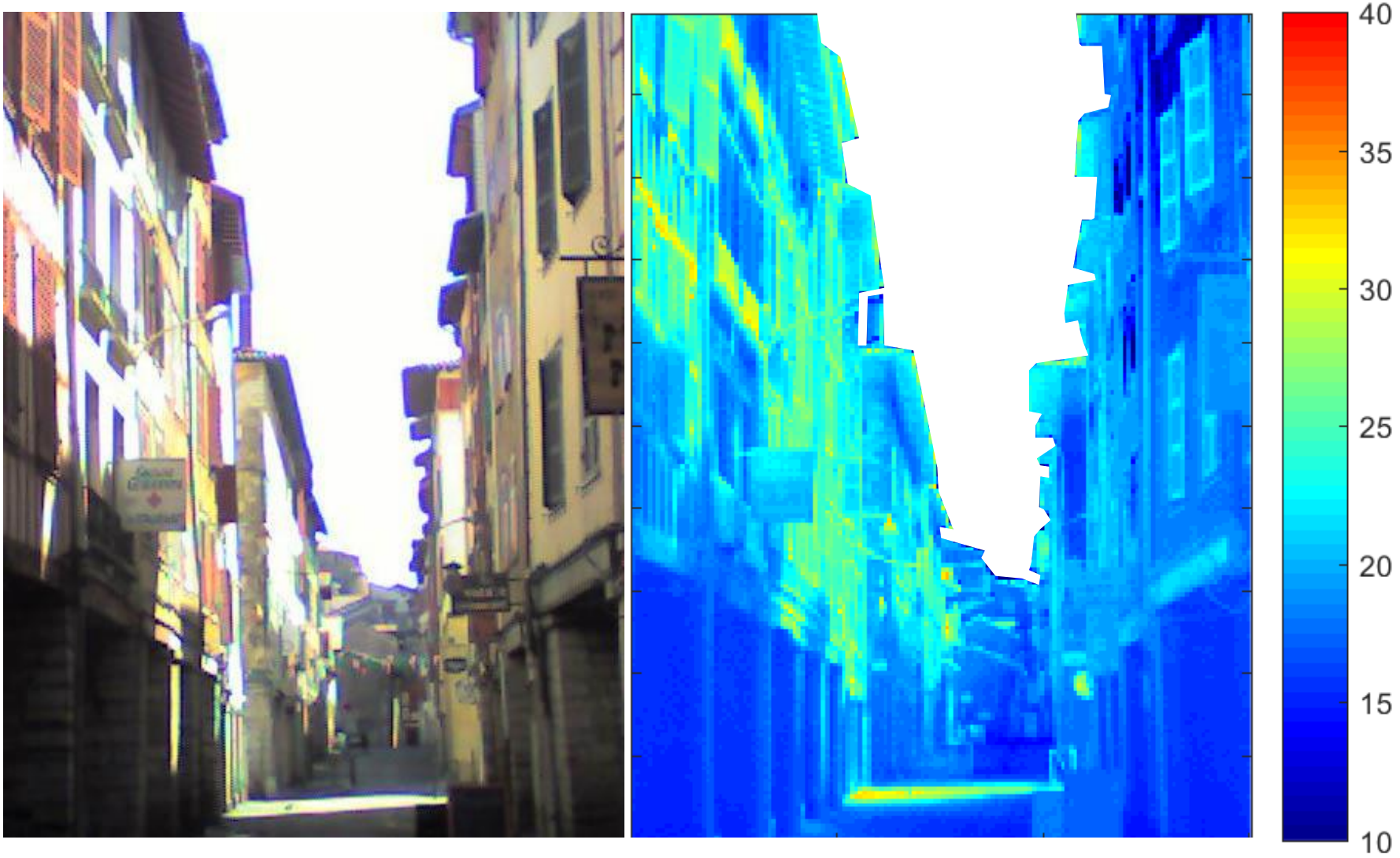

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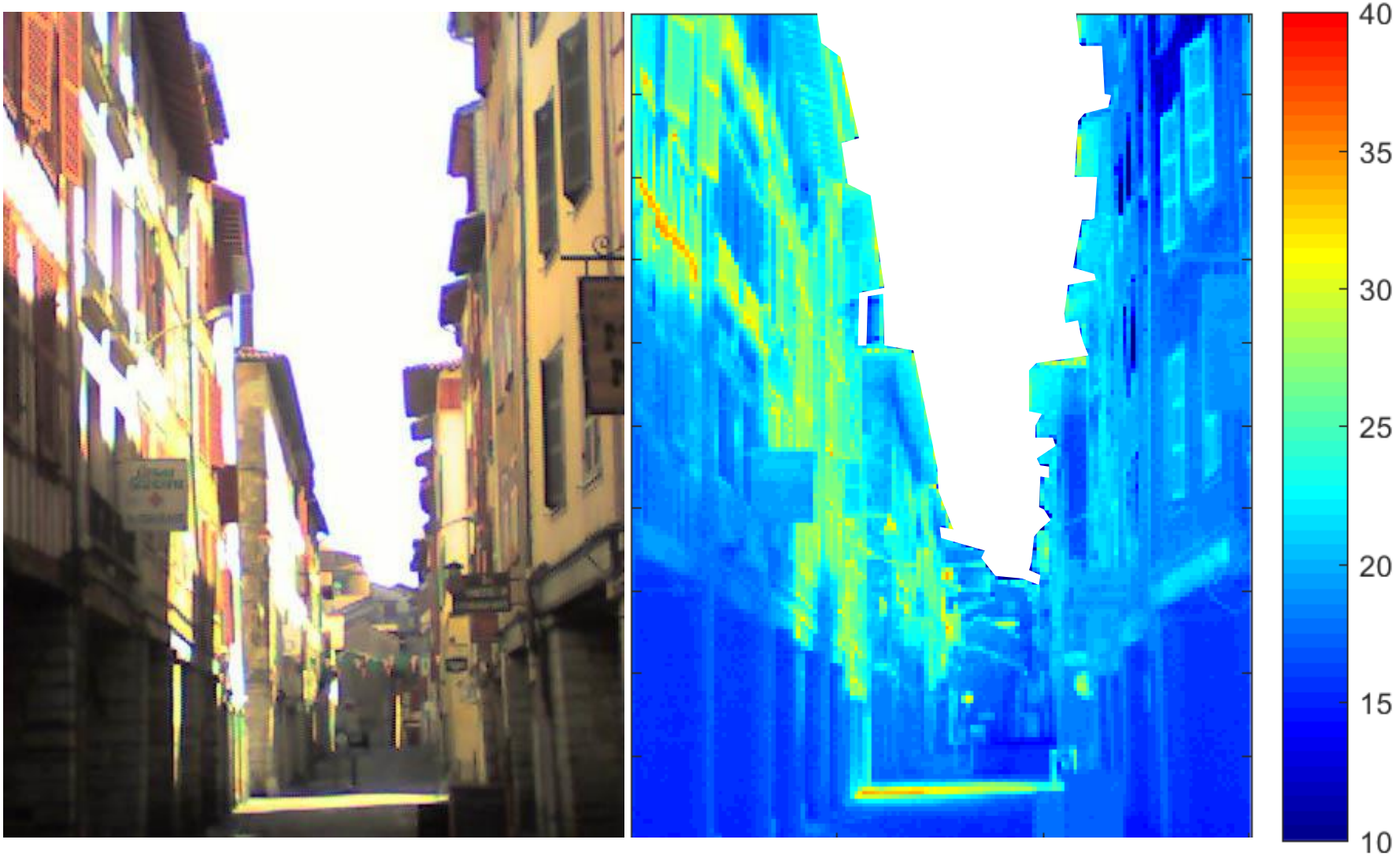

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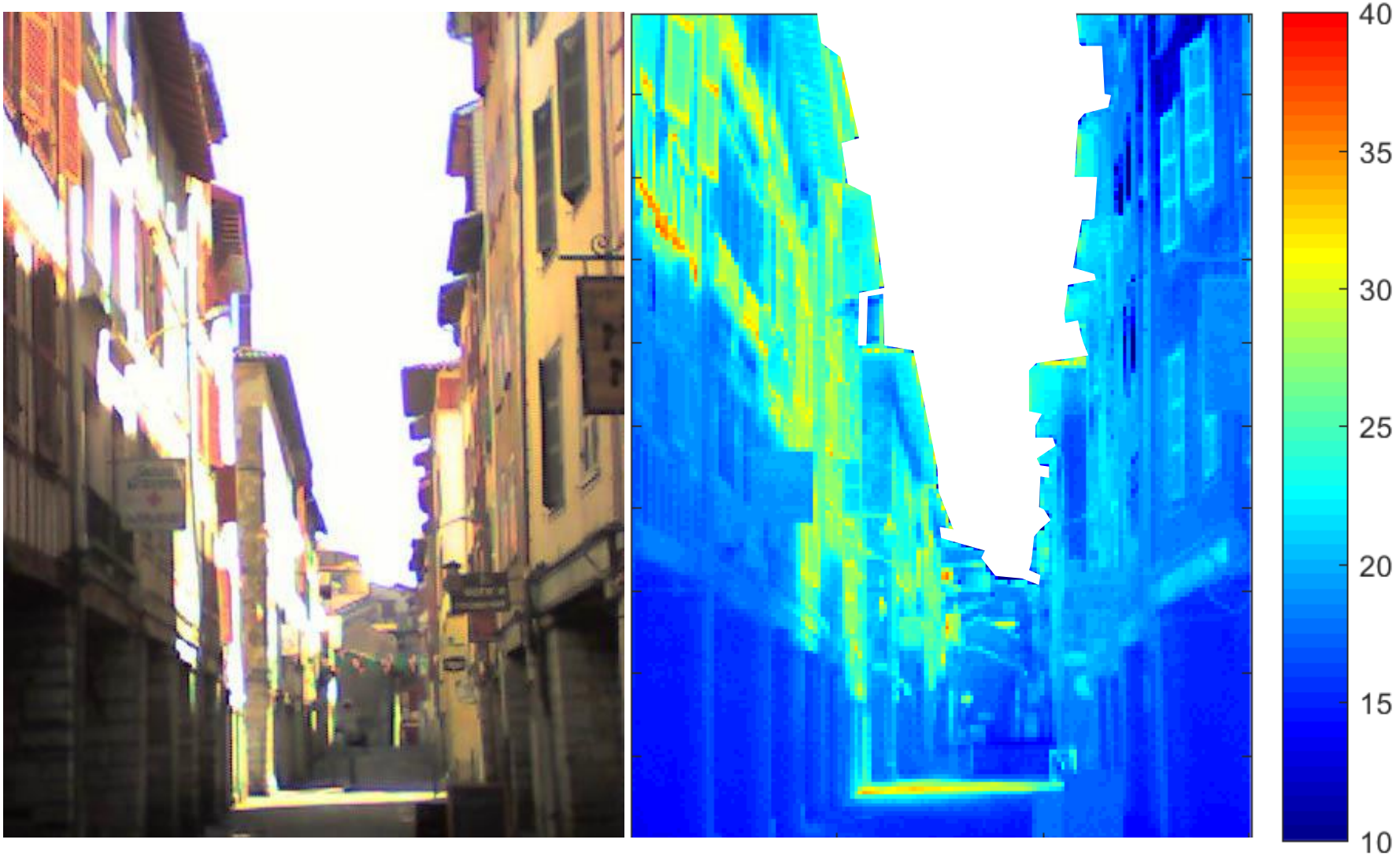

