Gas Flare Brightness - Land or Offshore

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Introduction

Do gas flares appear brighter on land or offshore to the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS)? Since the OLS has been utilized to effectively measure the rate of gas flaring, it is possible that the environmental conditions surrounding the flare could bias these estimates [Elvidge et al, 2009].

In most cases land surfaces are more reflective than water over the range of OLS wavelengths (~450-850 nm) [e.g. Gillespie et al. 1998, Wendisch et al. 2004]. Therefore, it is reasonable to assume that flares would appear brighter over land than water. This research attempts to quantify this effect. Our conclusion is that a small bias does exist (~3%), but this bias is within the limits of our detection errors. Therefore, no correction for this effect is recommended.

Investigation

We looked at four flares with observations of annual avg_lights_x_pct. This product is created by multiplying two OLS products. The first product (avg_lights) is the average visible brightness of each pixel when it is detected as a light (e.g. above the local background noise threshold). The second product (pct) is the percent of observations which this pixel was observed to be a light. The product serves as a measure of the flare's burn rate [Elvidge et al, 2009]. The unit of this product is Digital Numbers (DN) and is roughly proportional to radiance at the satellite (W cm^{-2} Sr^{-1}).

The data are summarized in Table 1. These flares were selected because they were sufficiently bright, isolated, and situated on the coast or just slightly offshore. The Yemen LNG flare is shown in Figure 1.

Table 1. Flare inventory.

FLARE	LOCATION	TIME SPAN	NUMBER OF DATA POINTS	NUMBER OF DATA POINTS BETWEEN 9 AND 60 DN
Nigeria_8	4.533N 8.02E	1992-2009	272	209
Russia_16	53.28N 143.24E	2000-2009	123	121
Yemen_LNG	14N 48.18E	2007-2009	21	21
Russia_other	50.3N 143.799E	1994-2009	193	193

Figure 1. The Yemen LNG flare from Google Earth.

The investigation was performed with our Nightime Lights avg_lights_x_pct data product for the years 1992 through 2009 to the present (geographic projection). Each annual product (usually there were two annual products created from different satellites) was subsetted to include a region around the flare. Figure 2 shows a typical flare subset. A land-sea mask was also subset to the same region.

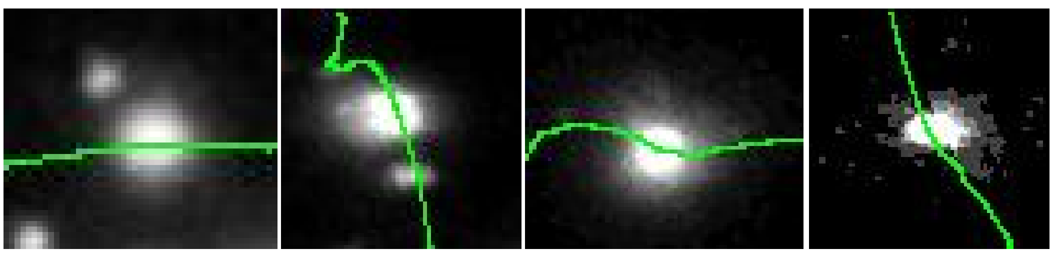

Figure 2. Subsets of the gas flares from F162009. The green line is the coastline. The order of the images from left to right are Nigeria_8, Russia_16, Yemen_LNG, and Russia_other. Each subset is approximately 0.5°x0.5°.

The method for each of these images is to find the peak brightness, and then work in concentric circles outward from the peak. For each concentric circle, two average values are computed. One average is of the land pixels and another is calculated for offshore pixels. The technique is illustrated in Figure 3.

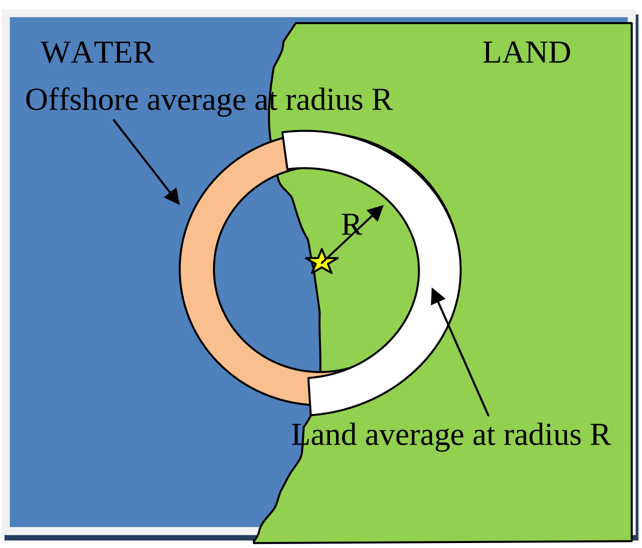

Figure 3. Analysis based on distance from the flare. The average of land pixels and offshore pixels are compiled as a function of radius.

