Can we observe the atmosphere by street lamps? Examining the potential for use of anthropogenic light emissions in atmospheric retrievals.

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1. Introduction

- Characterizing aerosol at night from satellite-based passive radiometers is extremely difficult due to a insensitivity of fine-mode aerosol distributions to traditionally available longwave infrared (LWIR) wavelengths.
- The Day/Night Band (DNB) on the Suomi National Polar-orbiting Partnership (S-NPP) satellite can observe low levels of light in the 500nm – 900nm range, offering sensitivity to most aerosol species and many anthropogenic light sources (e.g. Wang et al., 2016).
- It may be possible to exploit the attenuation and diffusion of anthropogenic light sources in the context of atmospheric aerosol detection and retrievals (e.g. McHardy et al., 2015).
- For this application, light sources must be well characterized and predictable.
- Here we present preliminary results characterizing anthropogenic light sources.

2. Data

We gathered one year (2015) of VIIRS data over multiple different cities. The data include DNB radiances, brightness temperatures at 3.7um and 11um, and the operational VIIRS cloud mask (VCM) product.

Steps:

1. Mask all pixels reported in the VCM as anything other than "confident clear."
2. Interpolate to a common grid for each city using nearest neighbor interpolation at 0.75km resolution.
3. Stack data in the time dimension to produce a three dimensional dataset where each latitude and longitude corresponds to a time series of observations.

3. Stability over time

To gain a qualitative understanding of light source stability, we examined statistics for each time series (pixel) over Las Vegas. Comparison of the minimum and maximum radiance images (Figs 1a and 1b) shows that some illumination sources are always present, while others are transient.

The average pixel radiances are shown in Fig 1c, and Fig 1d shows the relative standard deviation (RSD)—providing a measure of the stability of each pixel relative to its average value. Smaller values of RSD indicate higher stability. These tend to be associated with the urban-area pixels. Some embedded sources such as the Las Vegas Strip appear to be very unstable, with very high RSD (> 1.0).