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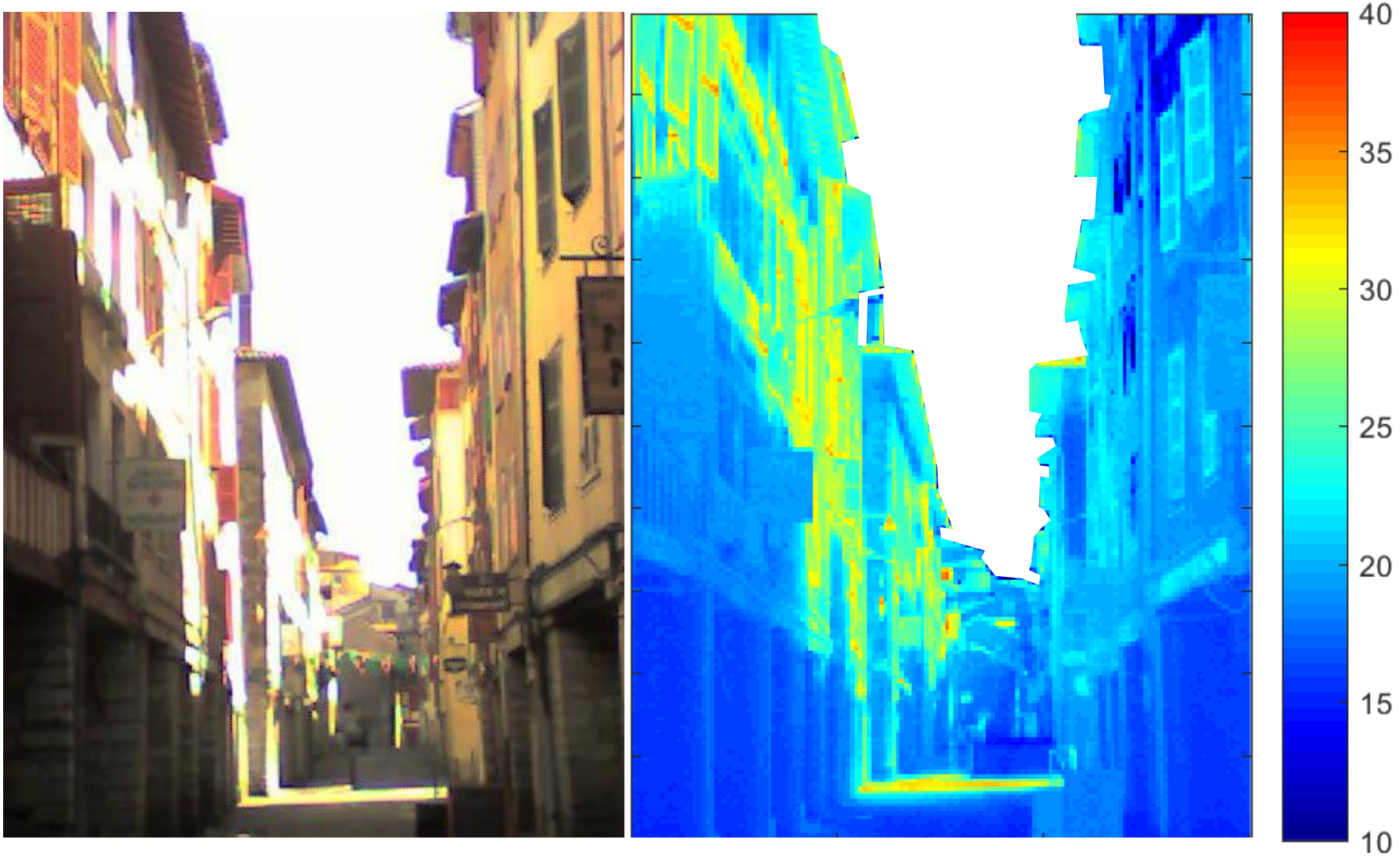

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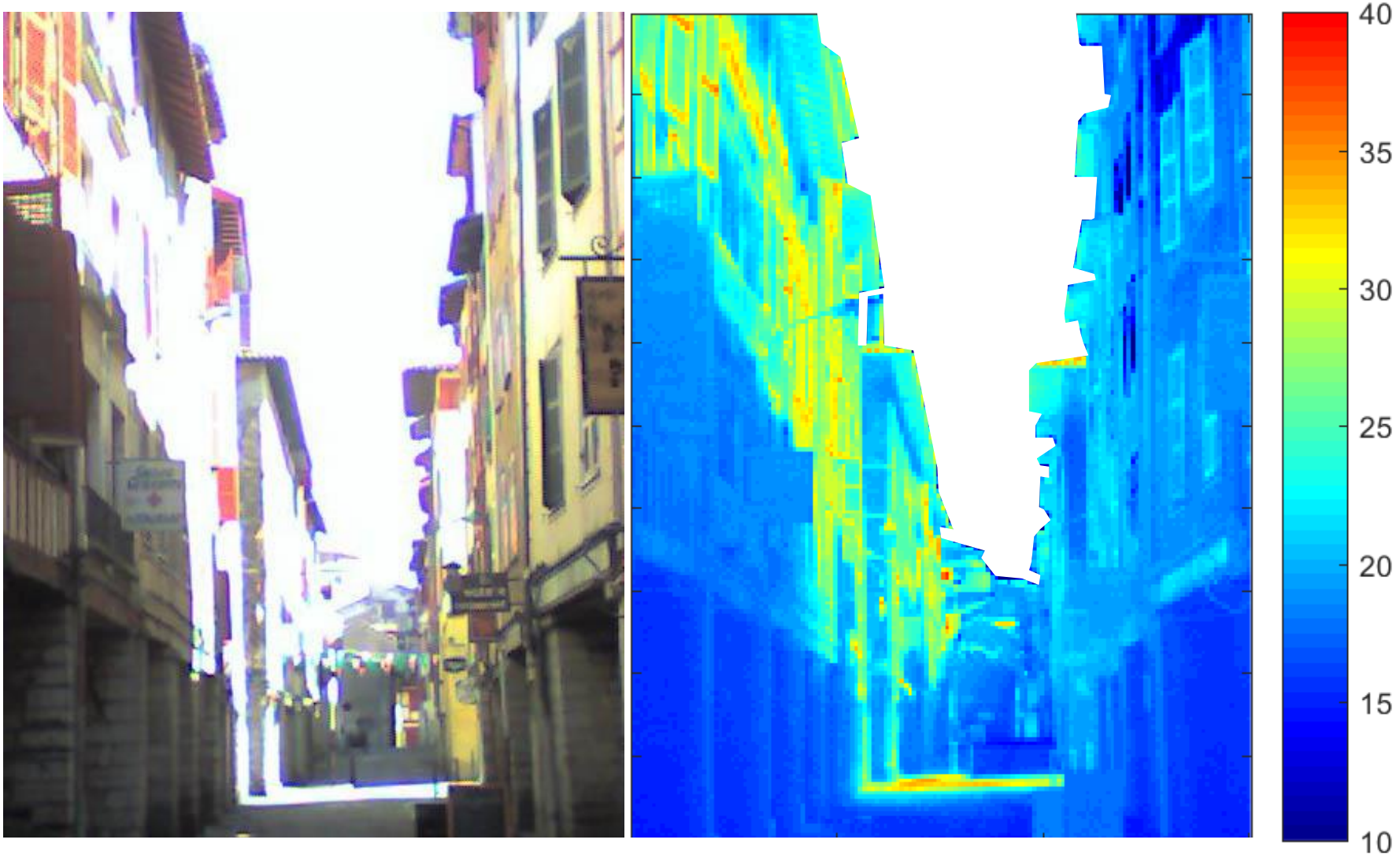

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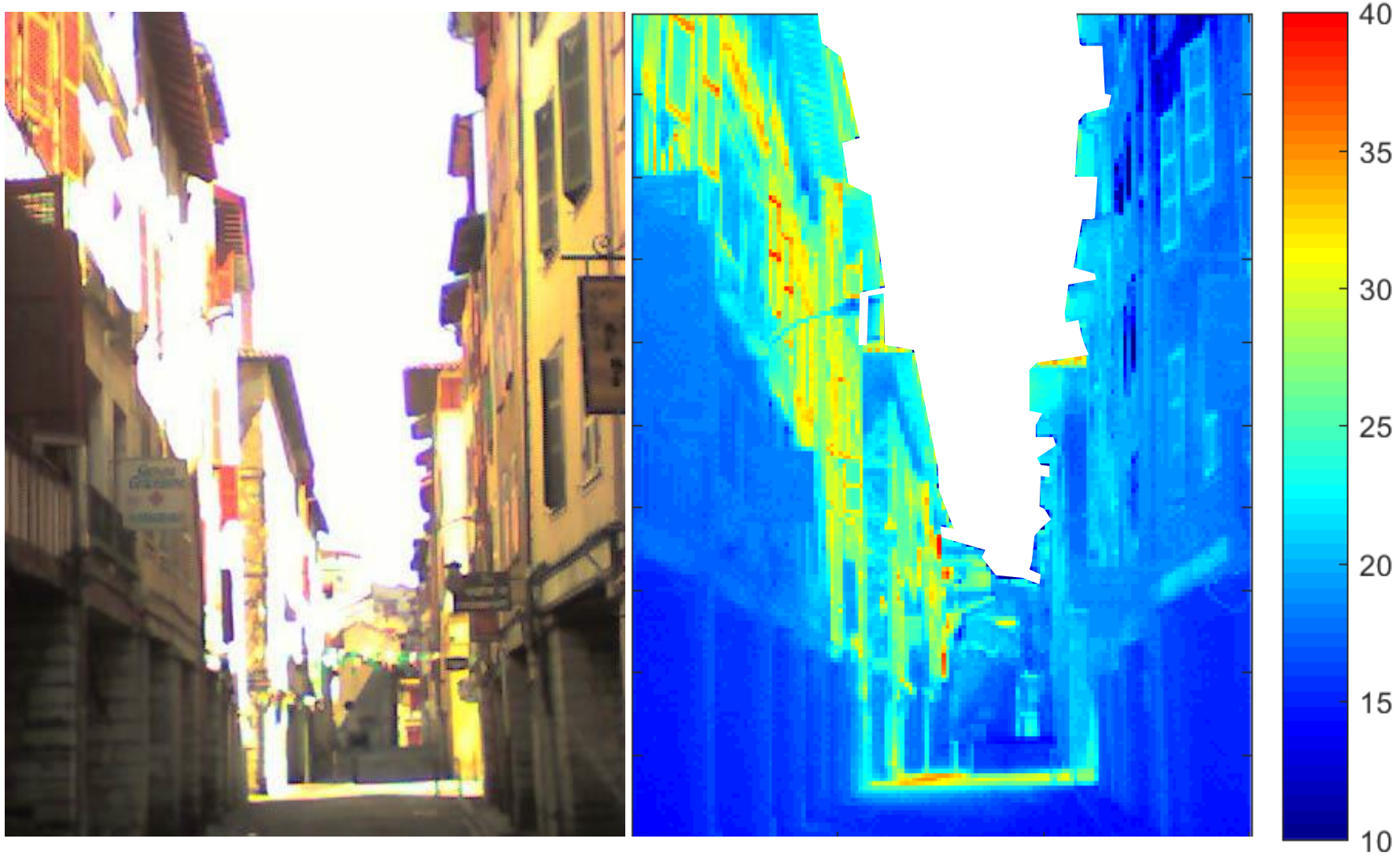

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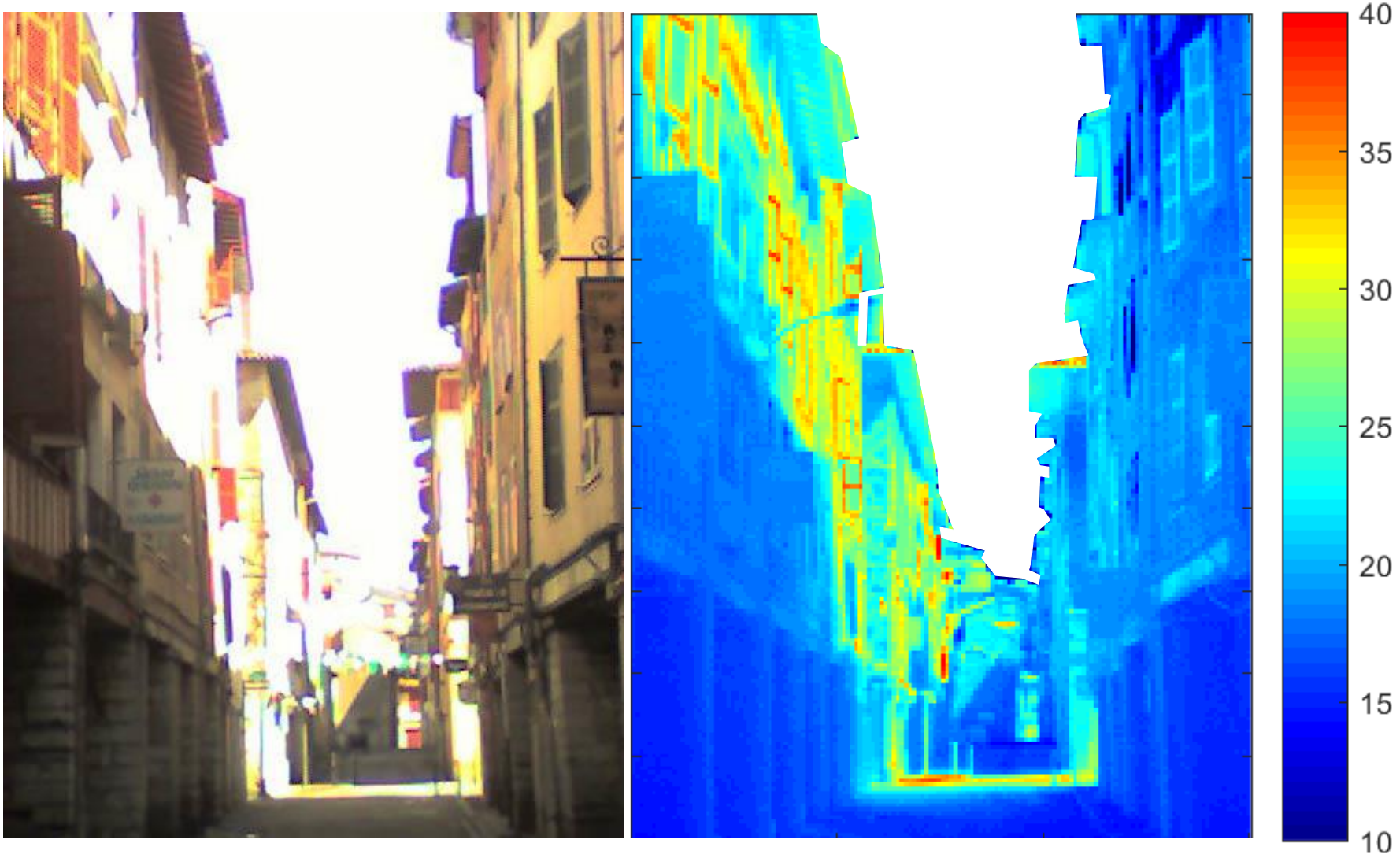

