*Proceedings of the Asia-Pacific Advanced Network* ***2013*** *v. 35, p. 62-69.*
*http://dx.doi.org/10.7125/APAN.35.7*
*ISSN 2227-3026*

# Why VIIRS data are superior to DMSP for mapping nighttime lights

**Christopher D. Elvidge[1]*, Kimberly Baugh[2], Mikhail Zhizhin[2], Feng Chi Hsu[2]**

[1] Earth Observation Group, NOAA National Geophysical Data Center
325 Broadway, Boulder, Colorado 80305 USA

[2] Cooperative Institute for Research in the Environmental Sciences
University of Colorado, Boulder, Colorado 80303 USA

E-mail: chris.elvidge@noaa.gov, kim.baugh@noaa.gov, mikhail.zhizhin@noaa.gov, feng.c.hsu@noaa.gov,
* Author to whom correspondence should be addressed; Tel.: +1-303-497-6121

---

**Abstract:** For more than forty years the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has been the only system collecting global low light imaging data. A series of twenty-four DMSP satellites have collected low light imaging data. The design of the OLS has not changed significantly since satellite F-4 flew in the late 1970's and OLS data have relatively coarse spatial resolution, limited dynamic range, and lack in-flight calibration. In 2011 NASA and NOAA launched the Suomi National Polar Partnership (SNPP) satellite carrying the first Visible Infrared Imaging Radiometer Suite (VIIRS) instrument. The VIIRS collects low light imaging data and has several improvements over the OLS' capabilities. In this paper we contrast the nighttime low light imaging collection capabilities of these two systems and compare their data products.

**Keywords:** Suomi NPP, VIIRS, nighttime lights.

## 1. Introduction

Nighttime lights are a class of satellite observations and derived products based on the detection of anthropogenic lighting present at the earth's surface. This style of product can only be produced using data from sensors that collect low light imaging data in spectral bands covering emissions generated by electric lights. The DMSP-OLS nighttime lights represent one of the most widely recognized global satellite data products and have proven valuable in a wide range of scientific applications. However, the DMSP data and products have a set of well-known shortcomings [1]: coarse spatial resolution, six bit quantization, saturation on bright lights, lack of in-flight calibration, lack of spectral channels suitable for discrimination of thermal sources of lighting and lack of low light imaging spectral bands suitable for discriminating lighting types [2].

The OLS was designed to collect visible and thermal infrared data, day and night, for use in observing weather systems and cloud cover. The "visible" band may be termed panchromatic, spanning the visible and near-infrared (NIR) from 0.5 to 0.9 um. The low light imaging is achieved using a photomultiplier tube. For nearly two decades the digital DMSP data were brought to the ground and written to film for visual interpretation by trained meteorologists. There was no requirement for radiometric units since these could not be accessed from the film. In contrast, the recently launched VIIRS was designed to collect high quality radiometric data for digital analysis and input into numerical models. The VIIRS instrument includes a day / night band (DNB) which collects standard panchromatic image data by day and low light imaging data at night. The DNB low light imaging is based on a time delay and integration (TDI) charge-coupled device (CCD). The VIIRS instrument offers improvement in each of these shortcomings, except multispectral low light imaging. In this paper we review the characteristics of the DMSP-OLS and VIIRS low light imaging capabilities and compare cloud-free composited nighttime lights collected by both systems.

## 2. Methods and Results

### Comparison of DMSP-OLS and VIIRS Low Light Imaging Capabilities:

Table 1 summarizes the primary observing characteristics of the two systems. DMSP and SNPP have similar polar orbits, the OLS and VIIRS collect the same wide swath (3000 km) and similar bandpasses for the low light imaging band (0.5 to 0.9 um). The DMSP overpass time is in the early part of the evening – near 19:30. In contrast, the SNPP overpass time is after midnight – near 01:30. Peak lighting is in the early part of the evening, prior to 10 pm. After this time most urban areas exhibit some decline in the quantity of outdoor lighting. However, examination of VIIRS DNB data indicates that there is still plenty of lighting to be detected, even after midnight.