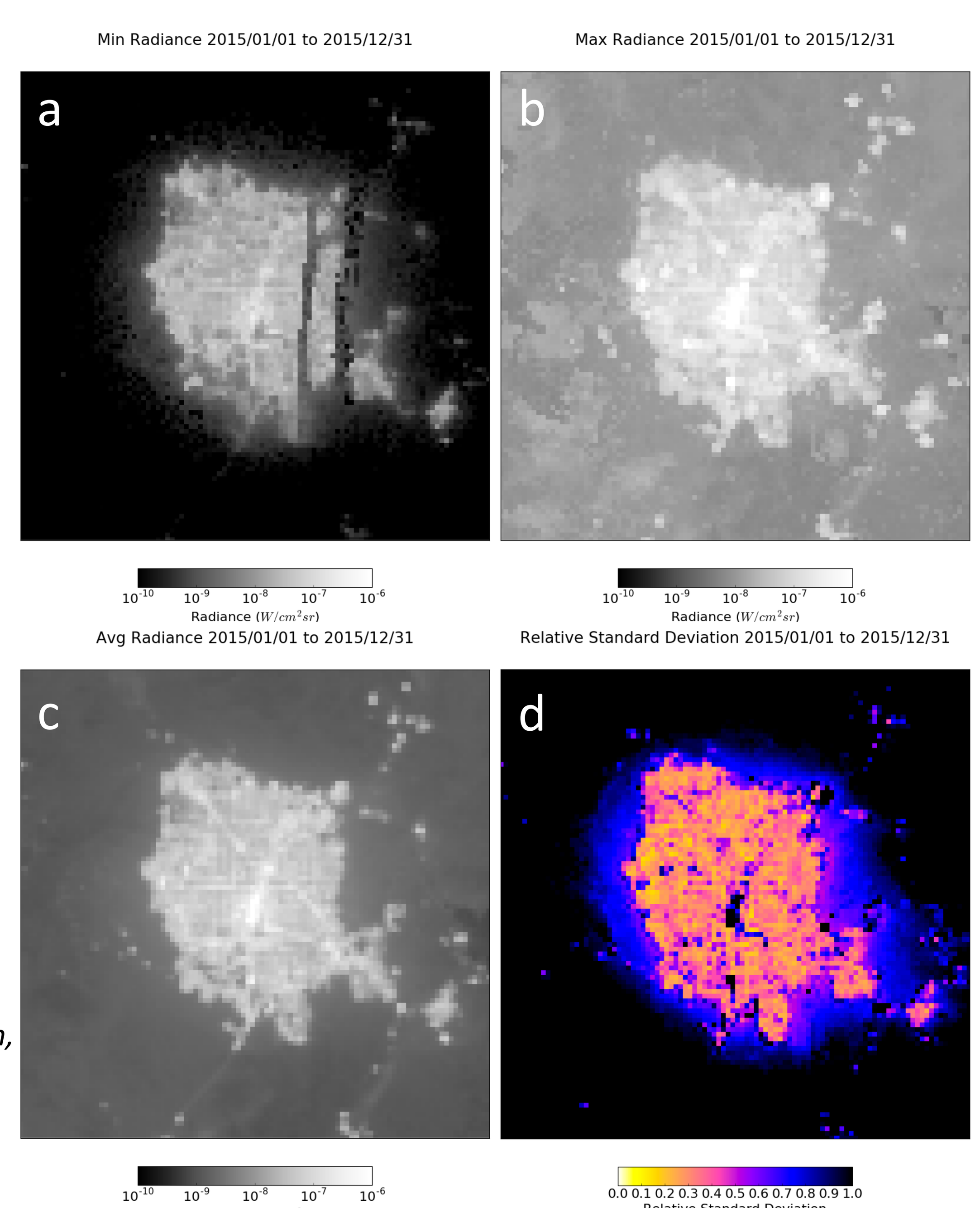

__Fig 1:__ (a) minimum, (b) maximum, (c) average, and (d) relative standard deviation of DNB pixel radiances over the city of Las Vegas, NV.

Citations:

McHardy, T. M., J. Zhang, J. S. Reid, S. D. Miller, E. J. Hyer, and R. E. Kuehn, 2015: An improved method for retrieving nighttime aerosol optical thickness from the VIIRS Day/Night Band. *Atmos. Meas. Tech.*, **8**, 4773–4783, doi:10.5194/amt-8-4773-2015.

Wang, J., C. Aegerter, X. Xu, and J. J. Szykman, 2016: Potential application of VIIRS Day/Night Band for monitoring nighttime surface PM2.5 air quality from space. *Atmospheric Environment*, **124, Part A**, 55–63, doi:10.1016/j.atmosenv.2015.11.013.

4. Radiance Predictors

For anthropogenic light emissions to be used in aerosol retrievals they must be well characterized. Fig. 2 shows linear correlation coefficients (CC) between several variables and observed DNB radiances over Qatar. Some of these relationships are expected. For instance, Fig. 2c indicates that radiance is a function of both the direction of the nearest light source and the satellite azimuth angle. Fig. 2e shows near zero correlation between radiance and lunar zenith angle for the city pixels, and strong negative correlation with moon zenith angle for unlit pixels.