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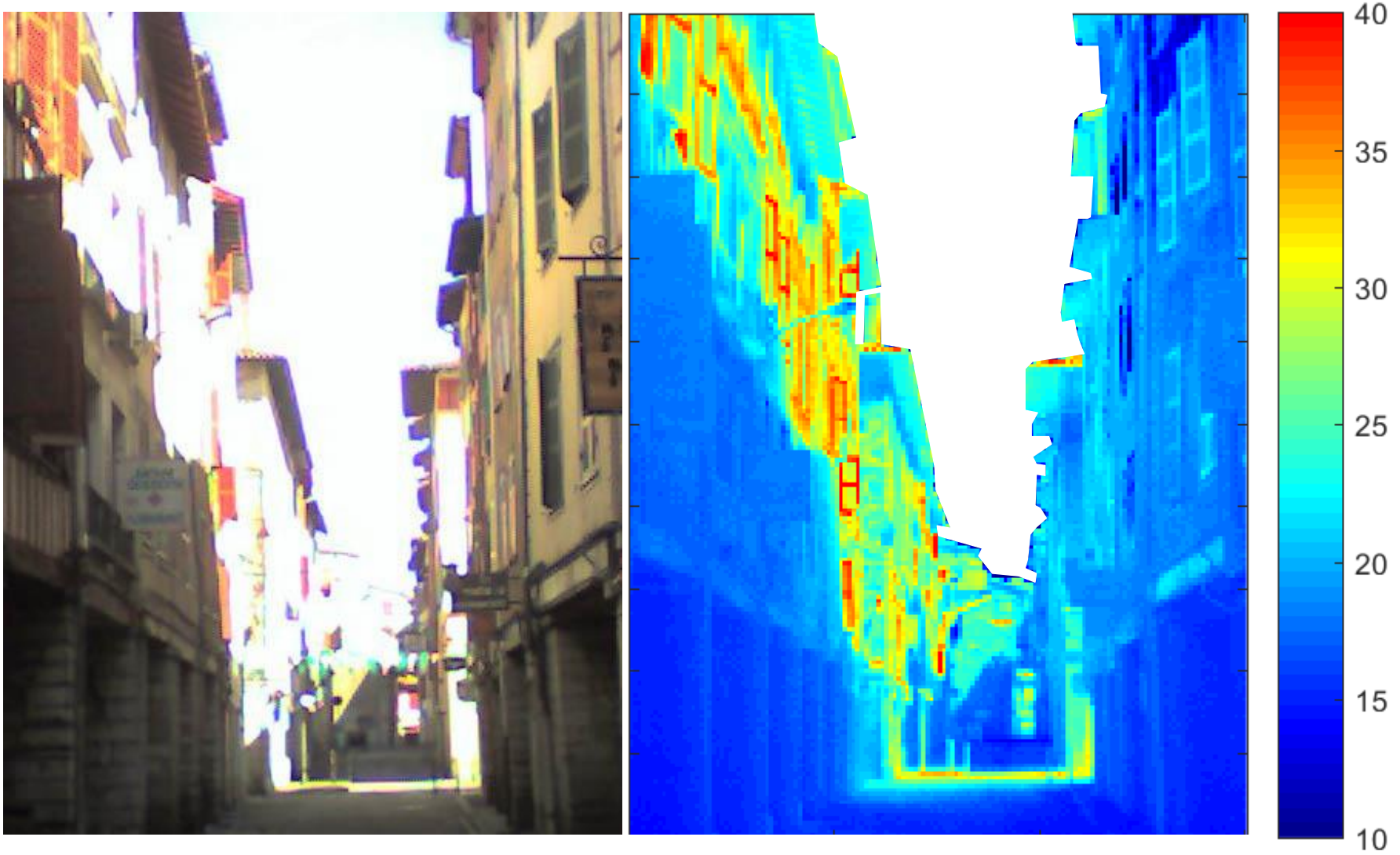

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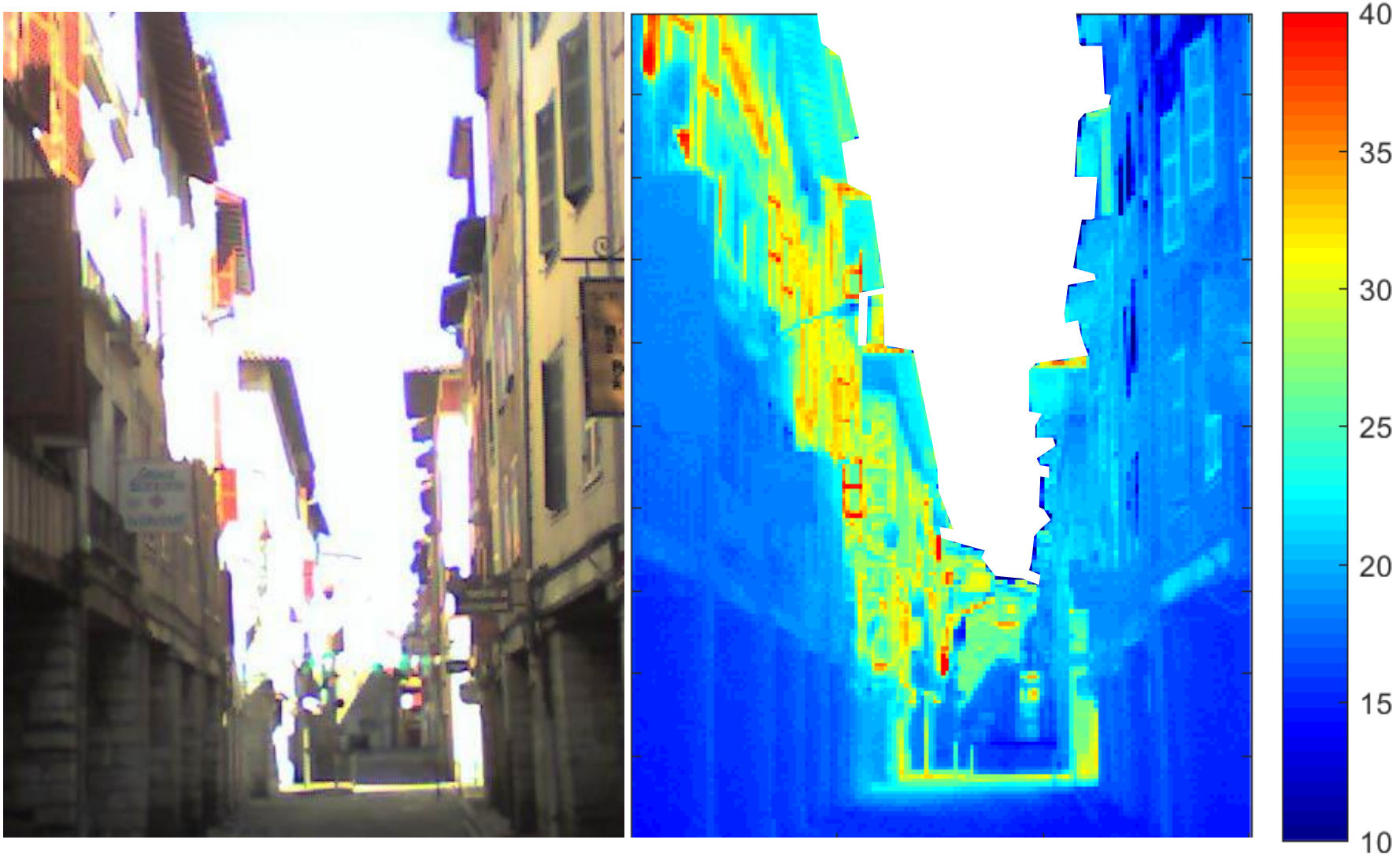