For each flare image a series of land and offshore averages are created. A typical result is plotted in Figure 4.

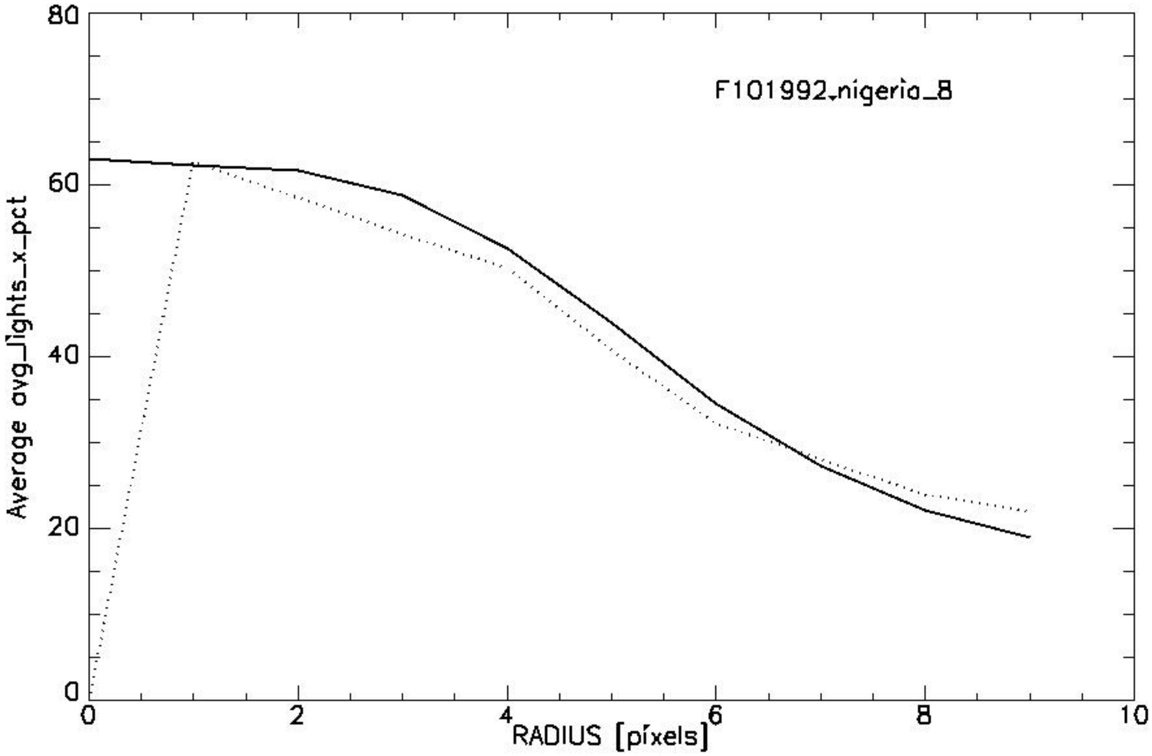

Figure 4. A plot of the average avg_lights_x_pct profile as a function of distance from the flare. The solid line is the land profile and the dashed line is offshore. The units of avg_lights_x_pct are in Digital Numbers (DN). The 0 brightness at the origin for the offshore line indicates that there was no offshore data at a radius of 0 pixels (i.e. the flare is on land).

Results

The profiles for each of the four flares at each radius were combined to determine if there was a systematic difference in brightness between land and offshore pixels. Points with DN values 60 and larger were excluded since these were probably were contaminated with saturated data. Likewise, points with averages less than nine were filtered out because extraneous light could be significant at that level. The results are shown in Figure 5.

