The Contribution of Street Lighting to Light Pollution

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1 Introduction

Urban centres create a bubble of light overhead, known as *sky glow*. Sky glow is a form of wasted energy and light pollution that reduces our view of the night sky, contributes to the destruction of wildlife habitat, and impacts human health.

There are many sources that contribute to sky glow: light from residential and business windows, illuminated signs, uplight on buildings and billboard advertizing, and street illumination.

An aerial view of a city at night suggests that street lighting is a major contributor to sky glow. In this note we quantify the percentage contribution of street lighting to sky glow, over the city of Reykjavik (Iceland).

2 Photographs of Reykjavik

One method of measuring the contribution of street lighting is to switch it OFF and then ON, and measure the difference. Unfortunately, that's generally not possible. In Toronto for example, street lights are activated by light sensitive switches, one for each lamp or small group of lamps. There is no *master switch* for street lighting. A power outage, while welcome by astronomers, is not useful for this measurement because it affects all light sources.

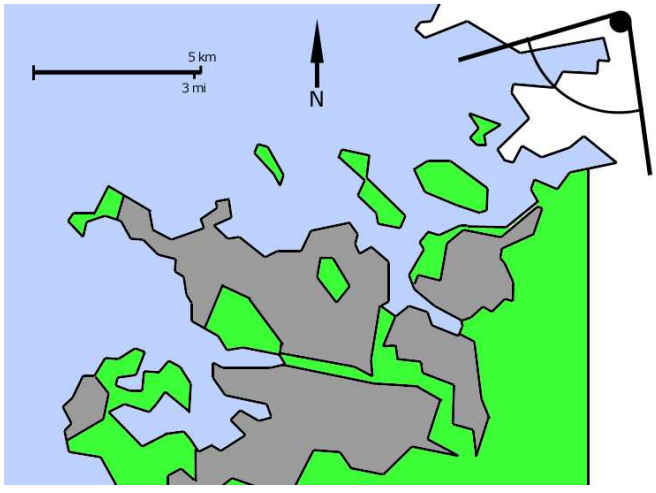


Figure 1: Map of Reykjavik. The filled circle and lines indicate the location of the photographers and the camera viewing angle.

To prepare for the opening ceremony of the Reykjavik International Film Festival, 10-10:30 PM 28 September 2006, all inhabitants of Reykjavik and the surrounding area, together with private companies and institutions in the public sector, were asked to shut off their lights. The idea was to create total darkness in the city.

The street lights were turned off. However, most private companies together with the public sector (schools, sports grounds etc.) did not shut off their lights. The change in sky glow from 10:20 to 10:40 was therefore almost entirely due to street lighting.

Members of the *Amateur Astronomical Society of Seltjarnarnes* Grétar Örn Ómarsson and Þórir Már Jónsson photographed the city and the sky from the location shown in figure 1. Around 170 thousand people live in the gray area where the street lights were switched off. The photographers were around 300 meters above sea level on the slope of the mountain Esjan. The weather on that evening is documented as

> *Temperature 12°C, no precipitation, around 75% cloud cover, height of lowest clouds around 100-200 meters.*

The photographs [1] are shown in figure 3 on page 3.

Each photograph is a panorama, with the city the bright area at the right (top) of the photograph. It is evident that the city and cloud cover above the city are brighter when the street lights are on. Clouds are usually not welcome in astronomical observation but in this case they serve fortuitously as a projection screen for the city lighting. The photographic information is as follows:

Camera Type	Canon D10
Lens	Canon 36mm F/L, f1.4
Image 1 Exposure	5 seconds
Image 2 Exposure	15 seconds
Film Speed	800 ASA
Focal Length used	f2.8

3 Average Brightness

Measurements were made of the brightness of the cloud cover, using the image analysis program *ImageJ* [2].

ImageJ allows one to select an area of the image and determine the average gray level within that area[1]. The level is reported in 8 bit pixel brightness units, between 0 and 255.

The area selected was entirely on the clouds, centred over the city, roughly in line with the island in the foreground. Results for the average intensity of the cloud area and the average intensity of the complete image are shown in the table.