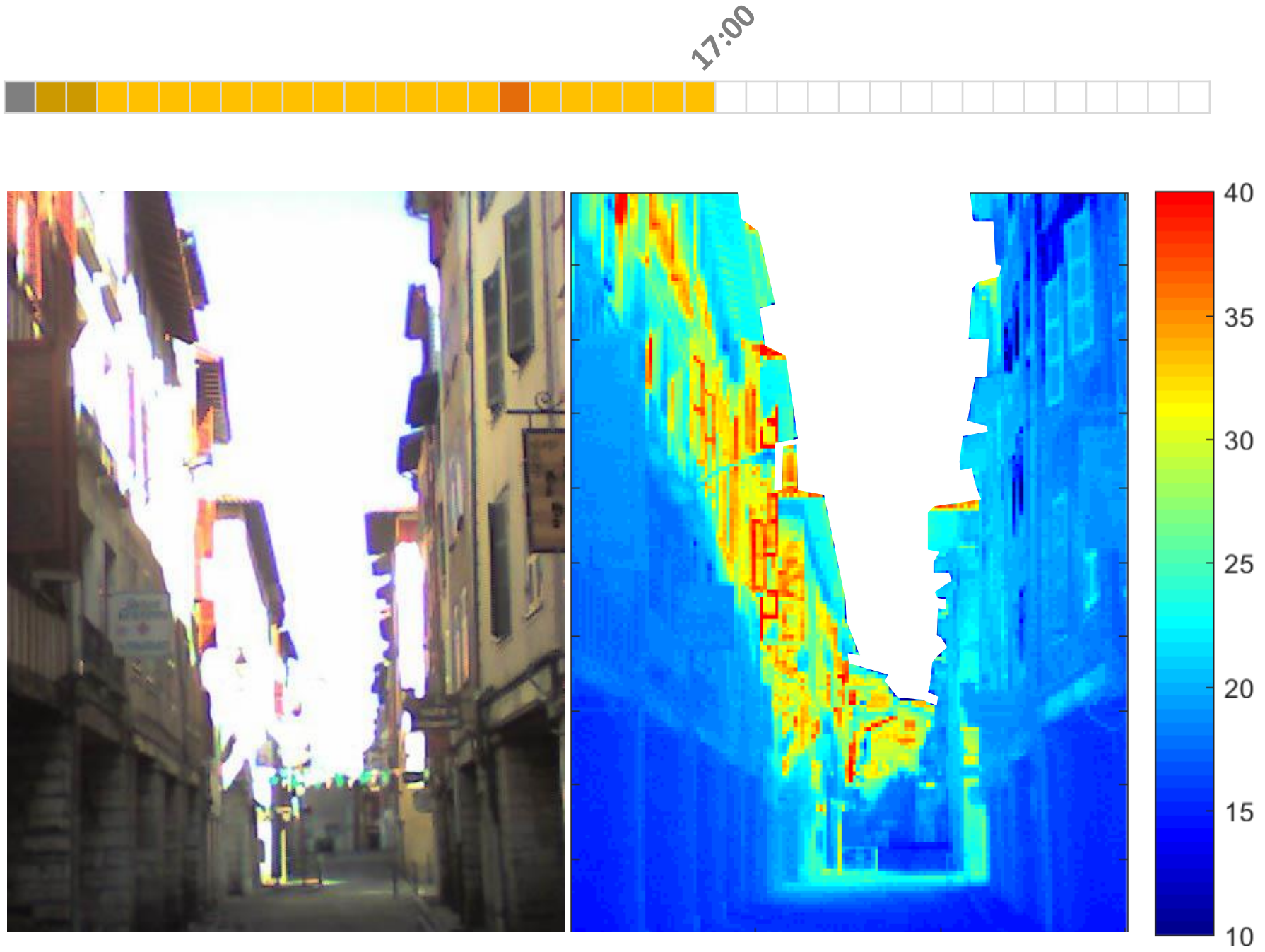
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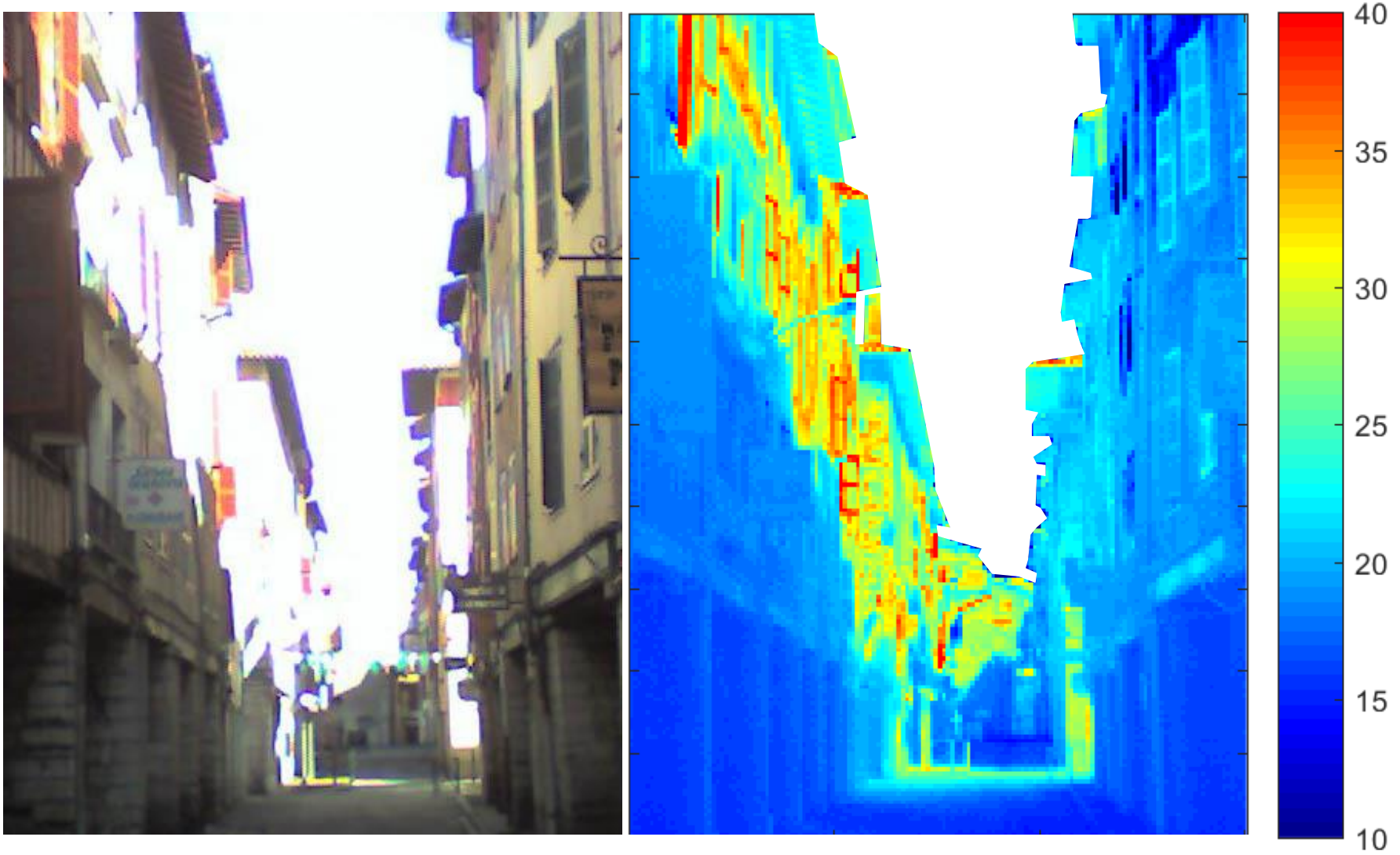

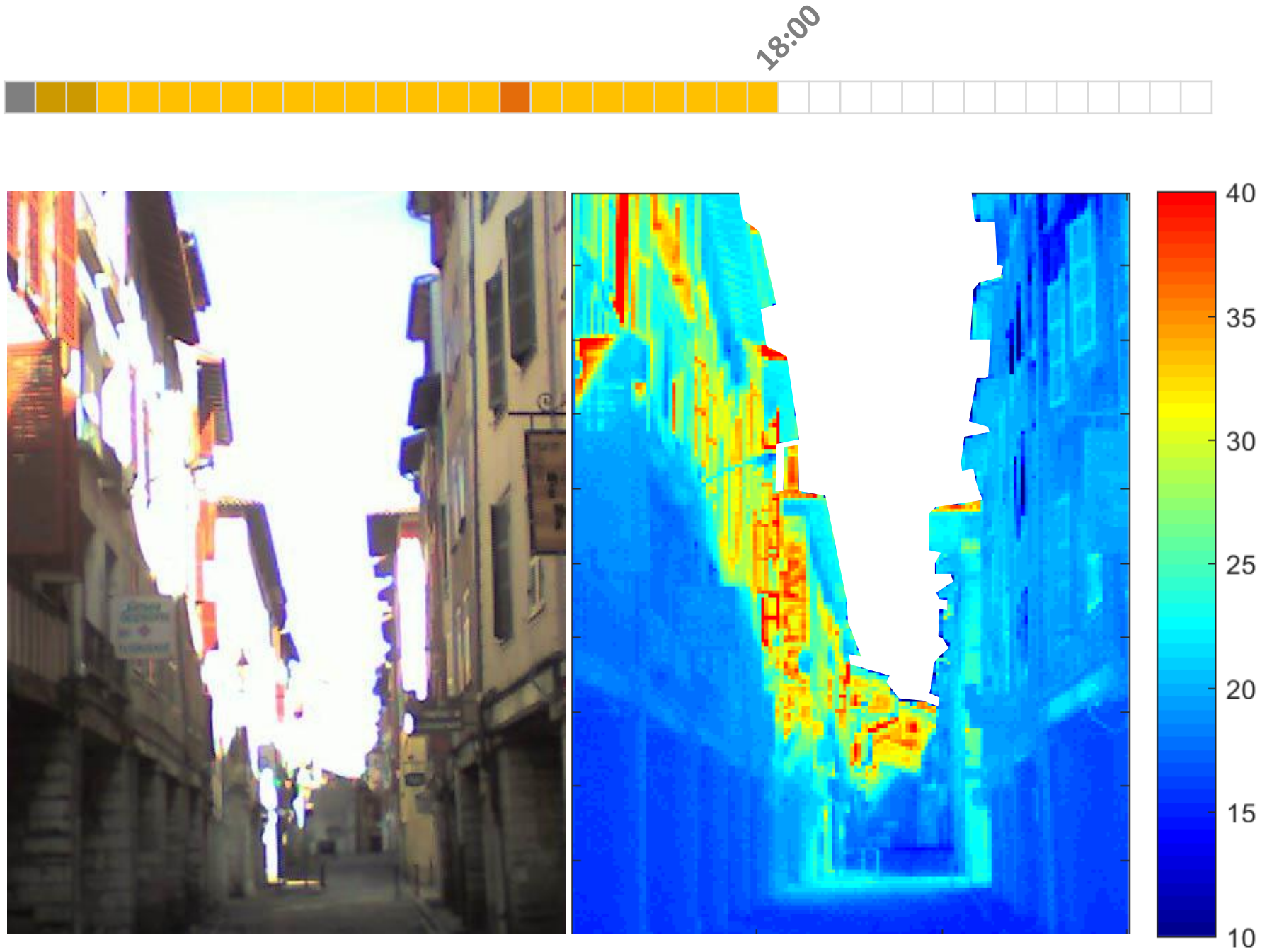
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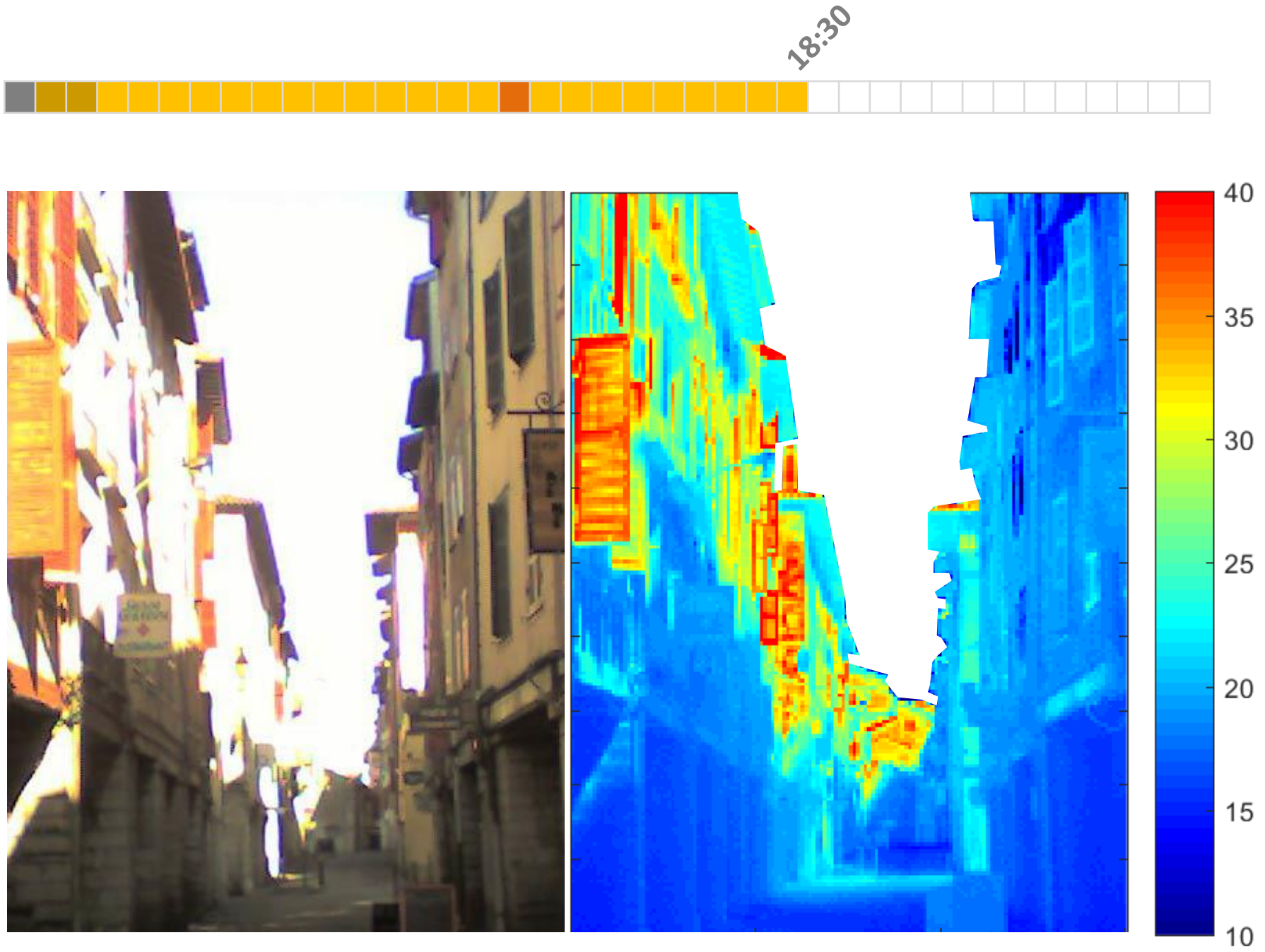
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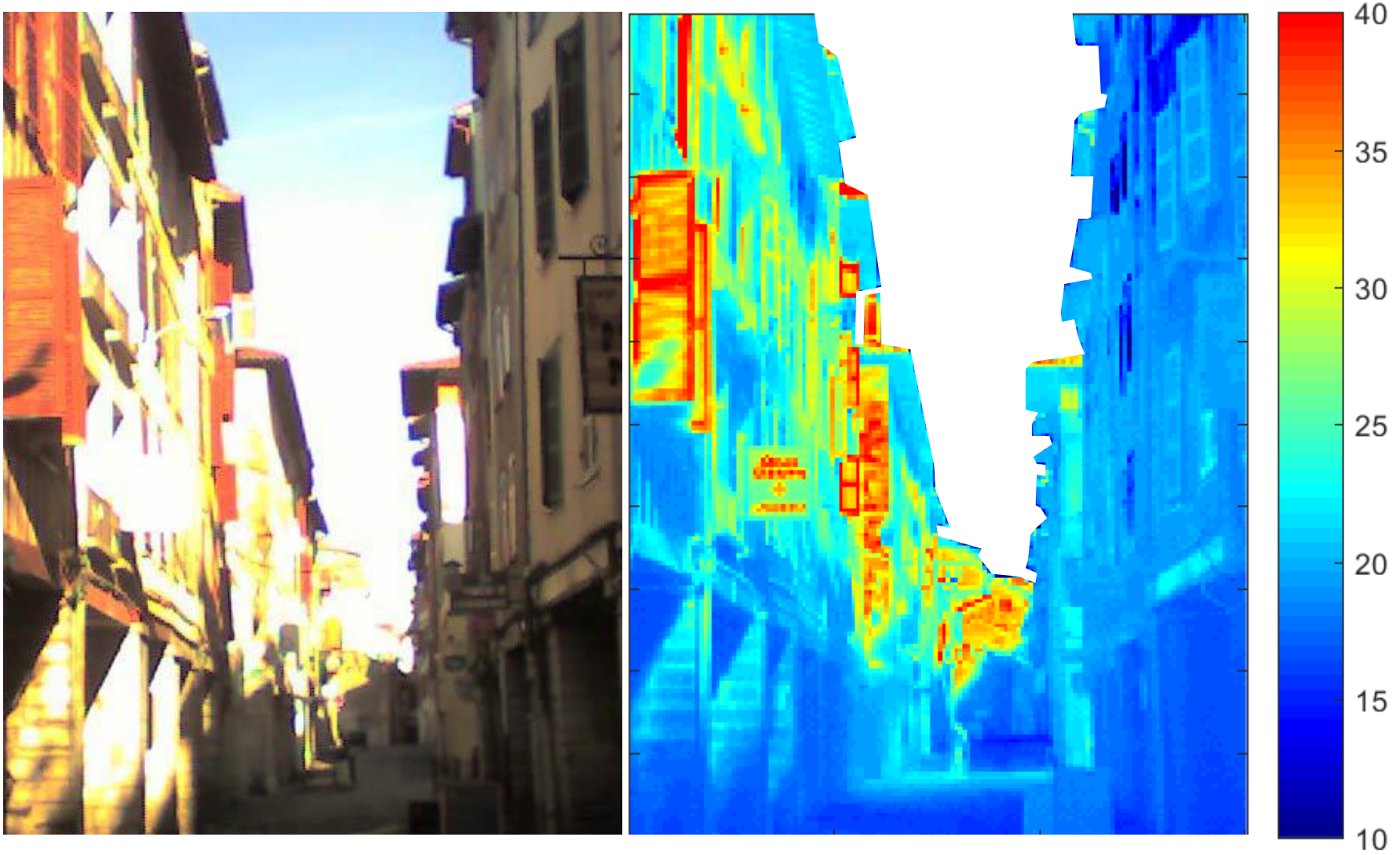

