International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

PO163

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DOI 10.25039/x46.2019.PO163

from

CIE x046:2019

Proceedings
of the
29th CIE SESSION
Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

The paper has been presented at the 29th CIE Session, Washington D.C., USA, June 14-22, 2019. It has not been peer-reviewed by CIE.

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LIGHT POLLUTION ANALYSIS USING HI-RESOLUTION NIGHT AERIAL LIGHTING MAPS

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DOI 10.25039/x46.2019.PO163

Abstract

Light pollution visualisation is mostly known from the public thanks to the large scale satellite images and the ones taken from the ISS (International Space Station). It appears obvious that the human activity has a strong impact on the environment and those images are useful to illustrate the phenomenon.

Today, the cities lighting optimisation is an important line of work. Responding to human kind needs is not the only objective anymore. It has to deal with reasonable energy consumption and preservation of biodiversity.

Combined with the in-house knowledge and existing data (providing from ground studies), the use of hi-resolution night aerial lighting maps has proven ability to give precise technical information on light pollution sources identification and lighting points localisation. The end-users maps are also particularly powerful to build awareness for both the general public and the decision makers to the light pollution and to motivate renovation projects.

Keywords: Light pollution, Luminance, Energy efficiency, Biodiversity, Aerial mapping.

1 Context and challenges

1.1 Light pollution definition

In a worldwide context challenged by the global warming, many countries have decided to engage themselves for a better energetic management and reasonable energy consumption. In France, an increasing number of territorial authorities (cities, collectivities, regional corporations for energies…) are facing the problem with the question of the cities lighting.

It is widely accepted that urban lighting has demonstrated strong abilities to respond to numerous human kind needs such as convenience, safety and aesthetics (architectural heritage…). It was and stays an important part of the nocturnal human life.

However, for several decades now, negative effects have also been highlighted (Challéat *et al.*, 2017). They are related to various preoccupations, for example concerning human health (increasing risks for several diseases, sleep disorders and exposure to blue light) and environment (threat to biodiversity). Another well-known demonstration comes from the astronomers' community which has warned of the alteration of the sky visibility and its study (skyglow effect). All those preoccupations, counterbalancing the merits of urban lighting, have led to the light pollution global discussion.

Light pollution corresponds to the excessive, misdirected or obtrusive artificial (usually outdoor) light (Globe at Night, 2019). This inappropriate use of artificial light includes effects such as (International Dark-Sky Association, 2019; Lighting Research Center, 2007):

- Glare: excessive and uncontrolled brightness leading to visual discomfort;
- Skyglow: brightening of the night sky over inhabited areas leading to the effect of reducing the ability to view the stars;
- Light trespass: light falling where it is not needed, wanted or intended;

- Clutter: bright, confusing and excessive groupings of light sources that may generate distraction and potential accidents.

Light pollution analysis and the reduction of its consequences have become major challenges for many cities, with strong implications in the energetic and environmental areas. Building the “city of tomorrow” comes with an optimised lighting system, less consuming, responding to human kind needs while avoiding perturbations on the environment.

1.2 The legislation framework

The use of the light has to be rethought taking into account the new lighting technologies as well as the definition of the correct and real need. For example, the practice of extinction or lowering the light level at certain time periods is more and more developed in a lot of cities.

For several years now, many legislations have been implemented, concerning the light pollution topic and appropriate actions.

For example, in France, successive laws and decrees have been adopted:

- ***Grenelle Environnement* laws in 2009**: entrenching in the French law the obligation to constrain the light pollution (Ministère de l’Ecologie, du Développement Durable, des Transports et du Logement, 2011), they have encouraged the territorial authorities to renovate their old installations and to promote a reasonable use of the light;
- **Energy Transition law in 2015**: reinforcing the previous laws, several programs are implemented with actions regarding the outdoor lighting in order to realise energy savings and to answer to environmental challenges, in particular the preservation of the biodiversity. The definition of green and blue infrastructures, where the impacts of artificial light must be limited, contributes to improve the conservation status of natural habitats and species (Centre de ressources Trame vert et bleue, 2019);
- **Specific ministerial decree from 27th of December, 2018**: related to prevention, reduction and limitation of light pollution, the decree has also involved the private actors in its prescriptions and introduced the notion of temporality. Depending on the concerned ground spaces (parks and gardens, professional spaces, retail stores windows, parking areas…) the decree has specified lighting period limitations (Ministère de la Transition Ecologique et Solidaire, 2018).