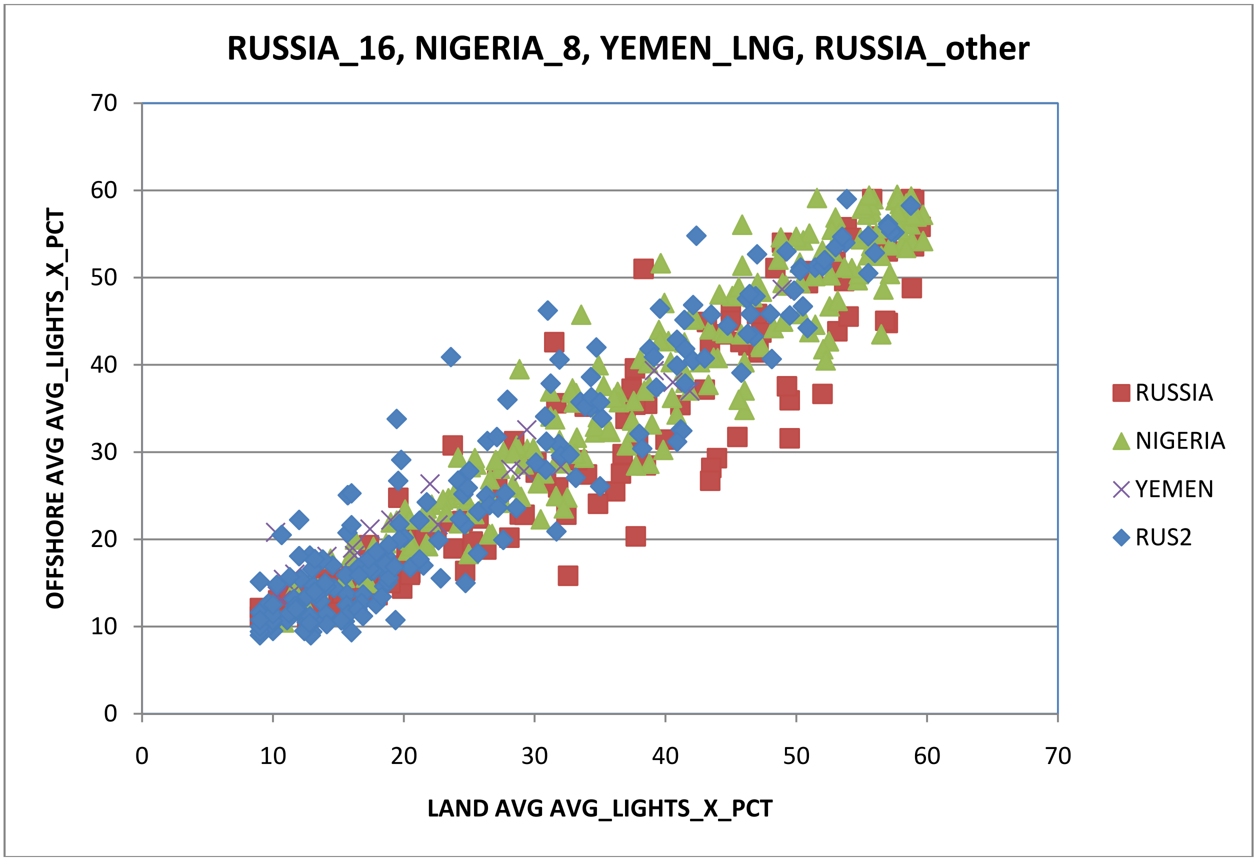

Figure 5. Offshore compared to land average brightness for four coastal flares.

When a regression between these points is performed, it should be done in a symmetric fashion because both Land and Offshore results have comparable uncertainty. Therefore neither of them should be considered dependent on the other (implying there is less uncertainty in the independent parameter).

To accomplish this, we perform the regression twice with the intercept set to 0. When a regression line is calculated through these points the results are:

S = 0.963 L [R^2 = 0.90], (R1)
L = 1.020 S [R^2 = 0.90], (R2)

where L is the brightness on land and S is the offshore brightness. The average of these two results suggests that the land pixels are about 3% brighter than the offshore pixels.

Furthermore, we constructed what the Sum Of Lights (SOL) would be if these coastal flares were entirely on land and offshore. The SOL is an integration over all annuli. The results are presented in Figure 6.