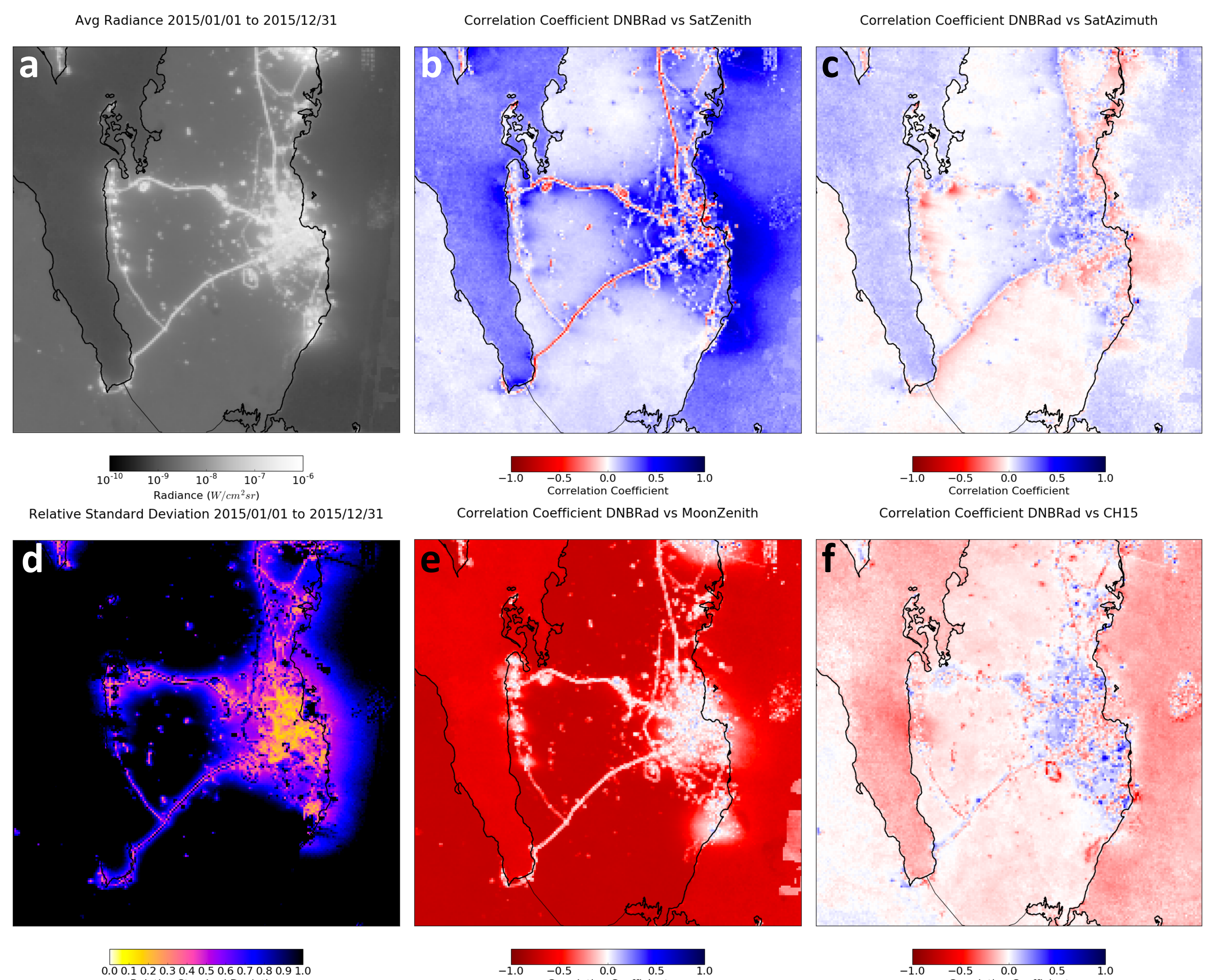

***Fig 2:** (a) the average radiance, (b) CC for DNB radiance and satellite zenith angle, (c) CC for DNB radiance and satellite azimuth angle, (d) relative standard deviation of DNB radiance, (e) CC for DNB radiance and lunar zenith angle, and (f) CC for DNB radiance and 11 μm brightness temperature for each pixel's time series.*

There are unexpected features as well. In Fig. 2b (the CC between DNB radiance and satellite zenith angle) some city pixels are strongly positively correlated, while others are strongly negatively correlated. Upon closer inspection, pixels with positive correlation appear to be suburban while those with negative correlation appear to be urban or lit highways. Results from the small town of St. George, UT (Fig. 3) reinforce this interpretation, showing a trend toward higher radiances at more oblique viewing angles for these suburban-class light emissions. It is possible the differences in light shielding practices accounts for these observed CC reversals.