## Table 1: Comparison Of DMSP-OLS and SNPP-VIIRS

| **Variable** | **DMSP-OLS** | **SNPP-VIIRS** |
|---|---|---|
| Builder / Operator | U.S. Air Force | NASA – NOAA Joint Polar Satellite System (JPSS) |
| Orbit | Polar – 850 km altitude, 98.8 degree inclination, 102 minutes | Polar – 827 km altitude, 98.7 degree inclination, 102 minutes |
| Swath | 3000 km | 3000 km |
| Nighttime overpass | ~19:30 | ~01:30 |
| Low light imaging bandpass | Panchromatic 0.5 to 0.9 um | Panchromatic 0.5 to 0.9 um |
| Ground footprint | 5 km x 5 km at nadir | 742 x 742 m |
| Additional spectral bands | Thermal infrared (10 um) | 21 additional bands spanning 0.4 to 13 um. |
| Quantization | 6 bit | 14 bit |
| Saturation | Common in urban cores | No saturation |
| Low light imaging detection limit | ~5E-10 Watts/cm2/sr | ~2E-11 Watts/cm2/sr |
| Calibration | None for low light imaging band. | Solar diffuser used to calibrate daytime DNB data. Calibration extended to low light imaging mode using data collected along solar terminator. |
| Future continuity | Last two satellites will likely fly in dawn/dusk orbits. | JPSS is building second VIIRS and plans third. Both will fly in after midnight orbits. |

There is a major difference in the pixel footprint (ground instantaneous field of view – GIFOV) . The global data collected by the OLS is the product of a five by five averaging of the native resolution "fine" data. This results in pixel footprints that are five kilometers on a side at nadir and the footprints expand as the scan moves toward the edge of scan. In contrast, the VIIRS DNB uses sixty-four detector aggregation zones (32 on each side) to maintain at a constant 742 meters from nadir out to edge of scan. Thus the footprint of the VIIRS low light imaging data is 45 times smaller than the DMSP footprint (Figure 1).

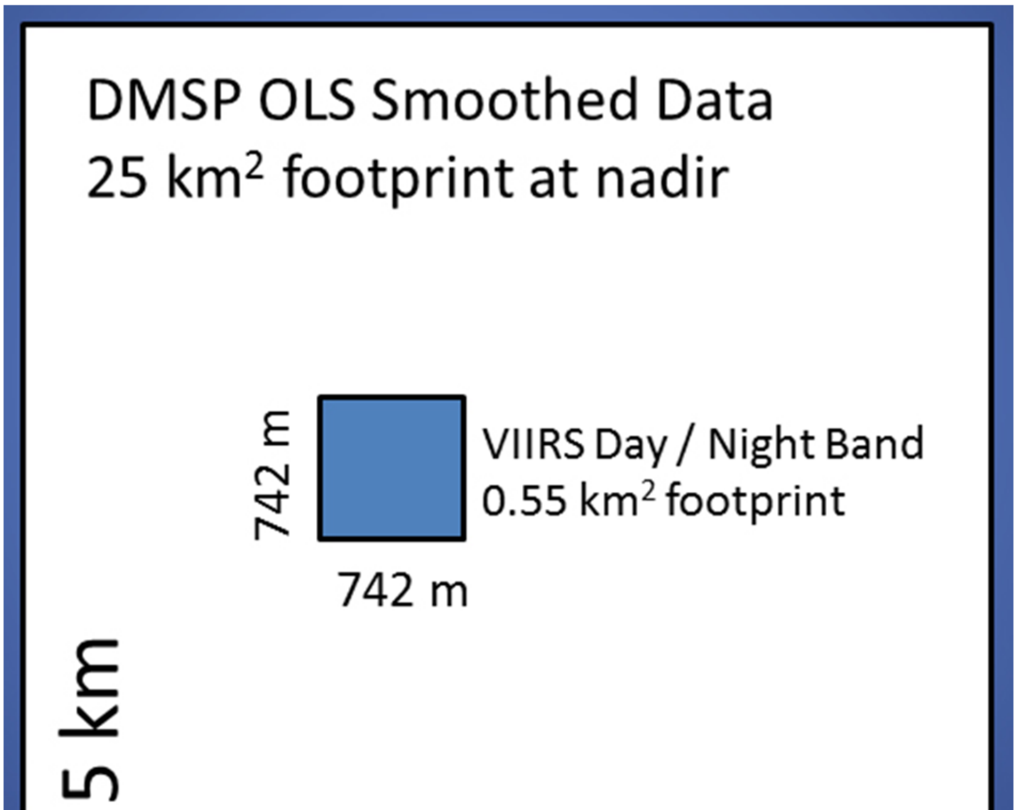


**Figure 1.** The VIIRS DNB data are collected with a constant 742 m x 742 m pixel footprint from nadir out to the edge of scan. In contrast the DMSP-OLS nighttime visible band starts at nadir with a 5 km x 5 km footprint (after on-board averaging) and the footprint expands toward the edge of scan. The DNB pixel footprint is thus 45 times smaller than the OLS pixel footprint.