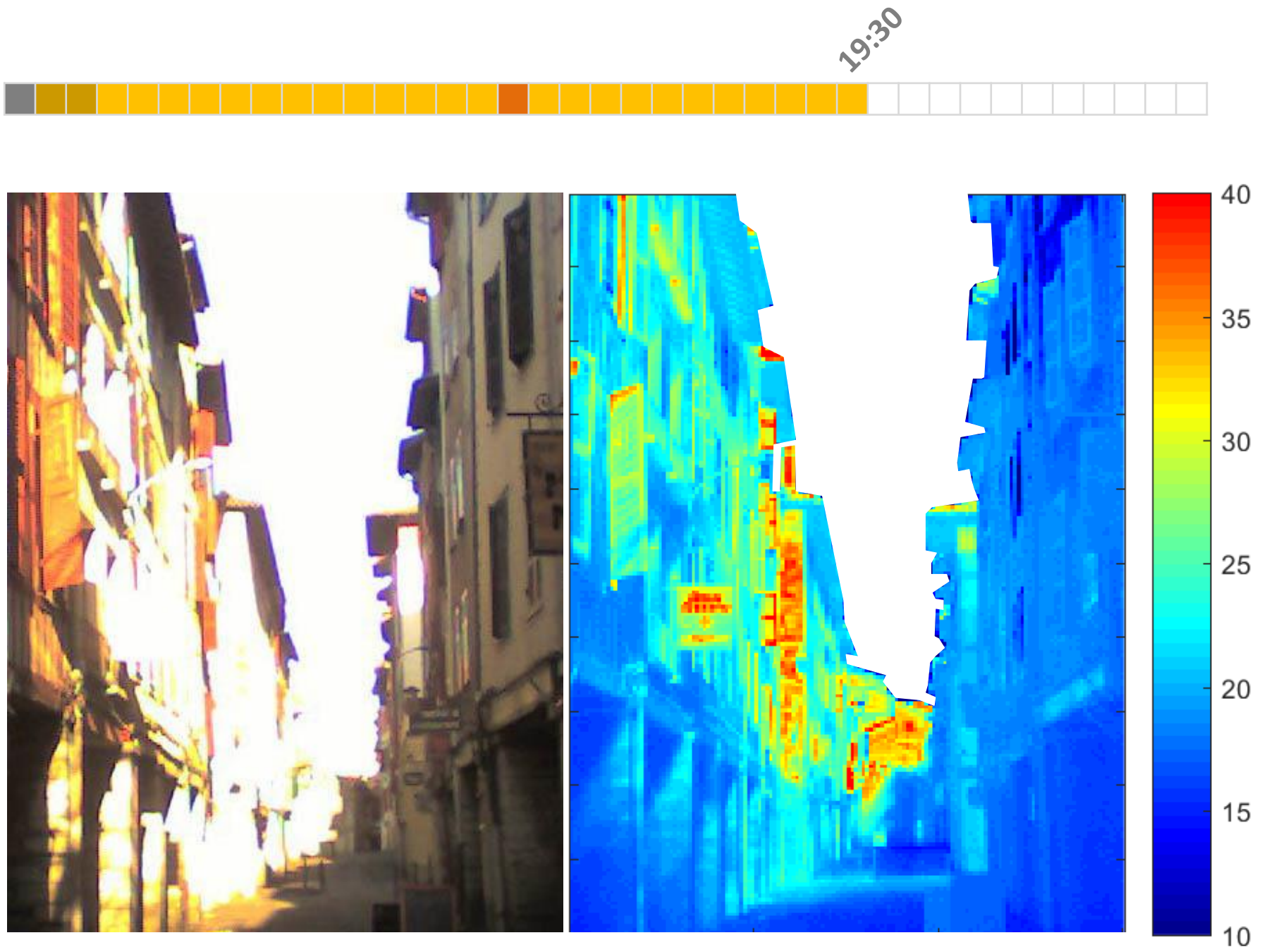
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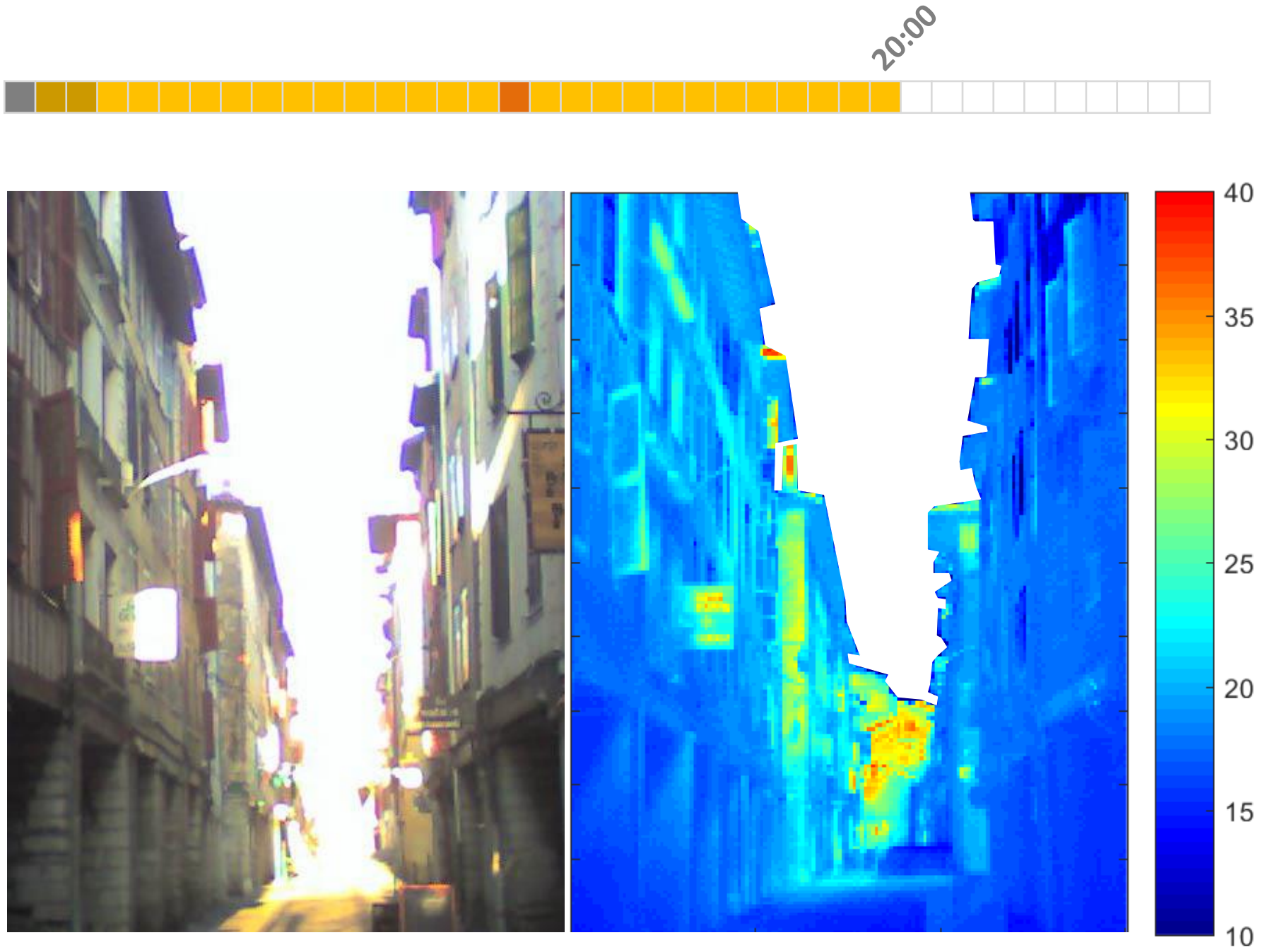
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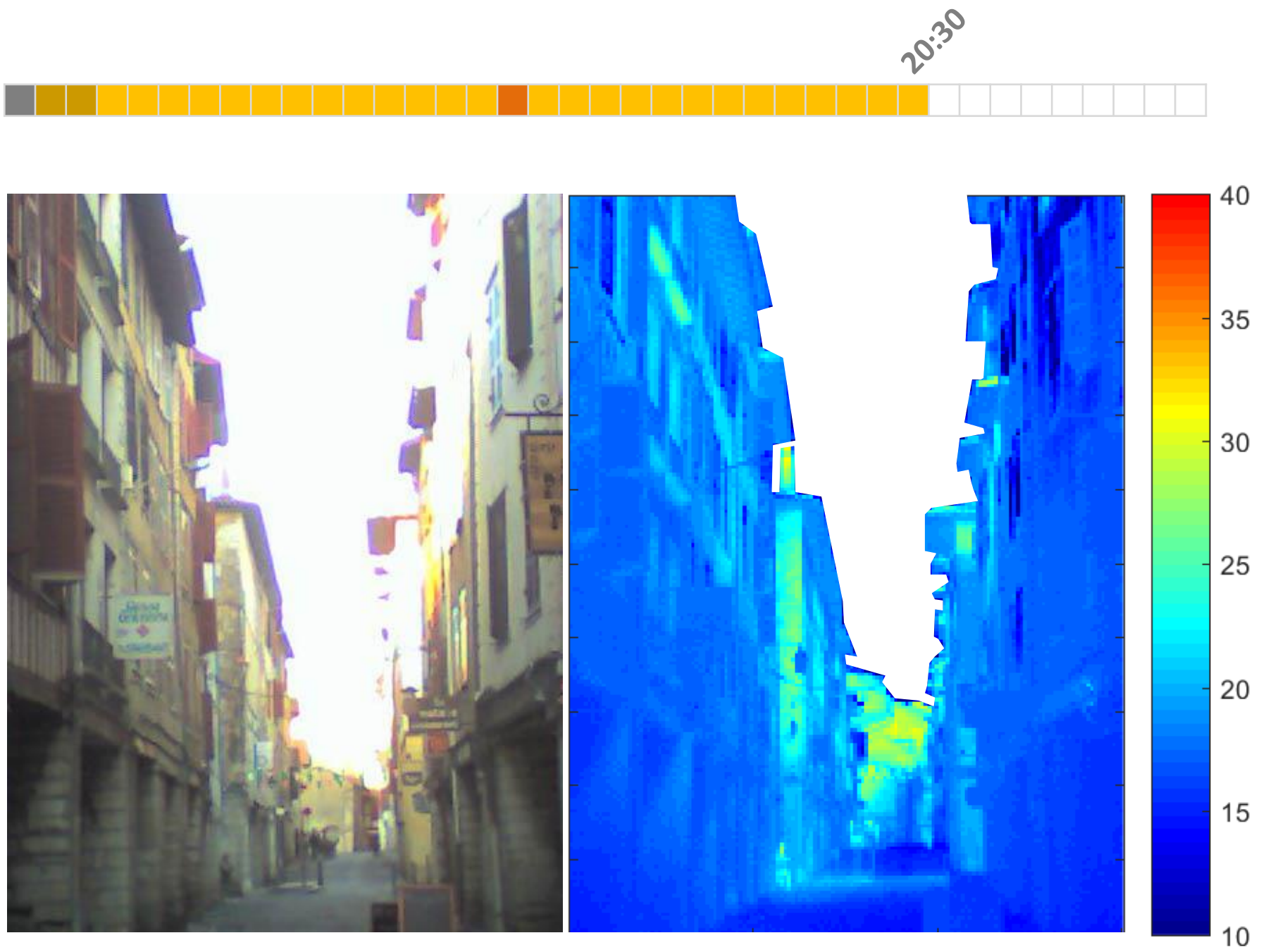
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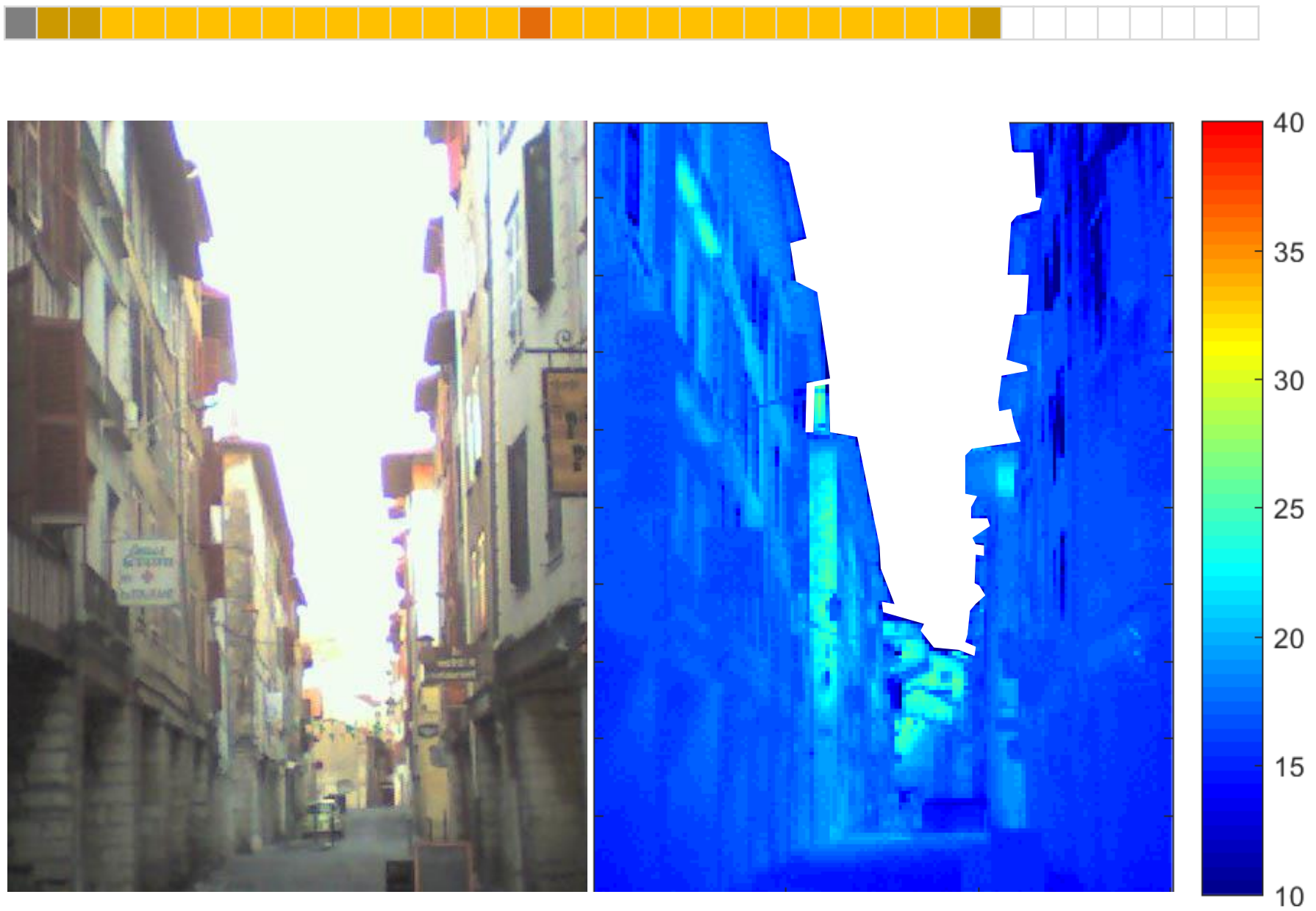