In this framework, the territorial authorities have to increase their skills and knowledge and master the lighting state of the art of their territory. The objectives are multiple, from direct renovation projects on the public lighted area (energy savings motivations) to awareness raising for the private actors in order to promote a better use of the light.

2 Night aerial lighting maps production

In order to face the complex situation as previously described, the territorial authorities need powerful tools in addition to their existing data base and knowledge. Giving the broad range of actors and competences that can be involved in the light pollution topic, these tools shall not only deliver technical and precise information but also constitute pedagogic and communication products.

Night aerial lighting maps are very interesting solutions to meet these objectives, enabling precise lighting points localisation and characterisation, thanks to their hi-spatial resolution, while enabling relevant communication actions, the products being visual by nature.

The development of such a technical provision is based on more than 15 years of experience at LNE (Laboratoire national de métrologie et d’essais) in working with French territorial authorities in the area of the Energy Efficiency Improvement. It involves remote sensing projects from the very first step (data acquisition) to the delivery of the results and maps production, combining skills in aerial operation, mechanic and design and GIS (Geographic Information System). For the specific light pollution analysis, these competences are completed by contribution from people involved in outdoor and indoor lighting characterisation and metrology with knowledge in photometry and colorimetry.

2.1 Context of the aerial measurement

Before detailing the data acquisition and processing methodology, it is necessary to explain precisely what are the measured quantity and the context of this measurement.

The present technical provision deals with aerial photographic operations, meaning vertical shootings taken from the sky. As a consequence, the observed phenomenon is a mix between direct and reflected light. Thus, the quantity expressed by the pixels in the acquired images is a luminance level, referring to the visual perceptions from the sky, and not an illuminance one.

2.1.1 Luminance vs. Illuminance

Luminance and illuminance terms are often mixed up though they are distinct quantities (CIE, 2014):

- Luminance: unit is candela/square meter ($cd \cdot m^{-2}$): luminous intensity of light, in a given direction, emitted or reflected from a surface per unit area of that surface. It relates to the human visual perception of brightness;
- Illuminance: unit is lux (lx): luminous flux incident on a point of a given surface, per unit area of that surface.

Data acquisition from sky can only deal with luminance observation. The illuminance measurement is not legitimate in aerial photography, unless knowing and taking into account the light reflecting factors of the lighted ground surfaces and the orientations of these surfaces.

2.1.2 Origins of luminance levels observed from sky

The luminance levels observed from sky are composed of three elements:

- The natural sky brightness related to radiation from celestial sources and atmospheric luminescence;
- Artificial glow related to direct light (see figure 1, left) coming from public and private sources (sky oriented lights dedicated to buildings illumination, decorative installations, advertisements…). Basically this is the first target of such a study with the purpose of limiting the ULOR (*Up Light Output Ratio*) from luminaires;
- Artificial glow related to reflected light (see figure 1, right) coming from public and private sources (ground oriented lights for road lighting purposes, parking illumination…).

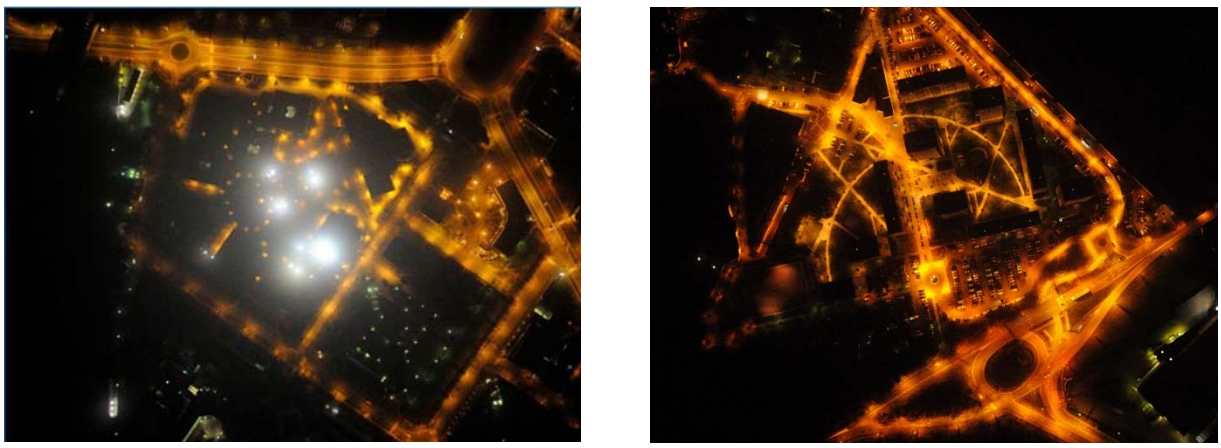

Figure 1 – Direct (left) and reflected light (right) observation from the sky (source: LNE)