A recent study [3] found that the VIIRS DNB has substantially lower detection limits than the OLS.  This finding is based on the DNB detection of clouds and high albedo terrain features on images collected with zero moonlight.  Cloud and high albedo terrain features  cannot be detected in OLS data when there is no moonlight.  Our examination of the radiances for dim overglow detected offshore from Los Angeles, California indicates the OLS detection limit is near 5E-10 Watts/cm2/sr and the DNB detection limit is 2E-10 Watts/cm2/sr. Apparently the DNB is capable of detecting bright scene features using nocturnal airglow emitted from the ionosphere, an extremely dim illumination source. The lower detection limits achieved by the VIIRS enables the detection of dimmer lighting.  However extracting the additional dim lighting details will be complicated due to the clutter generated by bright albedo surfaces, such as snow, ice and playa lakebeds.

Combustion sources are readily detected along with electric lighting in low light imaging data collected by the DMSP and VIIRS instruments. The DMSP thermal band is at too long a wavelength to be useful for the detection of fires and hot pixels.  To construction global maps of electric lighting from DMSP data, NGDC developed a temporal analysis algorithm to distinguish persistent lighting from ephemeral biomass burning [4].  This filtering leaves persistent gas flares, volcanoes, and industrial combustion sources present in the DMSP stable lights product. The VIIRS collects data in a larger suite of spectral bands at night and some of these bands work quite well for the detection of combustion sources [5,6].  The best of the VIIRS nighttime bands for distinguishing thermal sources of light from electric lighting is M10, centered at 1.61 um in the shortwave infrared.  M10 is a daytime imaging band. At night the M10 scene is dominated by background noise.  Combustion sources and hot pixels are readily detected, but not electric lighting (Figure 2).   NGDC's VIIRS Nightfire project produces tabulations of all "hot pixels" detected in the M10 bands. The Nightfire detections could be used to distinguish thermal sources of lighting from electric lightning detected in the DNB.  Note that the DNB records halos of emitted VNIR light surrounding combustion sources that are not detected in the M10 data. Complete separation of electric lighting from combustion source lighting in the DNB will require some algorithm development, but appears to be feasible within single orbits based on M10 detection of combustion sources.