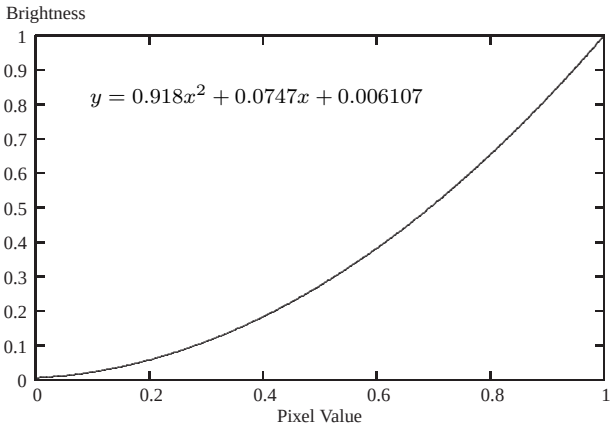
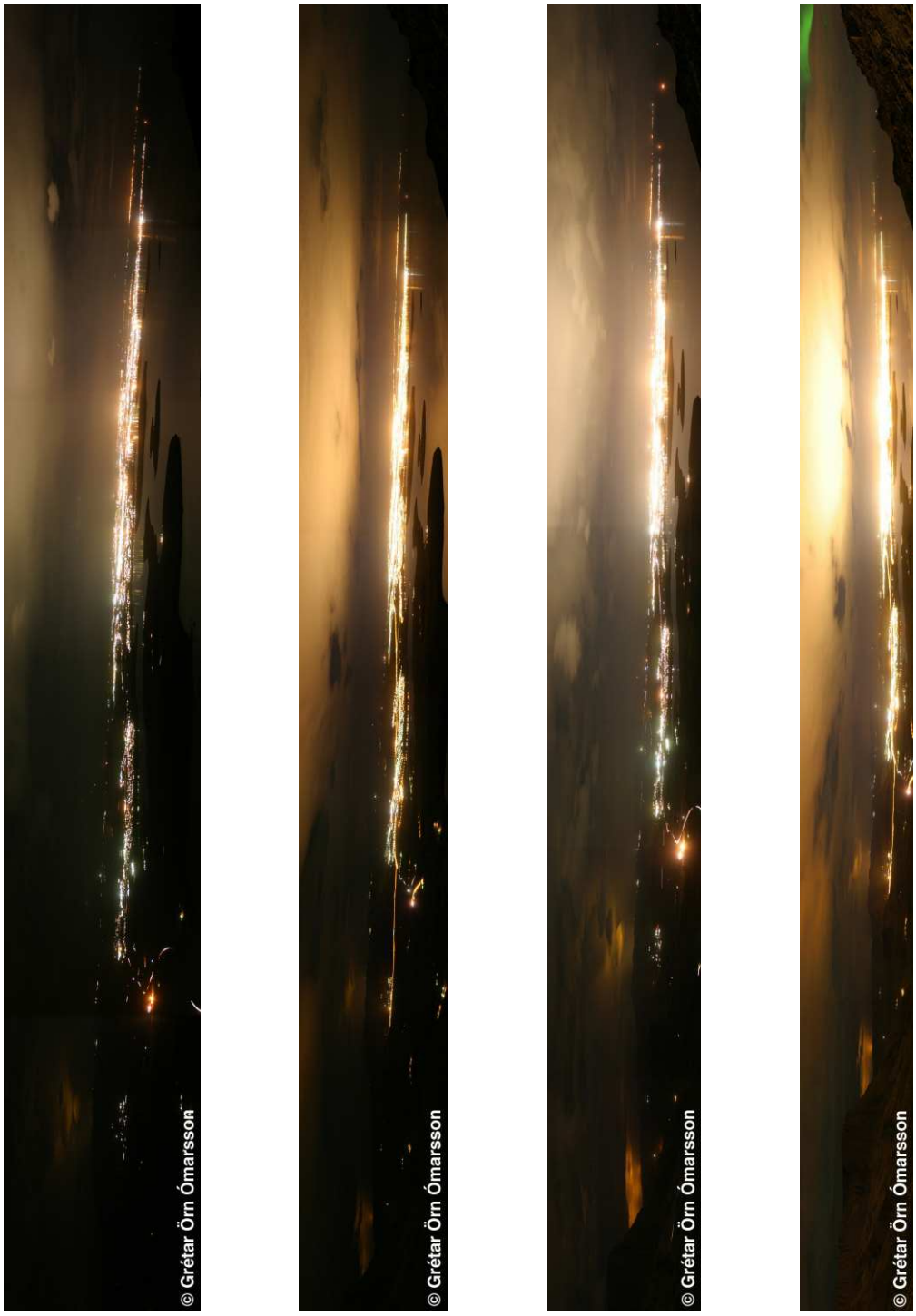