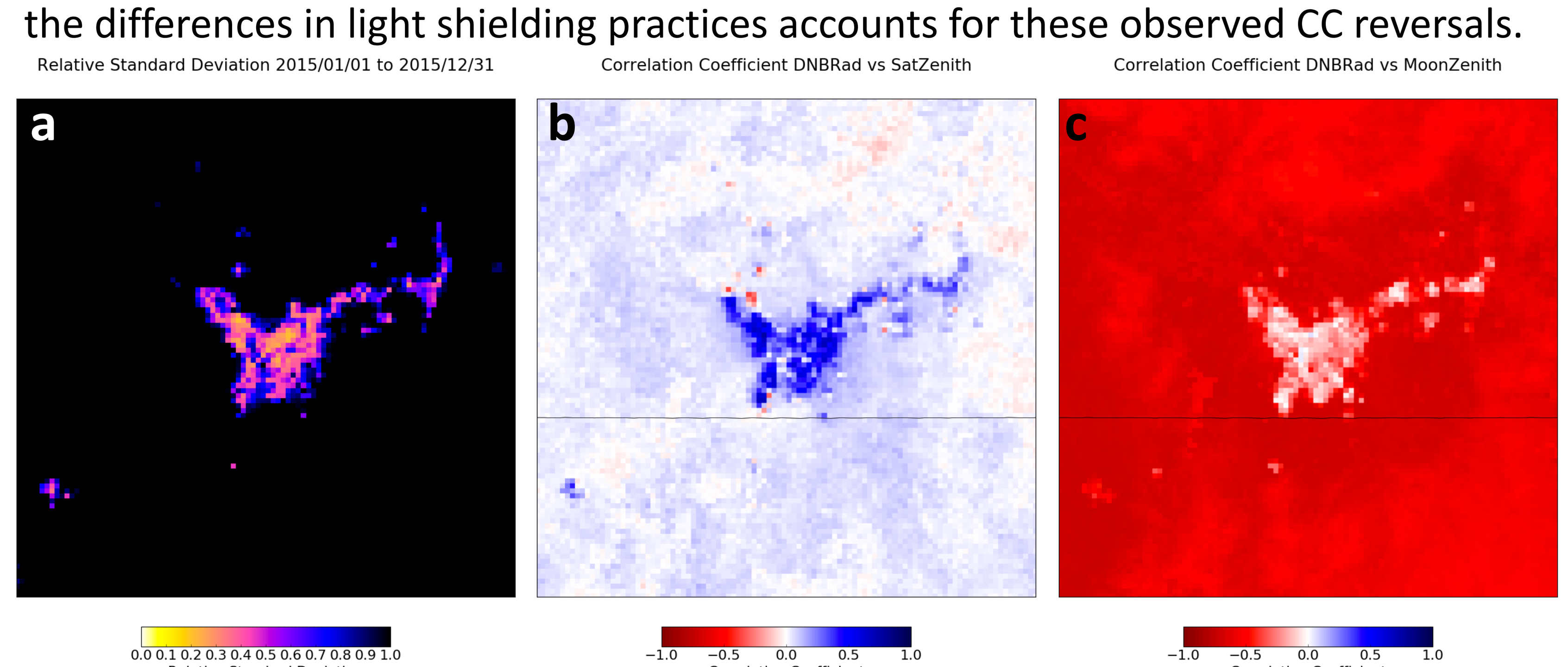

***Fig 3:** Images showing (a) relative standard deviation of DNB radiance, (b) CC for DNB radiance and satellite zenith angle, and (c) CC for DNB radiance and lunar zenith angle.*

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5. Light Source Classification (K-Means Clustering)

As a way of analyzing the complex light distributions, a K-Means clustering algorithm was employed to classify light sources into groups with similar characteristics. The dimensions of the data space used for clustering are linear CCs between the DNB radiances and each of the following: satellite zenith angle, satellite azimuth angle, lunar zenith angle, lunar azimuth angle, and brightness temperatures from VIIRS bands 13 (4.05 μm), 15 (10.763 μm) and 16 (12.013 μm). Each pixel is represented by a vector in the CC dataspace. Likewise, each cluster centroid is represented by the average vector of all pixels in the cluster. Pixels are assigned to clusters by calculating the euclidian distance between the pixel and the cluster centroid. The CCs that represent each cluster can be used as a model to predict the radiance that would be observed by the DNB under clear-sky conditions so that deviations from expected values can be compared to observed values.

Fig. 4 shows the results of the K-Means clustering. It is immediately apparent that some structure is observed in the CC data space that is representative of the type of illumination. In Fig. 4a, which shows the result of using six clusters, is significantly easier to interpret than the 12 cluster case shown in Fig. 4b. Close examination reveals that urban and suburban areas are classified into different clusters. Additionally, lit and unlit highways separate into different clusters.

