2007 Urban Remote Sensing Joint Event

Change Detection in Satellite Observed Nighttime Lights: 1992-2003

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Abstract— **NOAA's National Geophysical Data Center has developed a time series of annual global nighttime lights products at approximately 1 km resolution extending from 1992 to 2003. These products are cloud-free composites which have been processed to remove ephemeral lights from events like fires and background noise. Because the OLS has no on-board calibration an empirical approach was used to inter-calibrate the composites. In the inter-calibrated set it is possible to observe both expansions and contractions of lights. Many cities show rims of growth in lighting at their margins. The expansion of dim lighting detection into rural areas and smaller settlements occurred in many parts of the world. Contraction of lighting occurred in sections of the Former Soviet Union. More subtle declines in the brightness of lighting are detected in skyglow surrounding large cities, perhaps as the result of changes in lighting type and improvements in light fixtures.**

I. INTRODUCTION

In the 127 years since the commercialization of the light bulb, the extent of nocturnal lighting has continued to expand, becoming one of the hallmarks of modern civilization. The nocturnal lighting that escapes into space offers a unique observable that can be detected with satellite sensors. The global mapping of nighttime lights has emerged as one of the simplest, most cost effective ways to map the distribution of development / economic activity on an annual basis. In this paper we describe changes in lighting found in a time series of annual global nighttime lights produced from low light imaging data acquired by the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) spanning 1992 through 2003.

II. METHODS

The DMSP OLS was designed to collect global cloud imagery using a pair of broad spectral bands placed in the visible and thermal. The DMSP satellites are flown in polar orbits and each collects fourteen orbits per day. While the sensor collects data with a 0.5 km ground sample distance, the recorded global data are "smoothed" on-board by averaging 5 by 5 blocks of pixels. With a 3000 km swath width, the each OLS is capable of collecting a complete set of images of the earth twice a day. At night the visible band signal is intensified with a photomultiplier tube (PMT) to enable the detection of moonlit clouds. The boost in gain enables the detection of lights present at the earth's surface. Lights are detected from human settlements (cities and towns), populated exurban areas, fires, gas flares, and heavily lit fishing boats.

NGDC serves as the long term archive for DMSP data and has data holding extending from 1992 to the present. The archive is organized as individual orbits which are labeled to indicate the year, month, data and start time. For this project the individual orbits were processed with automatic algorithms that identify image features (such as lights and clouds) and the quality of the nighttime data [1, 2]. The following criteria were used to identify the best nighttime lights data for compositing:

1. Center half of orbital swath (best geolocation and sharpest features).
2. No sunlight present.
3. No moonlight present.
4. No solar glare contamination.
5. Cloud-free (based on thermal detection of clouds).

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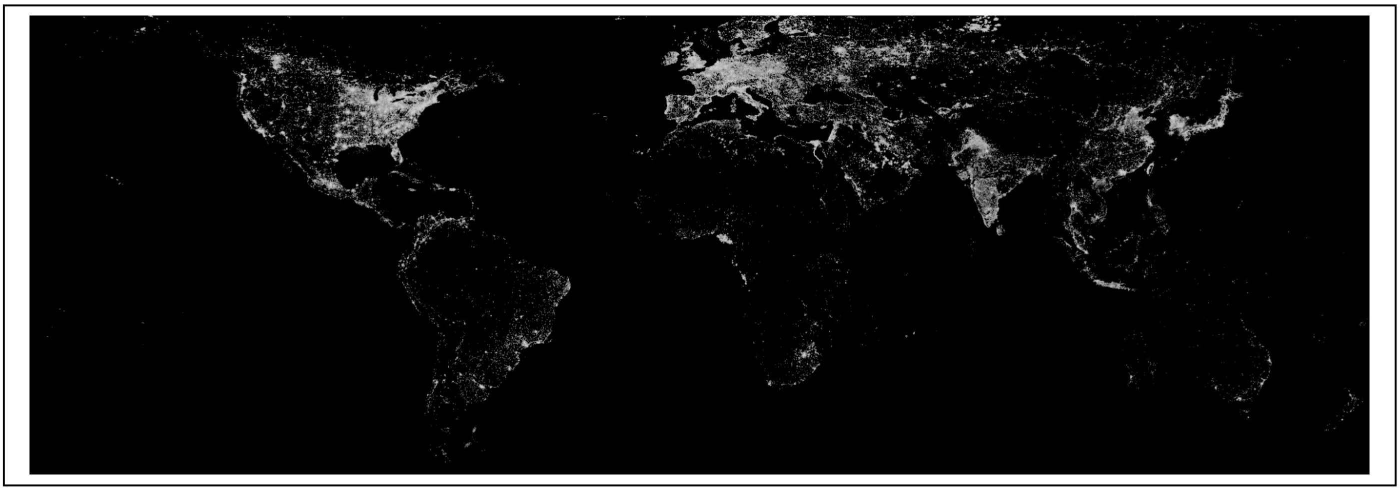