Figure 2: Canon D10 Pixel Value vs Brightness

Image	**Cloud Grey Level Pixel Units,** N	**Ratio**	**Image Grey Level Pixel Units**	**Ratio**
Image 1, Off	99.3		35.1	
Image 1, On	160.9	1.62	53.6	1.52
Image 2, Off	161.4		69.8	
Image 2, On	227.6	1.4	91.3	1.3

[1]These are colour images, so the RGB values must be converted to an equivalent gray level. ImageJ allows for a straightforward average or weighted average (based on human vision). Both settings yielded similar results, probably because the image is gray to begin with.



(a) Image 1, Lights Off

(b) Image 1, Lights On

(c) Image 2, Lights Off

(d) Image 2, Lights On

Figure 3: Composite images of Reykjavik with night sky. (a), (b), 5 seconds exposure at 800 ASA. (c), (d), 15 seconds exposure at 800 ASA.

Measured in pixel units, the clouds are substantially brighter when street lights are on. However, is this what a human observer would perceive? To answer that, we need to convert pixel units into luminance values. The relationship between pixel value and brightness (luminance) is non-linear and varies between cameras. The Canon D10 characteristic [3] is shown in figure 2 on page 2.

Each pixel reading is converted into its corresponding X value using:

$$X = N/255$$

Then the corresponding Y value is found from the Canon D10 characteristic:

$$Y = 0.918X^2 + 0.0747X + 0.006107$$

This relationship is applied to the Area Grey Level data of the previous chart to obtain the corresponding Luminance (Y) values.

Finally, we need to correct for the response of the human eye to changes in brightness. According to Ngai [4] *the sensation of brightness increases monotonically with the cube root of luminance*. Consequently, the luminance ratio is converted into *Perceived Luminance Ratio* by taking the cube root. These entries are shown in the last column of the following table.

Image	**Area Grey Level Pixel Units,** N	**Relative Pixel Level** $X = N/255$	**Luminance** Y	**Luminance Ratio**	**Perceived Luminance Ratio**
Image 1, Off	99.3	0.388	0.173		
Image 1, On	160.9	0.627	0.413	2.39	1.33
Image 2, Off	161.4	0.630	0.4175		
Image 2, On	227.6	0.890	0.7997	1.92	1.24

From the last column in the table, the perceived increase in intensity is 33% for Image 1, 24% for Image 2, for an average of 28.5%. Consequently, the rule of thumb that *street lighting increases sky glow light pollution by 30%* is correct in this case.

4 Image Histograms

An *image histogram* shows the relative distribution of pixel intensities. Pixel value runs from 0 to 255 (dark to light) on the horizontal axis. The vertical axis is a count of the number of pixels at that pixel intensity. Figure 4 shows the histograms for Image 2, streetlights on and off.

In figure 4(a) (lights off), the large peak at the left indicates most of the pixels are dark. In figure 4(b) (lights on), there are fewer dark pixels and a large spike of bright pixels at right boundary of the histogram.