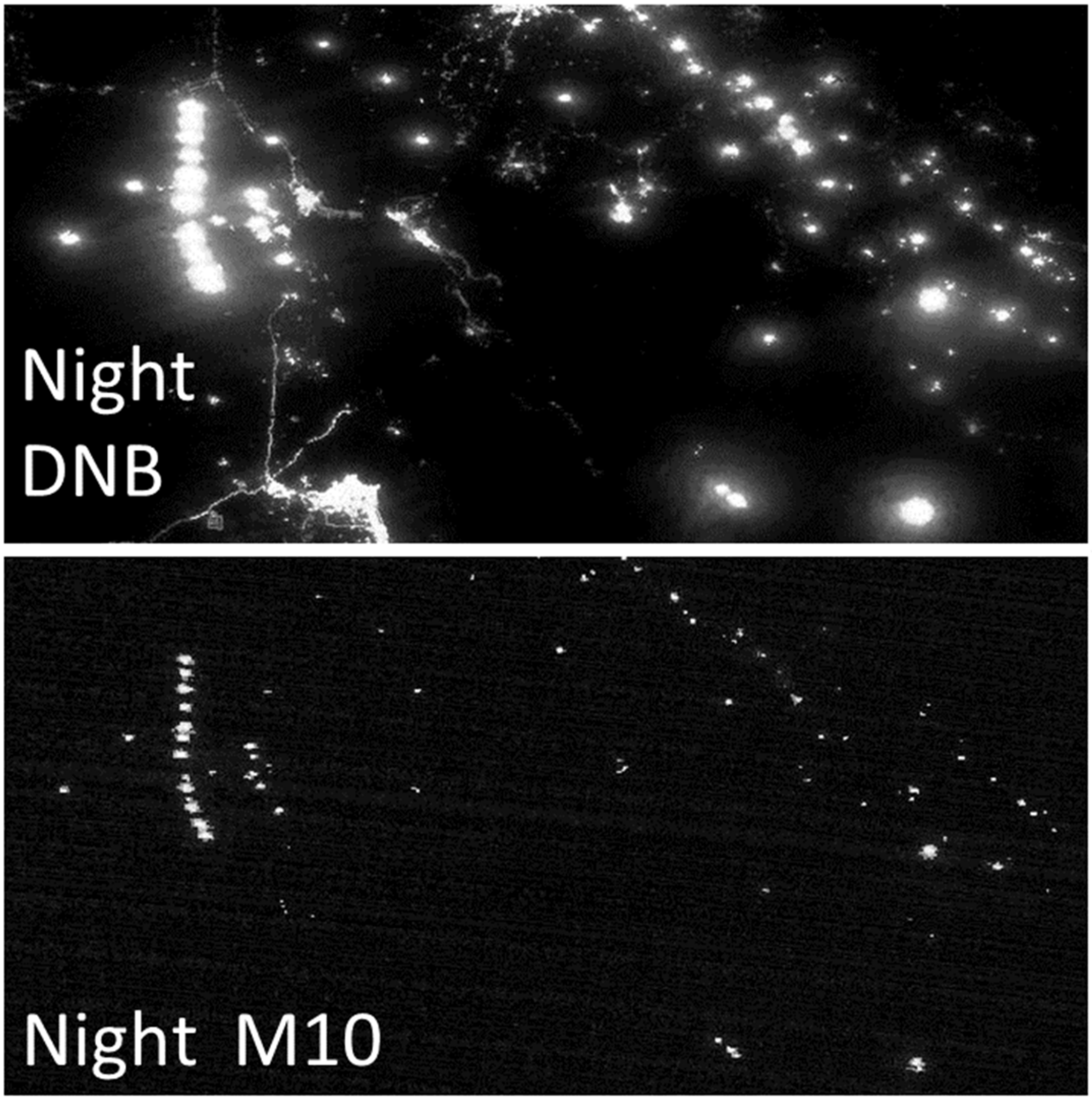


**Figure 2.** The VIIRS DNB light intensification enables the detection of urban lighting, lit roadways, gas flares and other combustion sources. The simultaneously collected M10 data (1.61 um) can be used to detect thermal sources of lighting. Note that none of the electric lighting features are detected in the nighttime M10 data.

**Comparison of DMSP-OLS and SNPP-VIIRS Nighttime Lights:**

To make a direct comparison of VIIRS and DMSP nighttime lights we produced a two month cloud-free composite from both systems using the same set of moonless nights from April and October 2012. The VIIRS and DMSP data were processed with the same algorithms [7]. The gridding was done at 24 arc second resolution. This DNB product is available at: http://www.ngdc.noaa.gov/dmsp/data/viirs_fire/viirs_html/viirs_ntl.html.

Figure 3 shows a side by side comparison of the average DNB versus average DMSP for the island of Oahu, Hawai'i. The DNB product shows substantially more spatial detail than the DMSP version. Also, the DMSP data have saturation (white pixels) centered on the major urban areas. The background areas with no detected lighting appear black on the DNB product and as a "salt and pepper" noise in the DMSP, suggesting it would be easier to apply a threshold to removed background noise in the VIIRS product.