Figure 1. Cloud-free composite of nighttime lights from DMSP satellite F15 year 2003.

Nighttime visible band data from individual orbits that meet the above criteria are added into a global latitude-longitude grid (Platte Carree projection) having 30 arc second resolution. This grid cell size is approximately a square kilometer at the equator. The total number of coverages and number of cloud-free coverages are also tallied. In the typical annual cloud-free composite most areas have twenty to a hundred cloud-free observations, providing a temporal sampling of lighting activity. Further processing is done to remove ephemeral light sources (primarily fires) and background noise separate fires from other types of lighting. The end result is an image recording the average visible band digital number values for persistent sources of lights. See example in Figure 1.

Because there is no on-board calibration for the nighttime visible band on the OLS an empirical procedure was developed to inter-calibrate each of the annual composites. Because the standard OLS data used to make the composites have variable amounts of saturation in the bright core of urban areas the approach was to use the satellite/year with the most saturation as the reference. This turned out to be the 1999 composite from satellite F12. Samples of lighting from human settlements (cities and towns) were extracted from three areas deemed to have relatively stable lighting from year to year. This approach was adopted because there are very few places where the lights have been stable over the fifteen years spanned by the time series. The assumption under this approach is that most areas of lighting changed very little from one year to the next. Linear regressions were developed between composite pairs from the same and adjacent years. The results were examined to select the best chain of regressions to concatenate based on r^2 values. Concatenating the regressions results in a single gain and offset that is applied to each composite to adjust its' values up to the level of the F121999 reference composite.

III. RESULTS

Five primary types of changes in electric lighting have been found in the time series:

A. Expansion of lighting surrounding urban centers

For many parts of the world there has been an expansion of lighting surrounding urban centers. This can be explained by the expansion of development that is ongoing at the outer rims of cities and towns. Unfortunately there is saturation in the cores of most urban centers, making it impossible to detect changes in lighting in those areas. The growth of lighting surrounding urban centers produces can be viewed by overlaying images from different years in a red, green, blue color composite, by differencing the annual composites, or in transects drawn across urban centers. Figure 2 shows a transect for three years of image data for a transect across Atlanta, Georgia in the USA.

B. Areas of new lighting

In a number of areas extensive areas of new lighting can be observed. One of the best examples is in the Northern Province of South Africa, where there was very little lighting detected in the early 1990's. Following the collapse of apartheid in 1994 infrastructure investments brought the electric grid to many new areas. Figure 3 shows a color composite image of the nighttime lights of South Africa with 2003 as red, 1998 as green, and 1992 as blue. The areas of new lighting show up as a bronze color.

Another style of new lighting, associated with the construction of heavily lit roadways, shows up in the United Arab Emirates and several other areas. An example is shown in Figure 4.