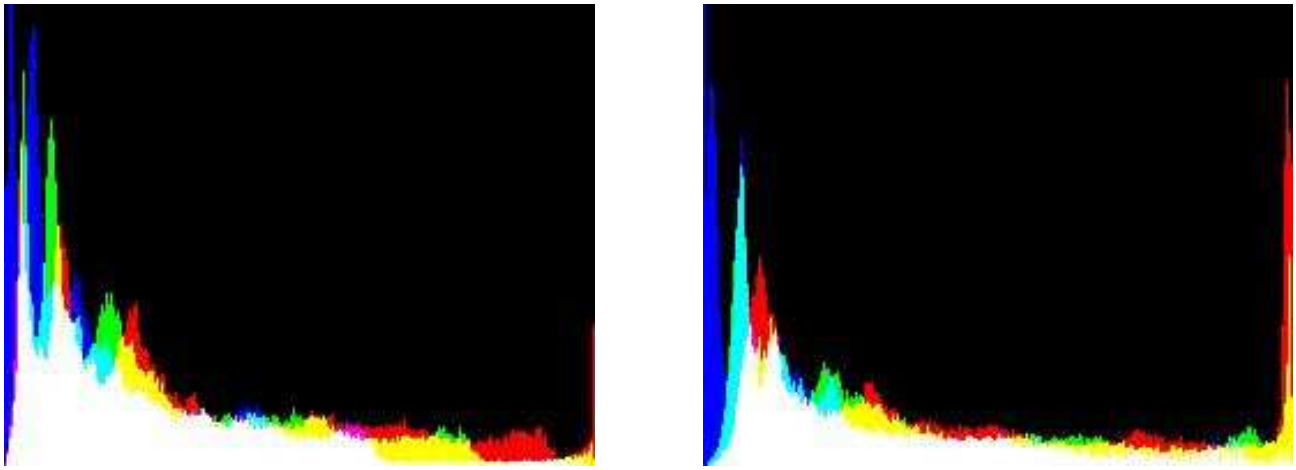
5 Brightness Ratio, Linear Sample

Section 3 showed the difference between average brightness, lights on and off, for an area of the cloud cover above the city. Figure 5 shows a plot of brightness ratio along a vertical line through the same clouds.

The horizontal axis of figure 5 is the position in pixels along this vertical line. The vertical axis is a measure of the perceived brightness ratio between lights on and lights off, calculated using the same method as section 3.

This shows up *hot spots* in the illumination where there is a substantial change in brightness with street lighting.

For image pair #1, the brightness ratio approaches 1.6, that is, 60% brighter with street lights on. For image pair #2, the peak brightness ratio is a little less at about 1.45, or 45% brighter with street lights on.



(a) Image 2, Lights Off

(b) Image 2, Lights On

Figure 4: Histograms

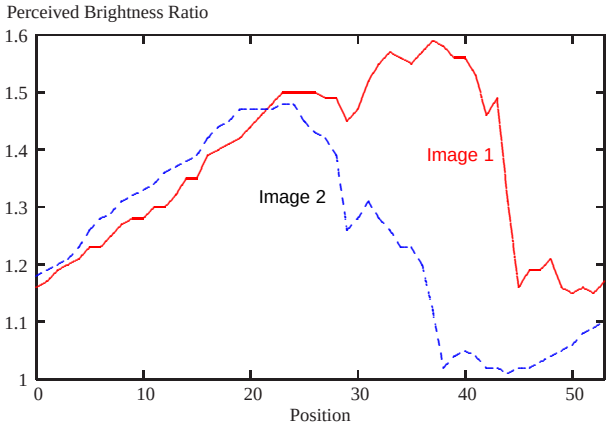


Figure 5: Luminance Ratio Along Cloud Sample Line

6 Conclusion

All three measures of brightness ratio – average over an area, histogram, and linear plot – show a substantial, detectable increase in brightness when street lights are on. This indicates that street lighting is a significant contributor to sky glow light pollution.

Acknowledgements

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Street Lighting in Reykjavik in 2006

Type	Wattage (MW)
Sodium	2.44
Sodium-Potassium	1.75
Metal-Halide	0.09
Other	0.15

References

[1] Icelandic Web of Astronomy and Stargazing
`http://www.stjornuskodun.is/light-pollution`

[2] ImageJ
`http://rsbweb.nih.gov/ij/`

[3] WebHDR, Camera Calibration for Canon 10D
`https://luminance.londonmet.ac.uk/webhdr/cameras/Canon__Canon_EOS_10D.html`

[4] *The Relationship Between Luminance Uniformity and Brightness Perception*
Peter Y. Ngai
Journal of the Illuminating Engineering Society, Winter 2000, page 41 fol.