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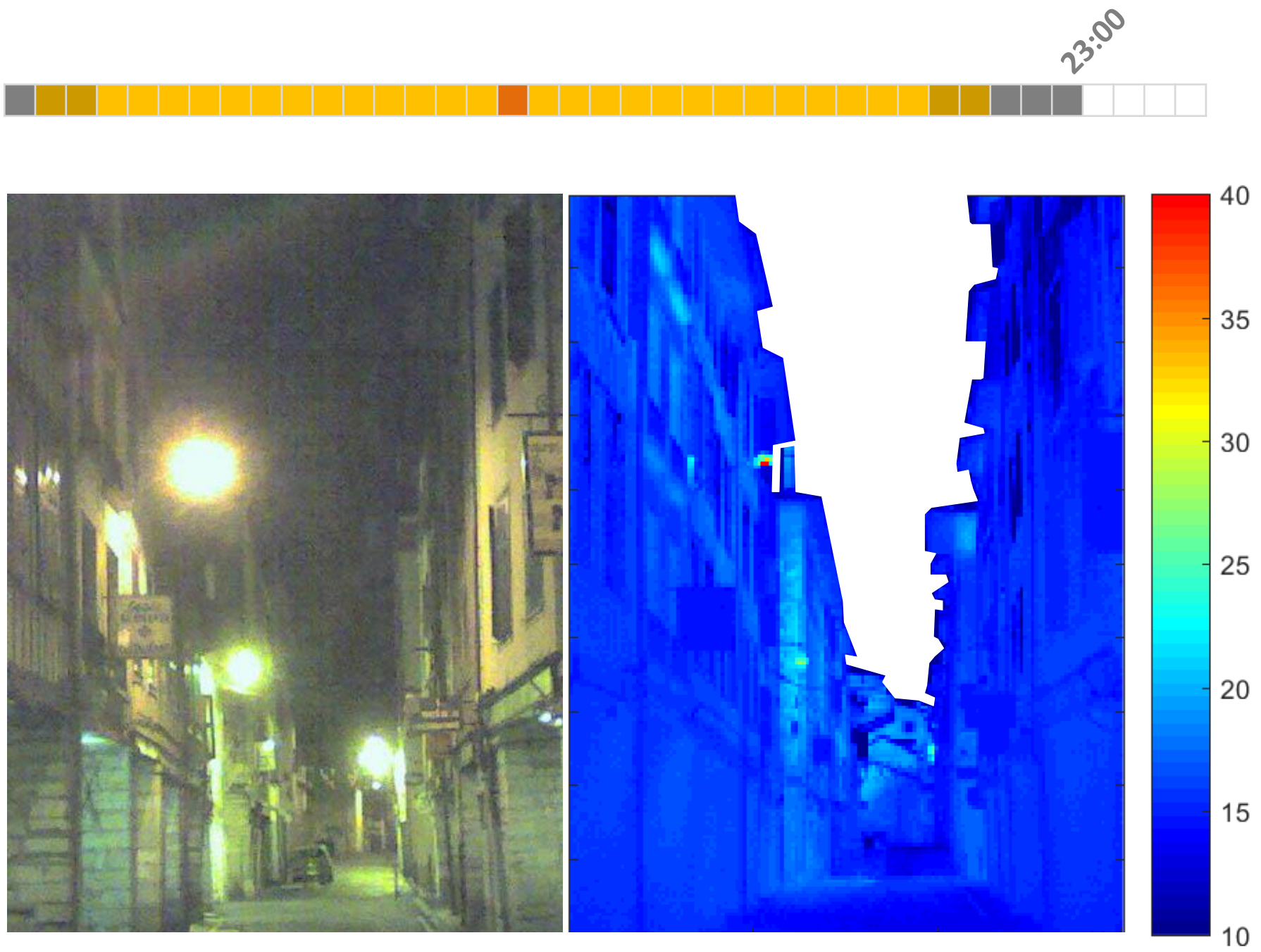
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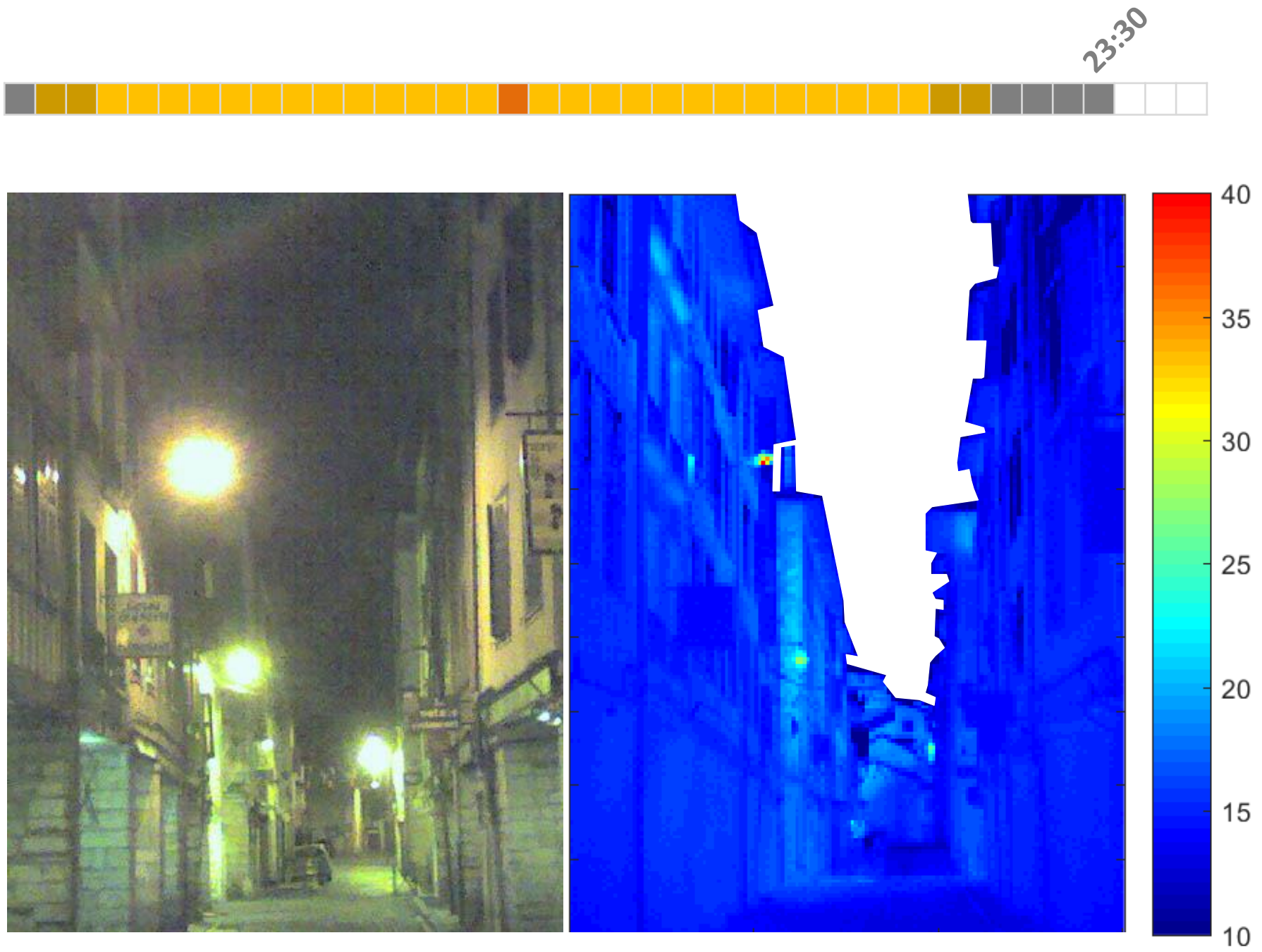
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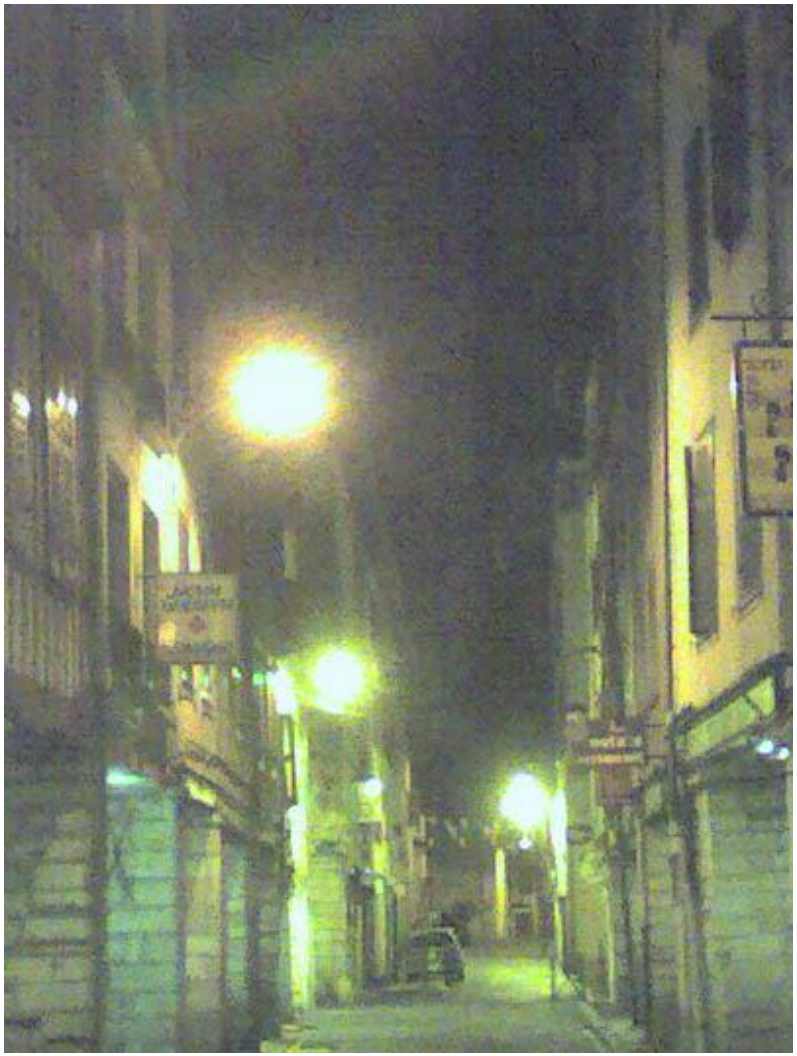