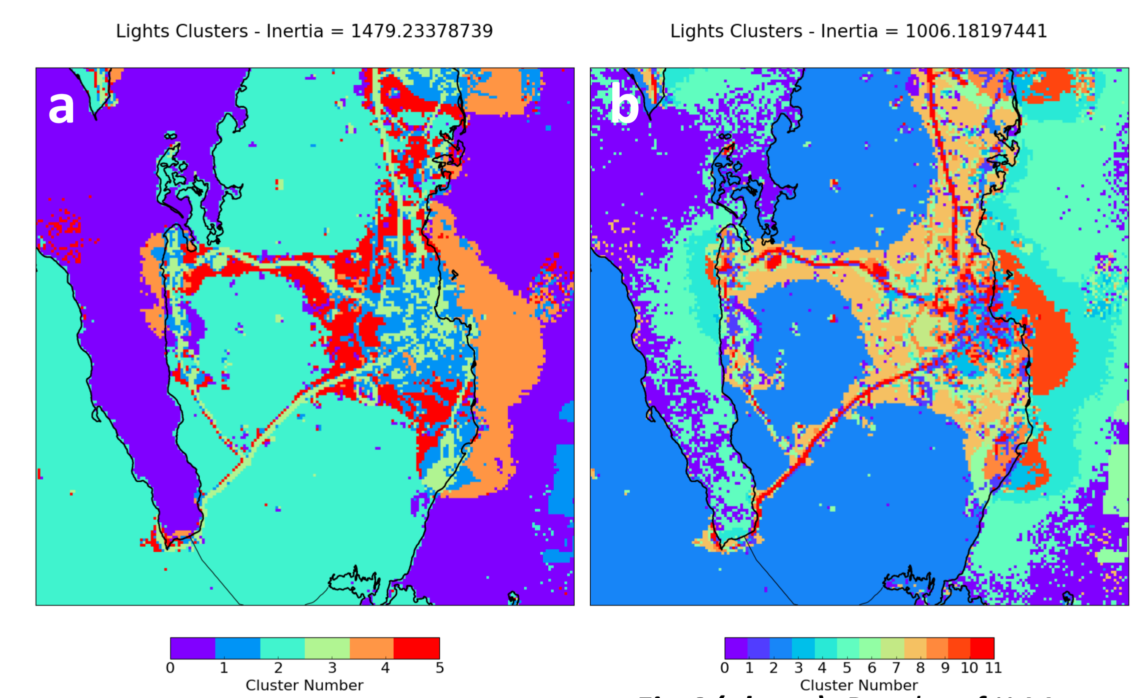


***Fig 4 (above):** Results of K-Means clustering using (a) 6 clusters and (b) 12 clusters in CC space.