C. Temporary lighting

Another type of change in lighting found are the occurances of temporary lighting. Some of these are small spots of lighting that arise and then disappear in the time series,

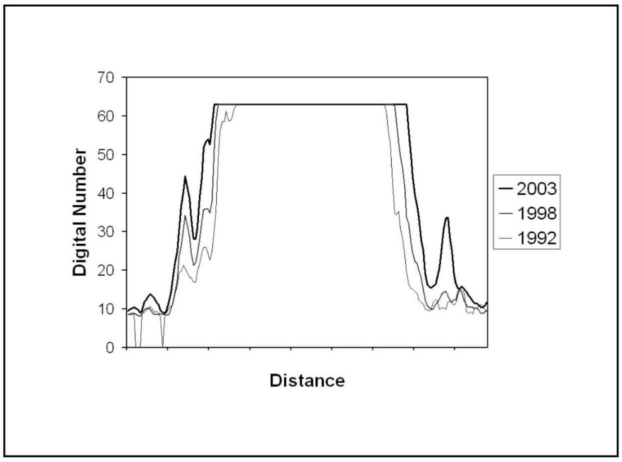

Figure 2. Nighttime lights digital number values from 1992, 1998 and 2003 for a transect drawn across Atlanta, Georgia, USA. Note that the core or the urban center was saturated (DN=63) in each date. Changes in nighttime lights can be observed in the unsaturated rim surrounding the urban core. The brightness of the lights increases over time in this outer rim, associated with the expansion of development.

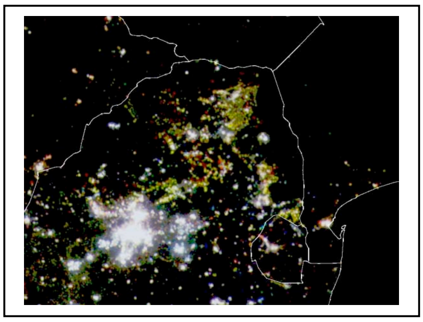

Figure 3. Nighttime lights color composite of northern South Africa made with 2003 as red, 1998 as green, and 1992 as blue. The large white area of lighting in the south is Johannesburg. To the north and east are clusters bronze colored new lighting, present in 1998 and 2003.

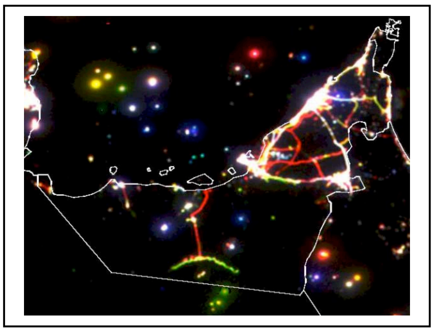

Figure 4. Nighttime lights color composite of United Arab Emirates made with 2003 as red, 1998 as green, and 1992 as blue. The red and bronze lines are heavily lit roads that were built after 1992.

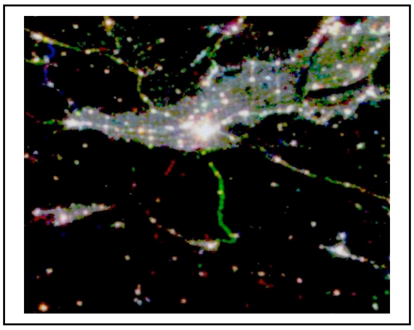

Figure 5. Nighttime lights color composite of the Xian, China region made with 2003 as red, 1998 as green, and 1992 as blue. The green line running south of Xian is typical of the sort of linear temporary lighting features found in China.

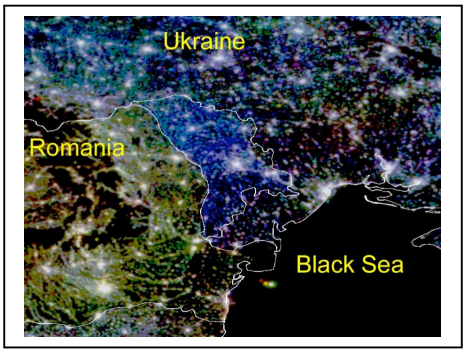

Figure 6. Nighttime lights color composite of the Moldova region made with 2003 as red, 1998 as green, and 1992 as blue. Moldova and many other parts of the Former Soviet Union lost lighting during the mid-1990's.