It is also necessary to take into account the effects of the atmosphere, diffusing the light rays and leading to a weakening of the observed luminance in accordance with the distance.

As a consequence, night aerial lighting maps are considered complementary products helping the identification of light pollution sources, taking into consideration that the following elements are measured:

- Luminance of the "useful" part of lights: reflection on public spaces mostly;
- Illuminance identified as "light pollution sources": direct light, reflection on building's façade, etc.…

2.2 Acquisition and processing methodology

The aerial lighting maps projects concerned by the present paper regroup all operational steps from the onboard aerial data acquisition through the data processing and end-user maps production:

- Mapping, at night time, during a dedicated flight, a specified geographic area in the visible spectrum to record the lighting perception from the sky. The used sensor (a low light digital camera) is combined with an inertial measurement unit to know the real-time vehicle's position with respect to the flight dynamics (altitude, pitch and roll angles). The choice of the shooting settings has to deal with the concerned territory and situation (size of the area and work altitude). It is also necessary to pay attention to the meteorological conditions, in particular the local fogs. The time slot for this dedicated flight is defined with the territorial authority taking into account the possible street lighting on/off schedules for some cities and the aim of the overall study. At the end, a large amount of visible images is acquired (around 1000 images for a 1000 km² area). The images present hi-spatial resolutions, with pixel sizes usually ranging from 15 to 30 cm (figure 2), depending on the specific characteristics of the aerial missions, letting the highlighting of various ground elements with high precision (visibility of cars, pedestrian crossings, road surface markings…);

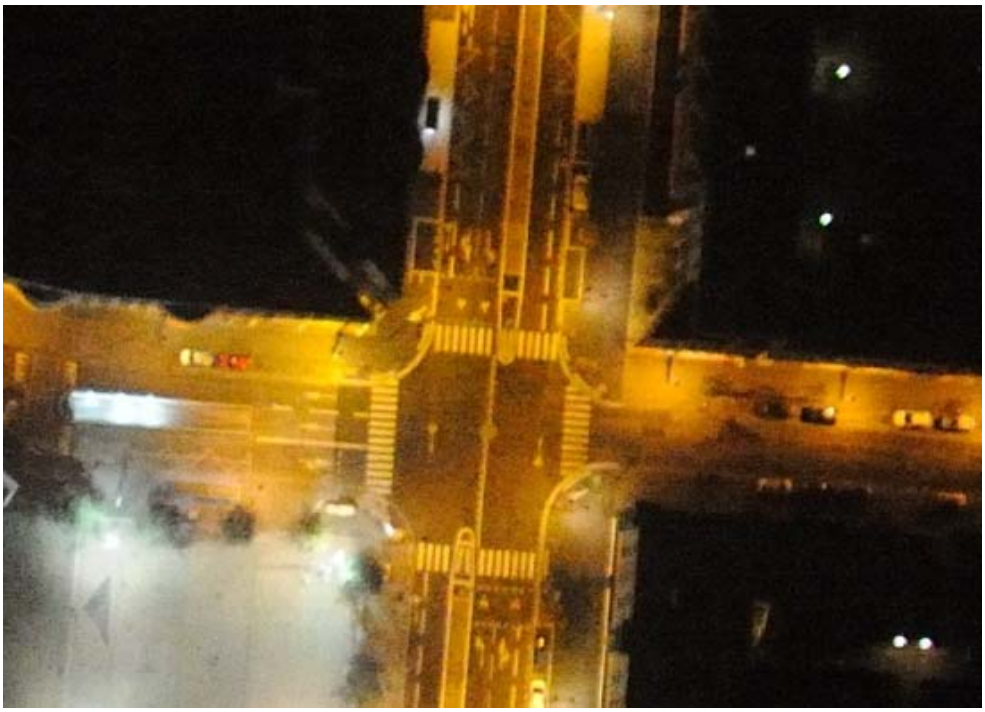

Figure 2 – Hi spatial resolution raw night image (source: LNE)