*

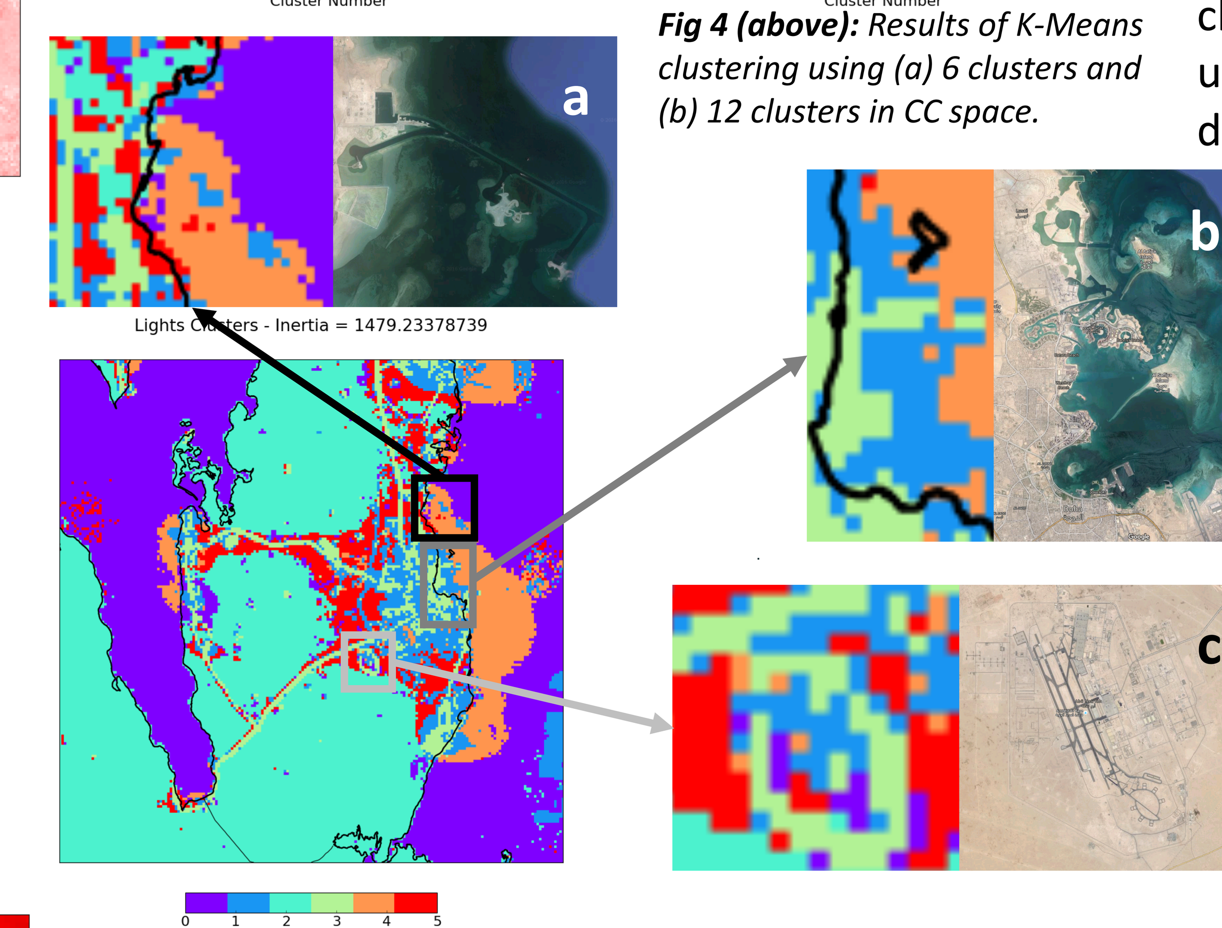
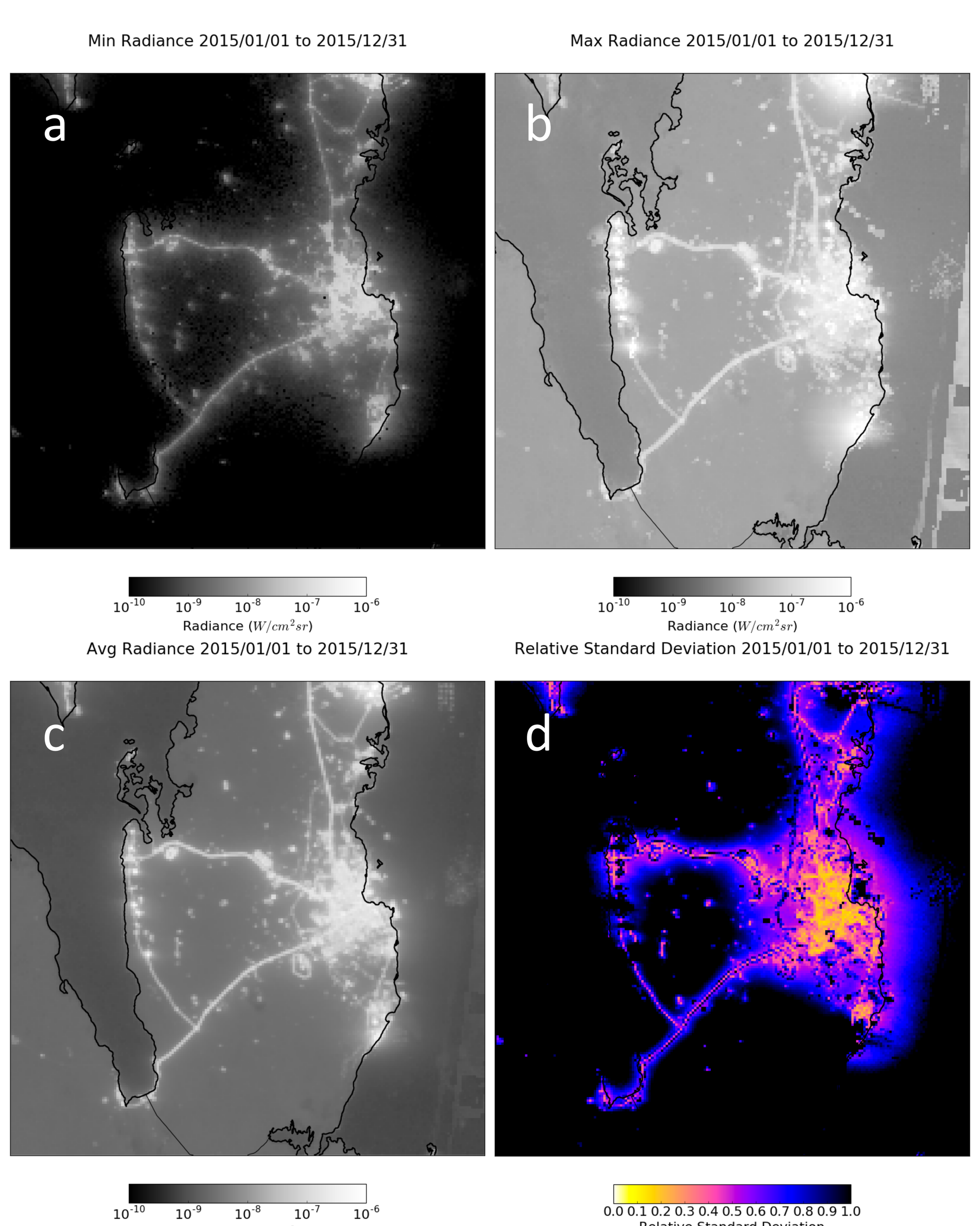
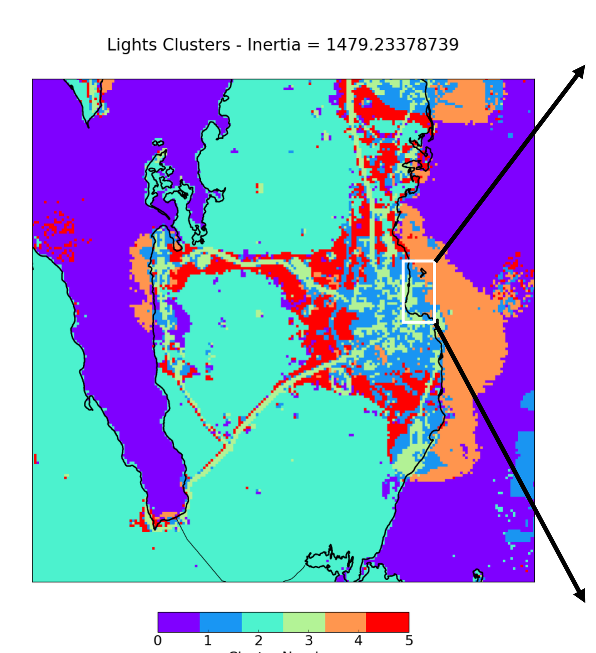