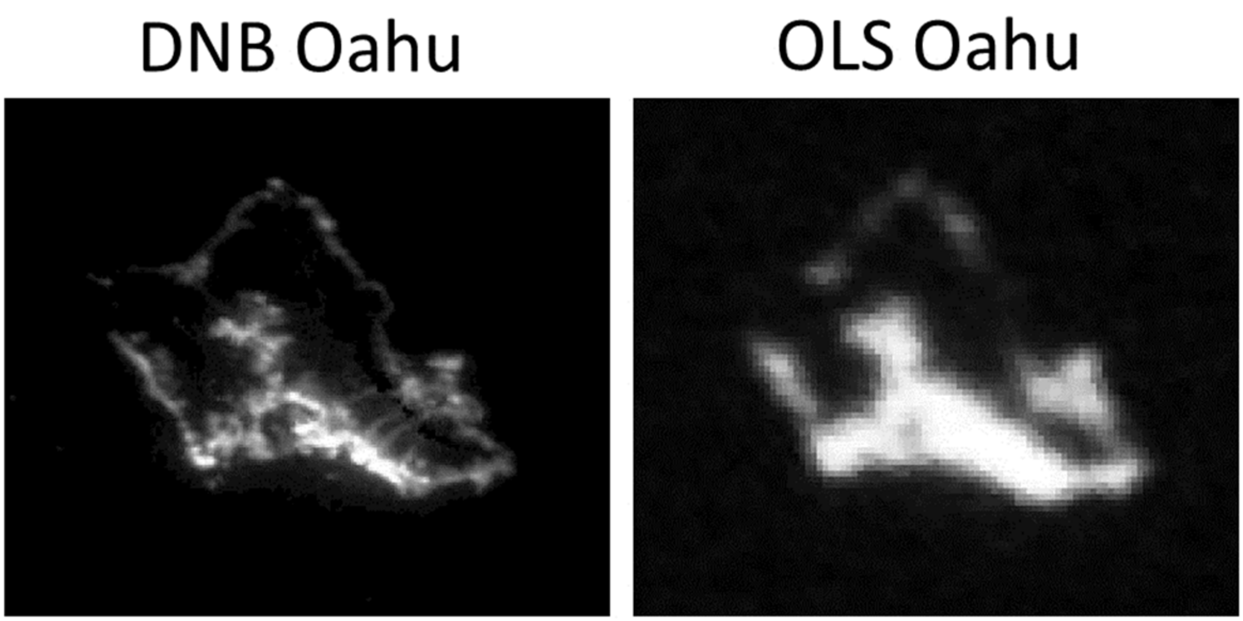


**Figure 3.** VIIRS DNB versus DMSP-OLS cloud free composited average visible band images of Oahu, Hawai'I processed from the same set of moonless nights from April and October, 2012.

## 3. Conclusions

Both the DMSP-OLS and SNPP VIIRS instruments have low light imaging capabilities suitable for collecting nighttime lights data. But the VIIRS offers a substantial number of improvements over the OLS in terms of spatial resolution, dynamic range, quantization, calibrations and the availability of spectral bands suitable for discrimination of thermal sources of light emissions. Side-by-side comparison of VIIRS and OLS cloud-free composites show the superiority of VIIRS product. It is anticipated that the VIIRS nighttime lights will enable advances in the science applications that have shown promise using the DMSP products.

## References


1. Elvidge, C.D., Cinzano, P., Pettit, D.R., Arvesen, J., Sutton, P., Small, C., Nemani, R., Longcore, T., Rich, C., Safran, J., Weeks, J., Ebener, S., 2007, The Nightsat mission concept, *International Journal of Remote Sensing*, 28(12), 2645 – 2670.

2. Elvidge C.D., Keith D.M., Tuttle B.T., Baugh K.E., 2010, Spectral Identification of Lighting Type and Character, *Sensors*, 10(4), 3961-3988.

3. Miller, S.D., Mills, S.P., Elvidge, C.D., Lindsey, D.T., Lee, T.F., Hawkins, J.D. Suomi satellite brings to light a unique frontier of nighttime environmental sensing capabilities. *Proceedings of the National Academy of Science*, **2012** 109:39, 15706-15711.

4. Baugh, Kimberly, Chris Elvidge, Tilottama Ghosh, Daniel Ziskin, 2010, Development of a 2009 Stable Lights Product using DMSP-OLS data, *Proceedings of the 30th Asia-Pacific Advanced Network Meeting*, 114-130.

5. Elvidge, C.D., Zhizhin, M., Hsu, F-C., Baugh, K. What is so great about nighttime VIIRS data for the detection and characterization of combustion sources? *Proceedings of the Asia-Pacific Advanced Network* ***2013****, 35, 33-48.* *http://dx.doi.org/10.7125/APAN.35.5*

6. Zhizhin, M., Elvidge, C.D., Hsu, F-C., Baugh, K. Using the short-wave infrared for nocturnal detection of combustion sources in VIIRS data. *Proceedings of the Asia-Pacific Advanced Network* ***2013****, 35, 49-61.* *http://dx.doi.org/10.7125/APAN.35.6*

7. Baugh, K., *Proceedings of the Asia-Pacific Advanced Network* ***2013****, 35, 70-86.* *http://dx.doi.org/10.7125/APAN.35.8*