- Data processing in laboratory: all acquired images are orthorectified and georeferenced, which means corrected by removing distortions and related to a geographic coordinate system. Then, the corrected images are mosaicked in order to build a unique lighting image in natural colours covering the overall area of study (figure 3). The resulting data is

fully integrated within the GIS of the concerned territorial authority and can be superposed with high precision to the existing geographic layers (orthophotography, lighting points database in vector layer…) as illustrated by the figure 4;

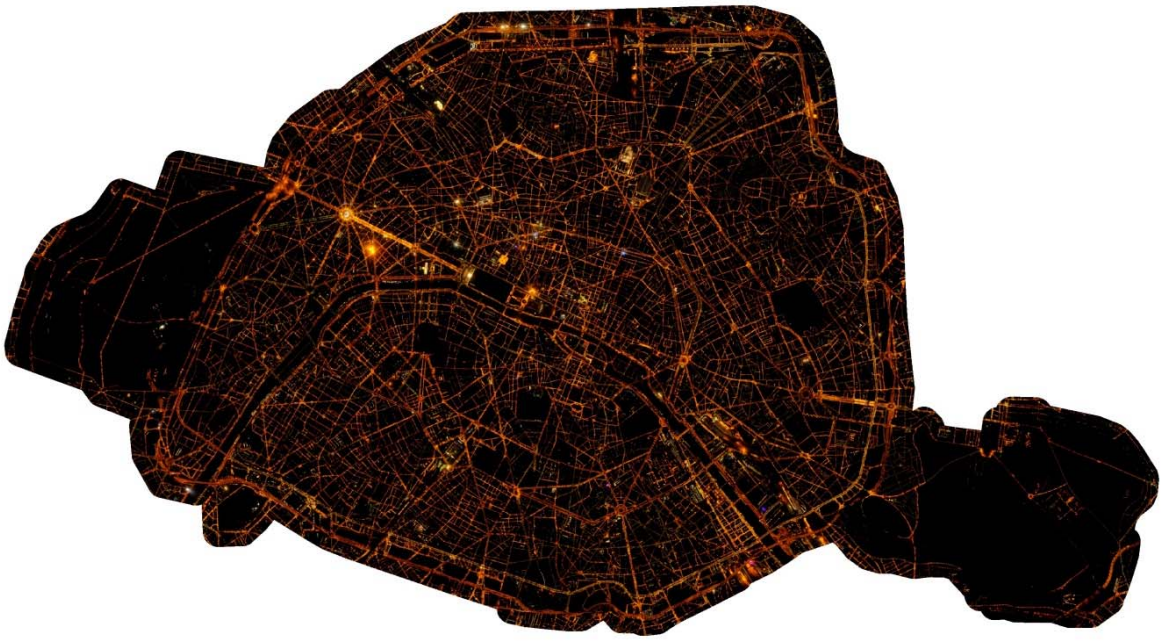

Figure 3 – Complete lighting image in natural colours, city of Paris (source: Mairie de Paris)

Figure 4 – Georeferenced lighting image superposed to the existing orthophotography in a GIS (source: Mairie de Paris)

- Processing of the previous lighting mosaic in a false colour 8-bit image (figure 5) to highlight the priority areas to study and allowing data classification and vectorisation in polygon type data (conversion of the image into a classical GIS vector data where each

polygon corresponds to an area regrouping pixels of the same class). The produced image is relevant for quick highlighting of areas presenting low and high luminance levels (figure 6) as well as for statistics calculation;