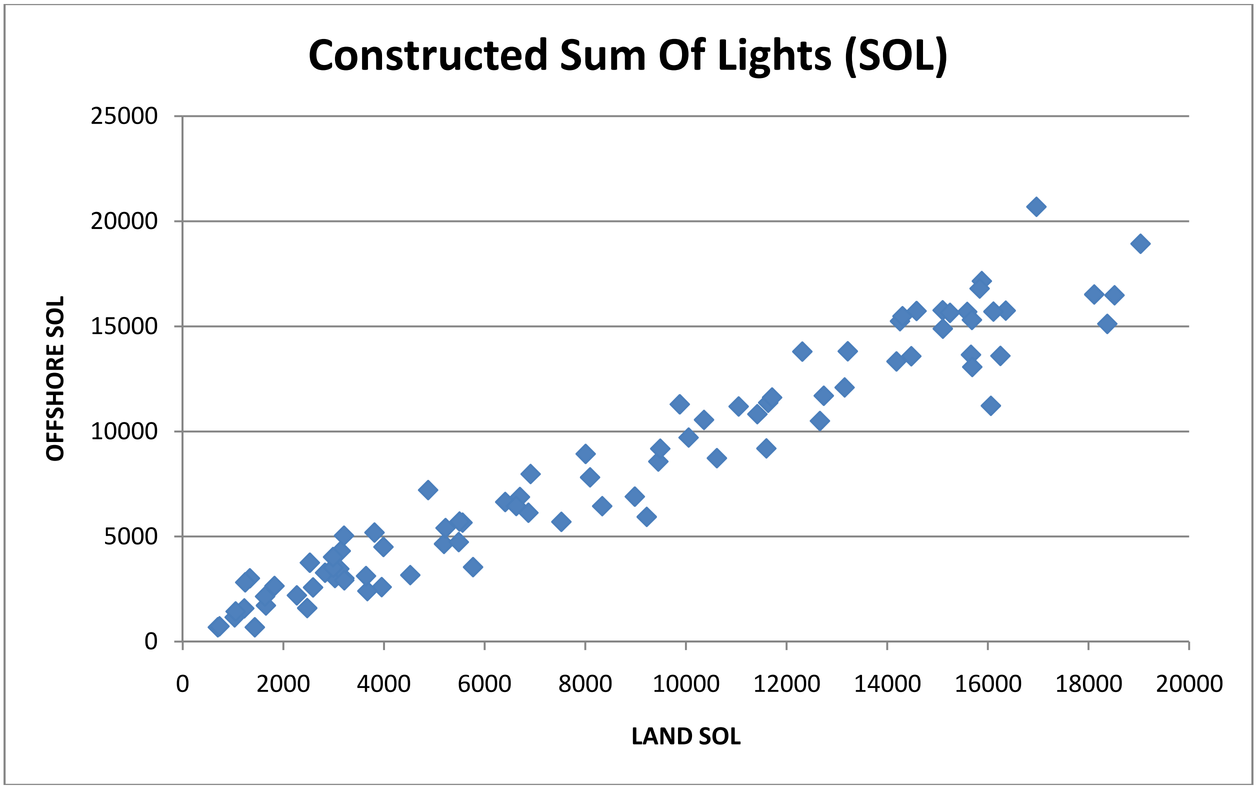

Figure 6. Constructed Sum Of Lights (SOL) if each of these flares existed entirely on or off shore.

The results of these regressions are:

S = 0.961 L [R^2 = 0.94], (R3)

L = 1.023 S [R^2 = 0.94], (R4)

The average of these slopes is consistent with the conclusion that land flares are approximately 3% brighter than offshore flares.

Are these differences significant using a one-sided T Test? The statistics are shown in Table 2.

Table 2. Description of the data

	Samples	Land Avg	Offshore Avg	Avg (L–S)	Std Dev (L-S)	Significance
Annuli	544	32.77	31.78	0.99	4.82	> 99%
SOL	88	8563.67	8326.64	237.04	1359.47	> 90%

Conclusion

Analysis shows that land flares appear 3% brighter than offshore flares to the OLS instrument.

There are several approaches available to correct for this bias, such as processing land and offshore flares separately or modifying the data used to construct the calibration between SOL and reported gas flaring volume. However, our calibration data set includes both individual flares and aggregates of many flares (i.e. national level reported flaring). National level reported values typically contain a mixture of land and offshore flaring, making the application of these results difficult. Furthermore, uncertainty in our determination of the calibration coefficient (to convert SOL to gas flaring volume) is estimated to be around 3 Billion Cubic Meters (BCM) which translates to a nationally aggregated uncertainty in SOL of 11000. This uncertainty far exceeds the land/offshore bias we detected.

Considering the difficulty in correcting the bias, the small magnitude of the bias compared to acknowledged uncertainty, and the risk of introducing unintended errors if this bias was addressed, we recommend that no correction be applied to the data in future gas flaring estimates based on SOL analysis.

References

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