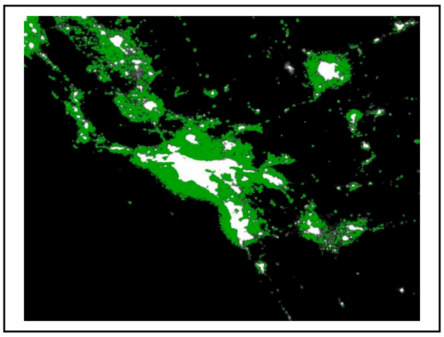

Figure 7. The brightness of lighting detected from skyglow has declined in many areas from 1992 to 2003. This image of the nighttime light of Southern California shows in green those areas where the digital number values of lighting were lower in 2003 than 1992.

indicating that a facility may have been established and then decommissioned. In some cases these appear to be associated with mines. In China a large number of linear temporary lighting features were identified (Figure 5). These appear to be transportation projects where construction continues through the night. Once the construction is complete - the lighting subsides.

D. Loss of lighting

Sections of the Former Soviet Union underwent collapse in lighting during the mid-1990's. In some cases lighting has returned. In other cases, such as Moldova, the loss in lighting has persisted to this day (Figure 6).

E. Reductions in skyglow

The intensification of the nighttime visible band on the OLS makes it possible to detect lighting down to the 10^{-9} watts/cm^2/sr range, sufficient to detect the skyglow that surrounds major urban center. The detection of skyglow is most obvious offshore from major coastal cities such as Los Angeles. Slight declines in the digital values of these skyglow areas were detected in many regions of the world. Figure 7 shows an example of the spatial distribution of these declines for Los Angeles and Southern California. These declines may be the result of changes in lighting type or the installation of lighting fixtures designed to direct lighting downward.

CONCLUSION

The DMSP-OLS has a unique capability to collect low-light imaging data of the earth at night. NGDC began producing global cloud-free composites of nighttime lights in 1996. The early products could not be compared directly since the algorithms used for each were substantially different. NGDC has now processed a consistently processed time series of nighttime lights - spanning 1992 through 2003. These products are openly available at http://www.ngdc.noaa.gov/dmsp/global_composites_v2.html.

While OLS data leave much to be desired for urban remote sensing (coarse spatial resolution, saturation in urban centers, 6 bit quantitization and no on-board calibration) significant changes in lighting can be observed. Examination of the global nighttime lights products reveals five primary types of changes in lighting: 1) expansion in the extent and brightness of lighting surrounding urban centers, 2) areas of new lighting, 3) temporary lighting, 4) losses of lighting, and 5) reductions in skyglow.

Based on these finding and previous studies [3, 4, 5] it is clear that nighttime lights respond to growth in development , population and economic activity. The plasticity of lighting is demonstrated by the collapse of light found in many parts of the Former Soviet Union. In addition, more subtle changes in nighttime lights are occurring as lighting types and lighting installations evolve to for improved energy efficiency and reductions in environmental impacts.

The follow on to the OLS is the Visible Infrared Imaging Radiometer Suite (VIIRS). The first VIIRS instrument is scheduled to be launched in 2009. The VIIRS low light imaging band will have better spatial resolution (742 m), wider dynamic range, more levels of quantitization and on-board calibration. It is anticipated that these changes will lead to improvements in the quality of the nighttime lights products from VIIRS over the OLS. Given the plans to fly VIIRS instruments throughout the next decade and beyond there will be continuity in the global record of nighttime lights at the ~1 km resolution level. Further improvements in the information content of nighttime lights could be achieved with higher spatial resolution and multispectral low light imaging.

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