***Fig 5 (left):** Comparison of features in the cluster image using 6 clusters with real features as seen in Google Maps. Features include (a) man made islands and shipping lanes, (b) man made islands near Doha, (c) a military air base.*

6. Conclusions

- Anthropogenic light emissions can be relatively stable, especially in urban centers, but can also be unstable in less populous areas.
- Emissions are anisotropic and different light sources have different directional emission functions (e.g. urban and suburban areas are different).
- Clustering based on correlations with different variables may lead to a predictive model for the cloud-cleared radiance that would be observed by the DNB.
- In the future we hope to further refine our methodology using by introducing non-linear relationships between variables and assessing different clustering methods.
- The results of this research are anticipated to be useful for informing our assumptions for aerosol retrievals, monitoring changes in human activity, and better understanding the types of light pollution produced by different types of anthropogenic sources.


Min Radiance 2015/01/01 to 2015/12/31
a
Max Radiance 2015/01/01 to 2015/12/31
b
Radiance (W/cm^2sr)
Radiance (W/cm^2sr)
Avg Radiance 2015/01/01 to 2015/12/31
c
Relative Standard Deviation 2015/01/01 to 2015/12/31
d
Radiance (W/cm^2sr)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Relative Standard Deviation


Lights Clusters - Inertia = 1479.23378739
0 1 2 3 4 5
Cluster Number