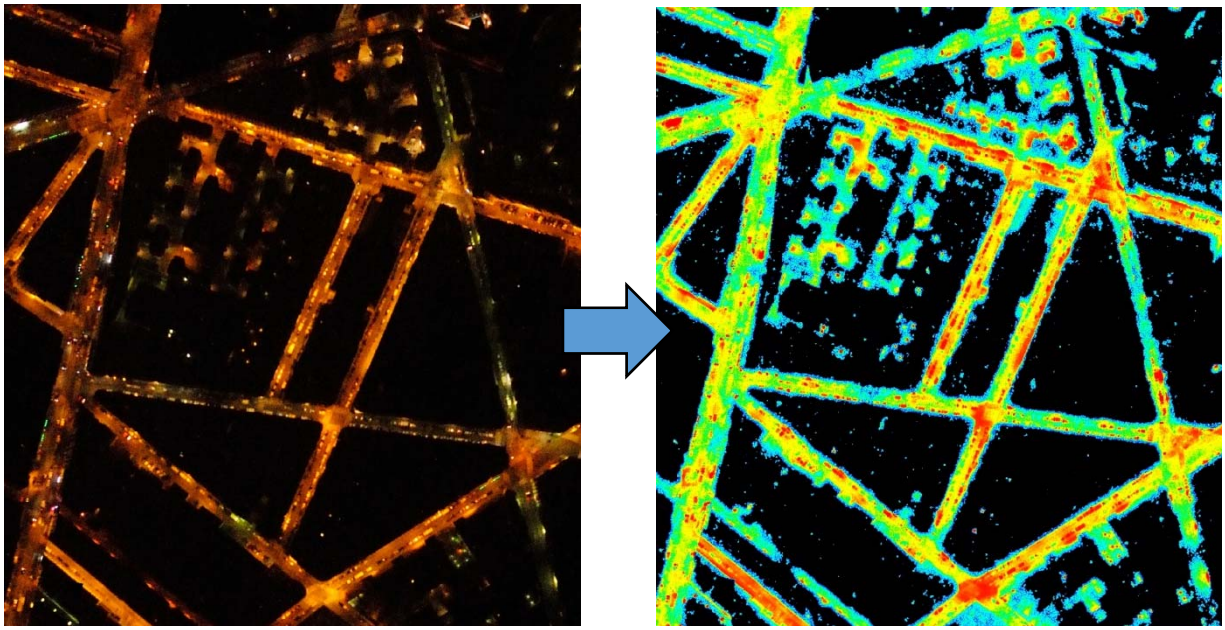

Figure 5 – From natural colours to 8-bit 256 colours image (source: Mairie de Paris)

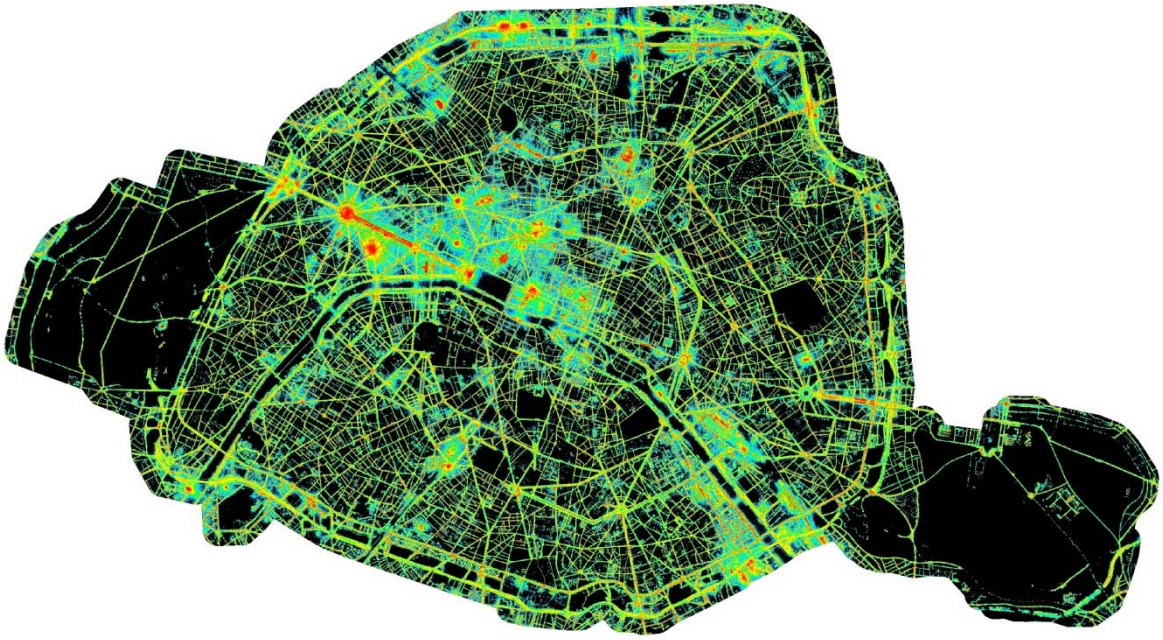

Figure 6 – False colour 8-bit (256 colours) image, highlighting in red high luminance levels areas, city of Paris (source: Mairie de Paris)