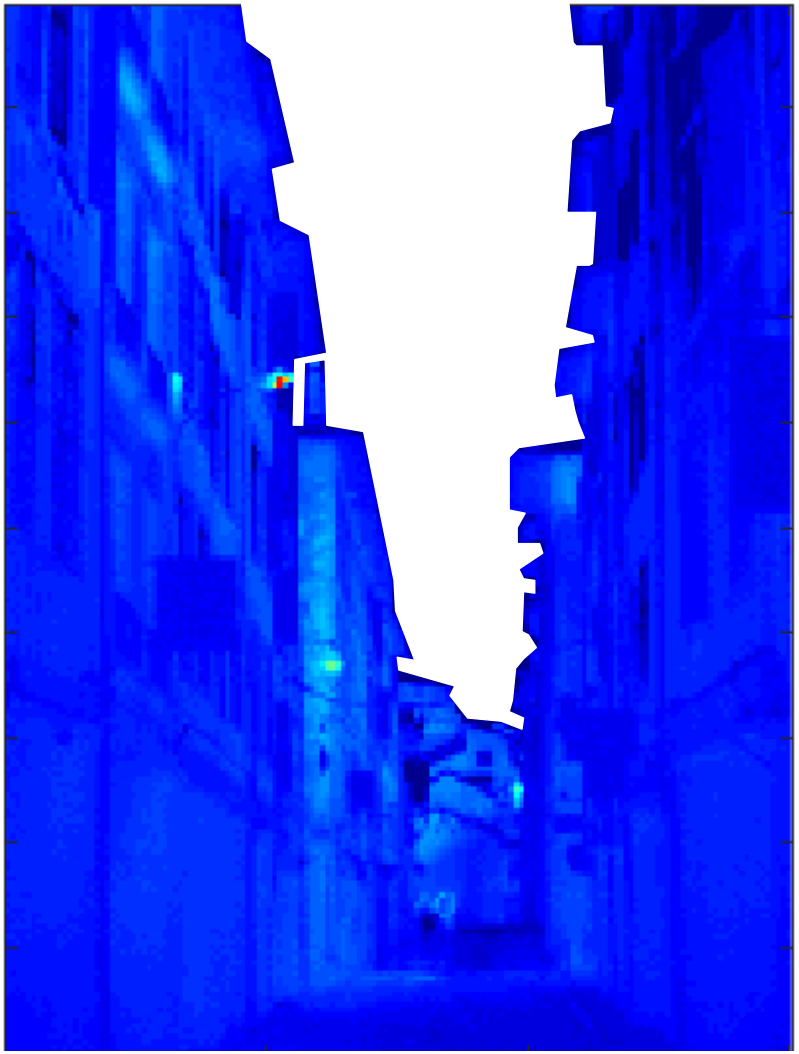

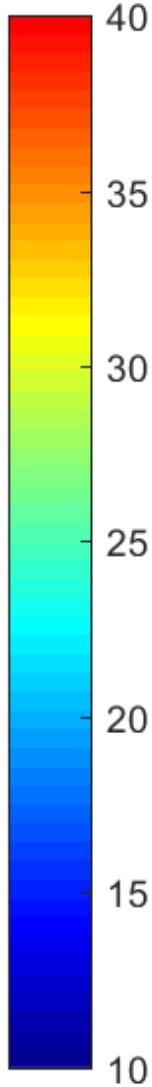

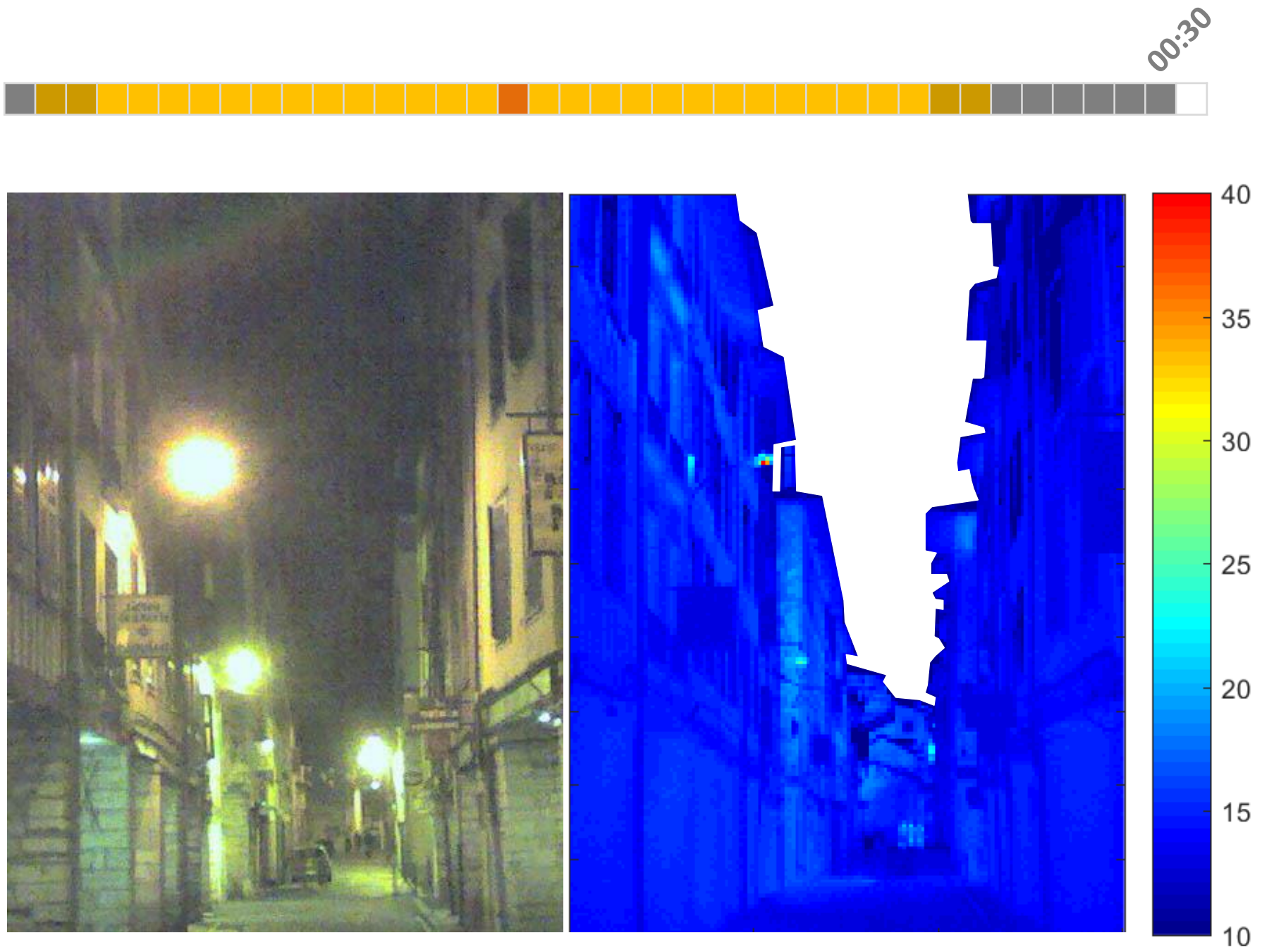
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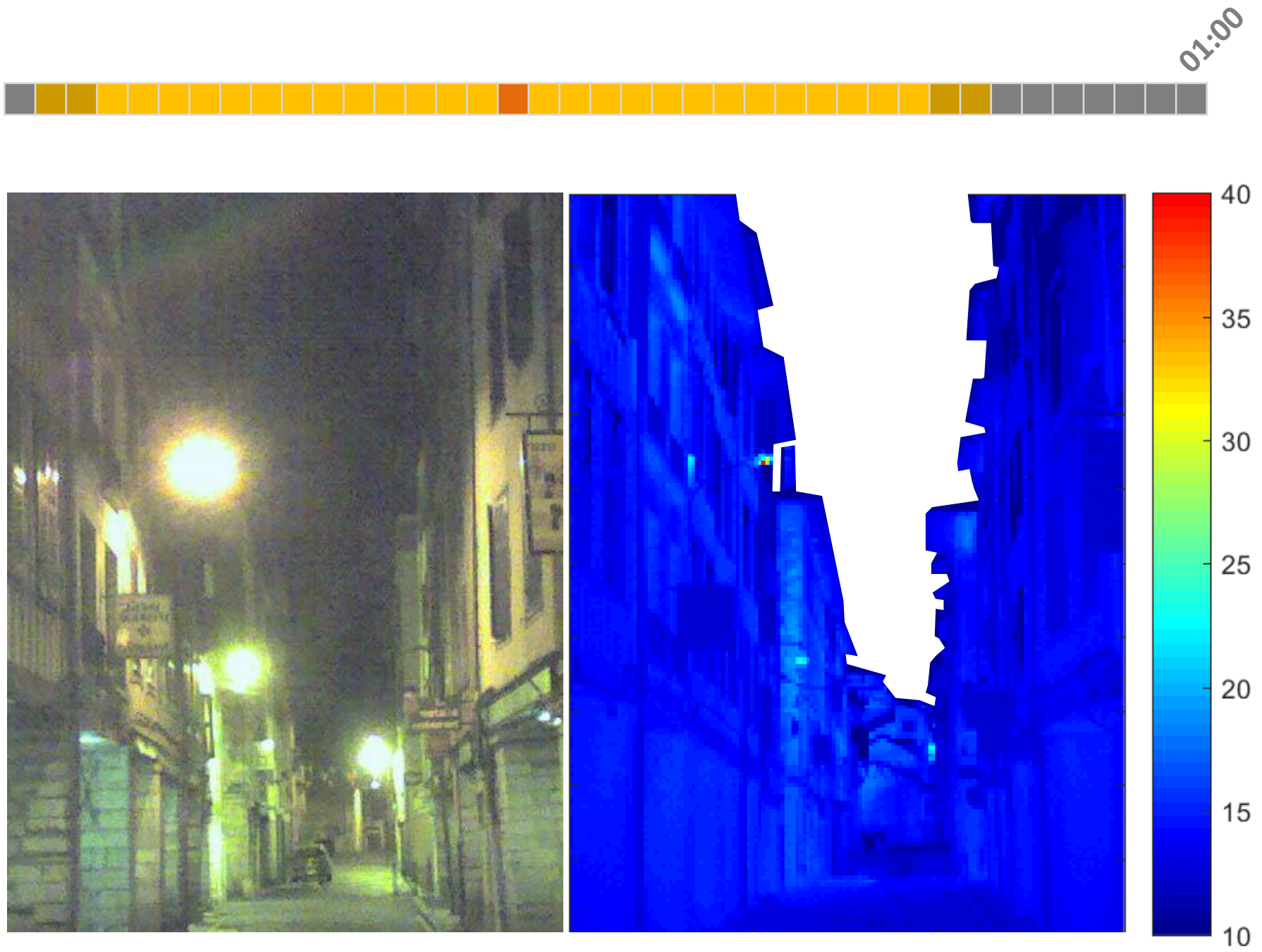
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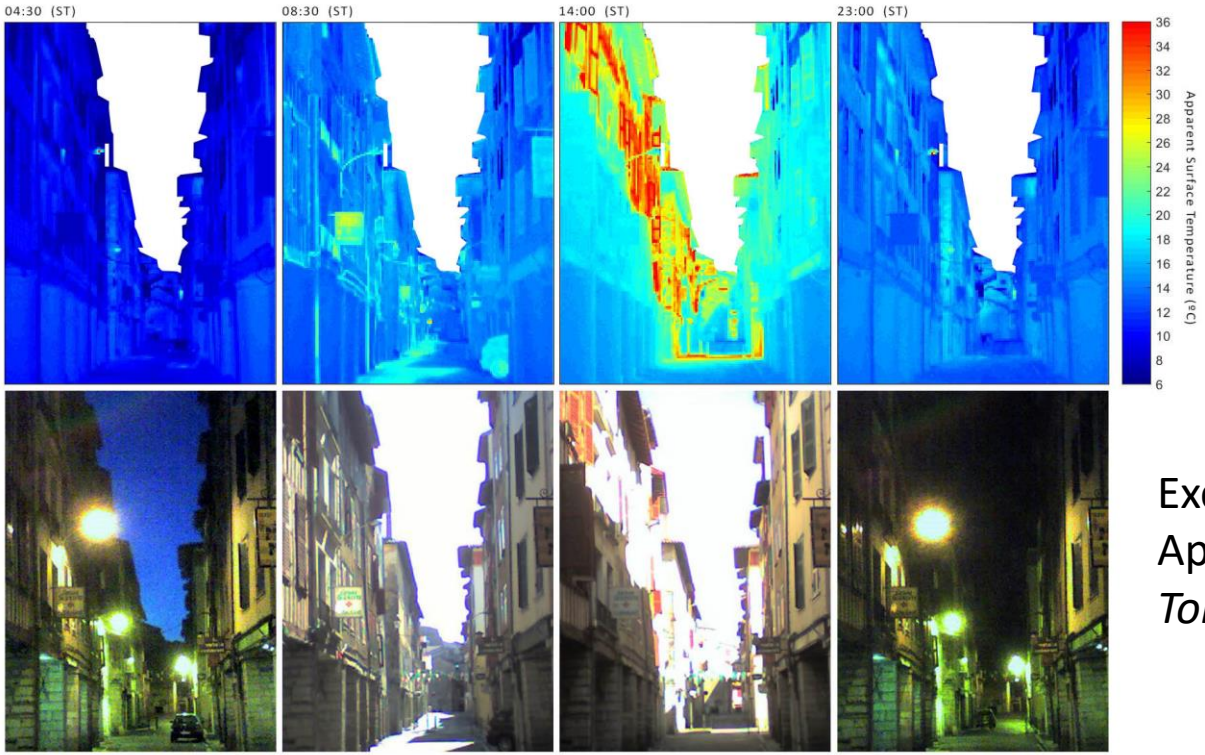
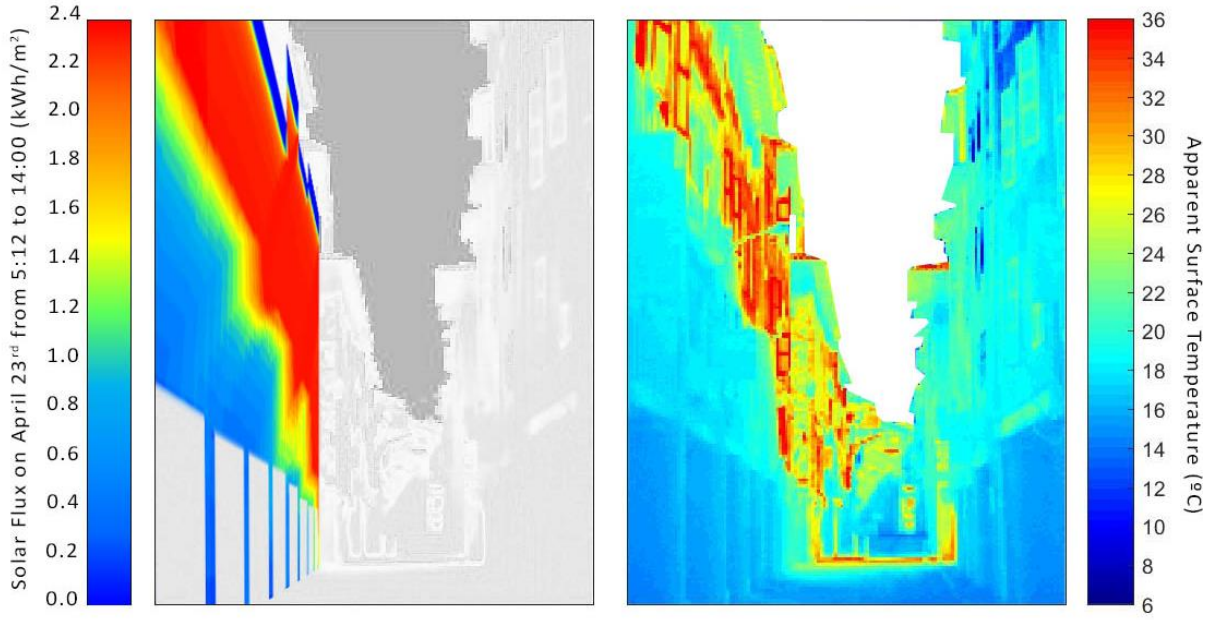


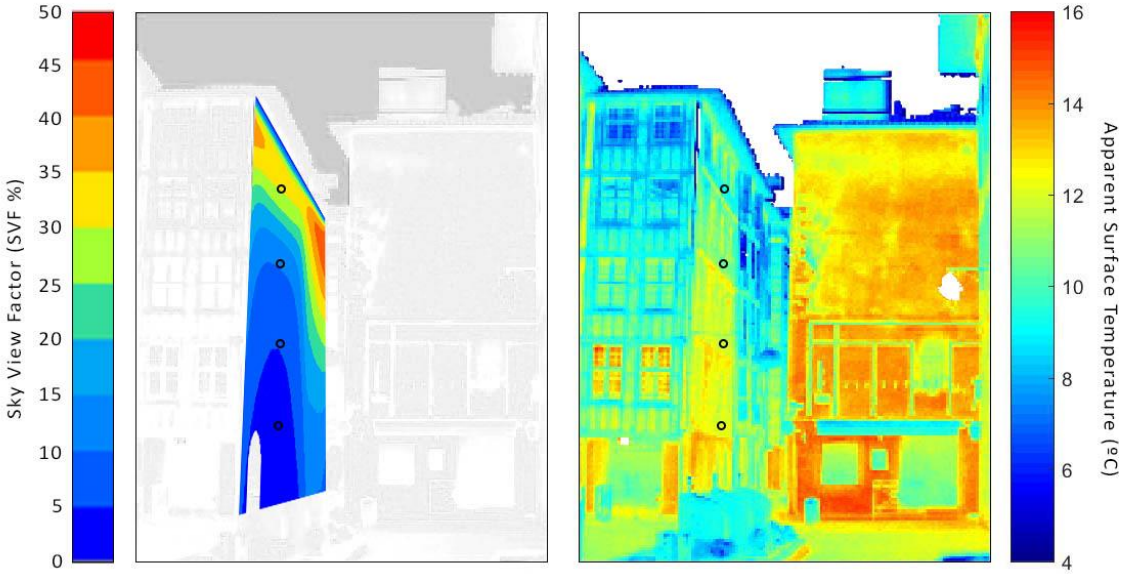
Excerpts from the sequence made on April 23, 2017 in the *rue des Tonneliers*

All the thermographs are on the same scale (color bar between 6 ° C. and 36 ° C.) and the emissivity of the surfaces is assumed to be unitary. In the first image, at 4:30 in the morning, the surface temperatures are substantially equal to that of the air. The common color bar does not favor details. Thus, for example, the heat emitted by the public lighting is scarcely visible on the image. At 8:30 am, the Sun comes from the east, from the camera, and heats the signs that face it. At 2:00 pm, the south-facing facades are illuminated at the top, and their temperature reaches a maximum value of 36 degrees. Finally, at 11:00 pm, the temperatures of the southern surfaces remain slightly higher than the temperature of the air, which is still 16 degrees. This is the consequence of thermal inertia.



Cumulative sunlight (calculated with Heliodon 2) and measured surface temperatures

To the left of Figure, the direct sunlight was accumulated throughout the morning until 2:00 pm, when the right thermography was taken. In general, there is a strong similitude between the two distributions, from which it can be deduced that sunlight and inertia of sunny objects govern surface temperatures when the Sun is present. The slightly projecting roofs explain that the top of the facades remains colder. The lighter parts of the facades are also colder, because a large part of the incident solar energy is reflected instead of being absorbed. It can also be deduced that the lateral conduction on the facades is weak.



Distribution of Sky View Factors (Heliodon2) and night surface temperatures

The distribution of temperatures on the other surfaces of the scene is, however, governed by another phenomenon: refreshment by radiative exchange with the sky. Whereas the temperature of the urban surfaces is very close to one another (with the exception of the ground and the roofs, the greatest temperature difference does not exceed ten degrees), the clear sky is much colder, and even more when approaching the zenith (in this image, the minimum temperature of the sky is already -25 ° C). So, the better a surface sees the sky (i.e., the higher its sky view factor is), and the more it cools. This effect is particularly obvious on the oblique façade, for which the sky view factors were calculated in Heliodon2 (on the left). It is clear that the most exposed areas are the coldest ones on thermography.