- Automatic identification and extraction of the major spots or “hot” spots (high luminance spots) of the territory. A point type vector data is generated for the GIS taking into account the possible aberrations and omissions (figure 7). The threshold used to identify a hot spot

is entirely configurable depending on the area of study and acquisition conditions (meteorology…);

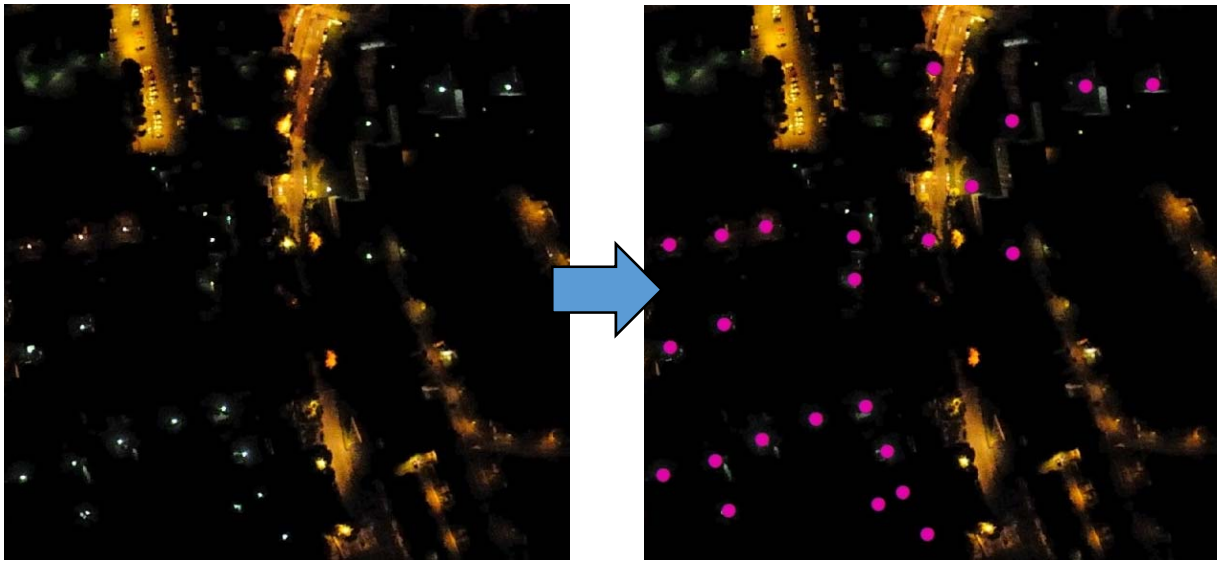

Figure 7 – Hot spots detection from light image and conversion to vector points (source: LNE)

- Production and analysis of end-users maps: qualification of entire street performance (4 to 6 levels classification), hot spots distribution in the public and private spaces…;
- Characterisation of light sources (LED, Sodium…) from the RGB (Red Green Blue) channels of the acquired aerial images (in development).

3 Night aerial lighting maps results and benefits

This methodology has been successfully applied with strong benefits through various projects of different French territorial authorities.

Several major French cities have decided to acquire their first hi-resolution night aerial lighting vision with three main objectives:

- Have a complementary vision of the lighting situation offering additional information to the existing lighting database and knowledge;
- Have a first global vision, a “reference” image, before the beginning of renovation programs consisting in light sources replacements (willingness to illustrate the evolution of the global perception through future periodic aerial data acquisitions);
- Prioritise the areas to focus on for the implementation of LED technology to maximise performance and energy savings.

Once integrated in the city’s geographical tools, the night aerial lighting maps and GIS analysis have immediately demonstrated capability to complete the existing knowledge and database concerning public lighting sources. In details, they have led to:

- Identify and illustrate the effect of the major spots of the public lighting system (historical buildings lightings…);
- Improve and expand the existing lighting database by revealing and adding to the GIS layers new spots not previously referenced.

In addition, the produced lighting image offers a powerful visualisation and communication tool (figure 8 and figure 9) for decision makers (elected local authorities).

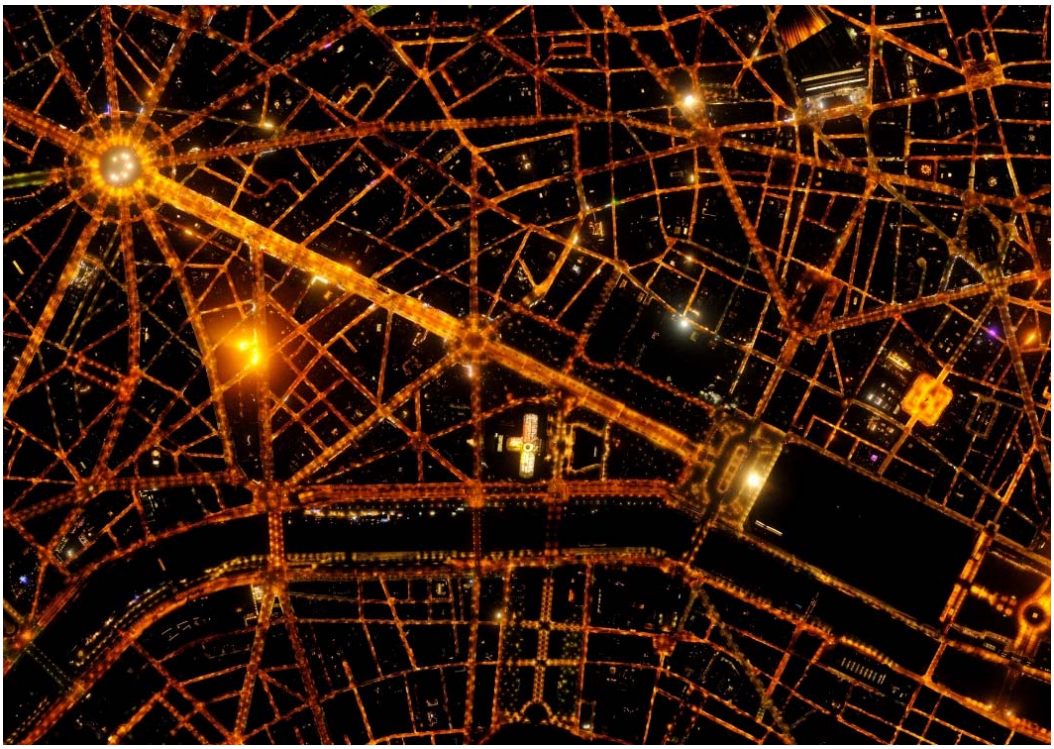

Figure 8 – Extract from a lighting image, district of Champs-Elysées, city of Paris, showing many questionable lighting points (source: Mairie de Paris)

Figure 9 – Extract from a lighting image, port of Saint-Tropez (source: SymielecVar, Syndicat mixte de l'Energie des communes du Var)

As previously explained, night aerial lighting maps are able to deliver precise information regarding public lighting sources.

On the other hand, such products can constitute a relevant mean to deliver direct information about private lighting sources allowing awareness raising for private actors and general public. This dimension is not covered by the existing ground databases.

According to the 2018's ministerial decree, several private spaces (parking areas, construction sites, advertisements lightings…), in addition to public ones, have to respect technical standards and specific authorised lighting time slots (Ministère de la Transition Ecologique et Solidaire, 2018). The control concerning the respect of these prescriptions is notably under the jurisdiction of municipalities. The use of night aerial lighting maps can be a very first step to approach the private actors and deliver awareness. Indeed, this tool delivers a powerful message showing immediately and visually the strong impact of several lighting points: decorative lightings, commercial and advertisements, parking lightings. It enables lighting spots detection the private spaces, representing a significant part of the global lighting (figure 10).

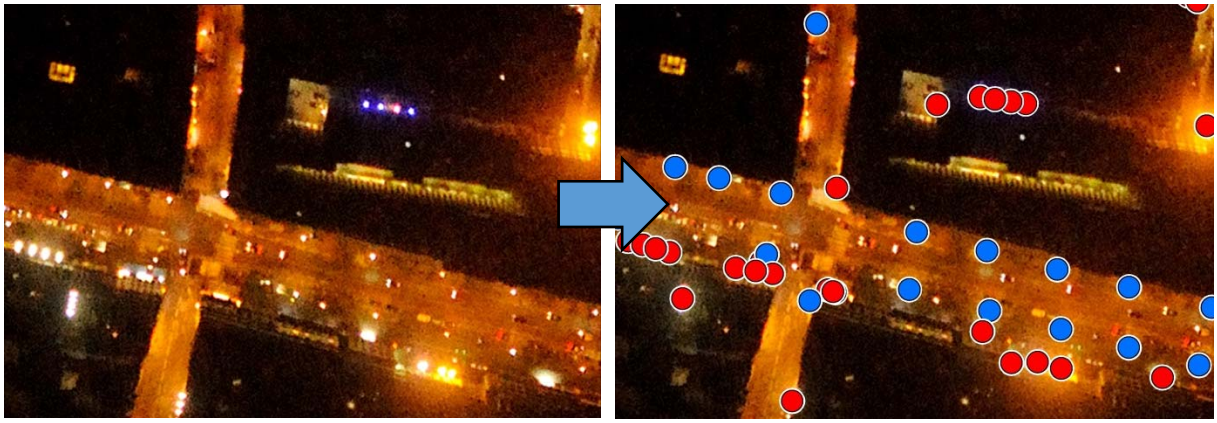

Figure 10 – Hot spots detection on a lighting image, in blue for the public spaces and in red for private ones (source: Mairie de Paris)

As a consequence, the lighting maps also enable to open a dialogue between the public organisation and the private actors and to have a discussion regarding the purpose of lighting (indoor and outdoor), the most relevant technology to use and the lighting time slot in compliance with the objective and the prescriptions of the 2018's ministerial decree.

This study is still in progress with two other major objectives: the light sources characterisation from the aerial images processing and the impact studies of the urban lighting on the biodiversity, a major challenge for the future.

4 Conclusions

Once perfectly integrated in a GIS technology and used in combination with the in-house knowledge of the territories about their own lighting situation, hi-resolution night aerial lighting map is a powerful tool for analysing the global situation and to allow prioritising and acting.

Giving access to all lighting sources, including the ones coming from the private spaces, these maps allow to involve and to build awareness for all actors of the territory, not only the public authority.

Major issues such as the impact on the biodiversity may be studied thanks to this type of data, for example with the precise identification of dark areas that relate to wildlife corridors.

Acknowledgement

The authors wish to thank P. Duguet (Head of public lighting, Mairie de Paris), P. Icke (Director, SymielecVar, Syndicat mixte de l'Energie des communes du Var) and the cities of

Paris and Saint-Tropez for having allowed use of relevant illustrations related to each of these territories.

References

CENTRE DE RESSOURCES TRAME VERTE ET BLEUE 2019. *Definition of green and blue infrastructure*. France: Centre de ressources Trame verte et bleue. <http://www.trameverteetbleue.fr/definitions-trame-verte-bleue?language%3Den=en>

CHALLEAT S. and LAPOSTOLLE D. 2017. Prendre en compte les usages pour mieux éclairer la nuit. *Métropolitiques*, 14th December 2017. <https://www.metropolitiques.eu/Prendre-en-compte-les-usages-pour-mieux-eclairer-la-nuit.html>

CIE 2014. *International Lighting Vocabulary eilv*. Vienna: CIE. Online version available at < http://eilv.cie.co.at/>

GLOBE AT NIGHT 2019. *What is Light Pollution?* Tucson: NOAO National Optical Astronomy Observatory. <https://www.globeatnight.org/light-pollution.php>

IDA INTERNATIONAL DARK-SKY ASSOCIATION 2019. *Light Pollution*. Tucson: IDA. <https://www.darksky.org/light-pollution/>

LRC LIGHTING RESEARCH CENTER 2007. *Lighting Answers, Light Pollution*. New York: LRC. <https://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightpollution/abstract.asp>

MINISTERE DE L'ECOLOGIE, DU DEVELOPPEMENT DURABLE, DES TRANSPORTS ET DU LOGEMENT 2011. Décret n°2011-831 du 12 juillet 2011 relatif à la prévention et à la limitation des nuisances lumineuses. *Journal Officiel de la République Française*, 0161, 13th July 2011, text 5.

MINISTERE DE LA TRANSITION ECOLOGIQUE ET SOLIDAIRE 2018. Arrêté du 27 décembre 2018 relatif à la prévention, à la réduction et à la limitation des nuisances lumineuses. *Journal Officiel de la République Française*, 0300, 28th December 2018, text 18.