Documentation for the VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT)

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Chris Small[1], Center for International Earth Science Information Network (CIESIN), Columbia University

[1] Marine Geology & Geophysics, Lamont-Doherty Earth Observatory (LDEO), The Earth Institute, Columbia University, Palisades, NY 10964 USA

Abstract

The VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT) data set fuses nighttime lights imagery from the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) with a stable night light composite from the next generation Suomi National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day-Night Band to map the spatial distribution and temporal evolution of global nighttime lights between 1992 and 2015. The product visualizes changes in both brightness and extent of nocturnal low lights over two decades while minimizing the spatial overextent (overglow) and bright saturation that compromise the DMSP-OLS composites. The map product utilizes annual DMSP-OLS stable lights composites, produced by the NOAA Earth Observation Group and archived at the NOAA National Geophysical Data Center (NGDC), in a tri-temporal global change map. To achieve greater spatial resolution and radiometric accuracy, the DMSP-OLS composites are co-registered and fused with the 2015 VIIRS annual composite from NGDC. The final product therefore retains the spatial detail and dynamic range of the VIIRS product, and the decadal change information from DMSP-OLS images. In the image, warmer colors represent brightening of nighttime lights post-1992, while cooler colors reflect dimming. As with all pan-sharpening approaches, projecting the 1992 to 2013 changes onto the 2015 lighted extent does not necessarily show the true spatial structure pre-2015, but rather shows the temporal evolution of brightness of lighted areas circa 2015, without the effects of overglow or saturation.

Data set citation: Small, C. and Center for International Earth Science Information Network (CIESIN), Columbia University. 2020. VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/9ryj-6467. Accessed DAY MONTH YEAR.

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We appreciate feedback regarding this data set, such as suggestions, discovery of errors, difficulties in using the data, and format preferences. Please contact:

NASA Socioeconomic Data and Applications Center (SEDAC)
Center for International Earth Science Information Network (CIESIN)
Columbia University
Phone: 1 (845) 365-8920
Email: ciesin.info@ciesin.columbia.edu

Contents

I. Introduction

At night, artificial light sources emit electromagnetic radiation in the optical wavelength range, giving rise to “NightTime Lights” low-light imagery observed by remote sensors. The DMSP-OLS (1976 - present) and VIIRS instruments (2011- present) are two prominent space-borne sensors measuring nocturnal near-infrared and visible light emissions from the Earth's surface, together producing a continuous record of nighttime low-light imagery. As temporally-stable nighttime lights provide a useful indicator of anthropogenic settlement and activity, such images offer a unique view of the human-earth system.

VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT) visualizes the spatiotemporal trajectory (1992 – 2013) of the Earth's Nighttime Lights (NTL), by leveraging VIIRS advanced detection capabilities and two-decades of DMSP-OLS composites. The product covers the spatial extent of 180 degrees West to 180 degrees East longitude and 65 degrees South to 70 degrees North latitude, but is supplemented with no data values beyond those latitudes in order to produce a fully global product. Fusion with the VIIRS day-night band composites resolves bright-saturated sources, increases spatial resolution, and reduces overglow, enabling more accurate and detailed registration of inter-decadal spatiotemporal dynamics. Given these improvements, the VIIRS+DMSP dLIGHT can contribute to a broad range of socioeconomic, geospatial, ecological, public health, and demographic analyses at varying scales. To date, NTL data have made substantial contributions to a wide-ranging body of research, with documented use as a proxy for economic activity, population dynamics, energy consumption, and Carbon Dioxide (CO_2) emissions (Doll 2008). Therefore, this data set can be flexibly employed to meet numerous research needs and real-world applications.

Colors accord with the Red Green Blue (RGB) channel assigned to each annual composite; blue is assigned to the 1992 annual DMSP composite, green to the 2002 annual DMSP composite, and red to the 2013 annual DMSP composite. The tri-temporal combination process is additive and, as a consequence, hues are effectively continuous across the color spectrum (Figure 1).[1] In the tri-temporal RGB composite, this color-coded information is a function of pixel-level brightness trajectories, indicating increasing, decreasing, or stable brightness trajectories over the study period. While this granular level should be interpreted flexibly, assuming some noise in the inputs, spatially clustered trends can be interpreted as changes in brightness owing to development processes on the ground. White areas are those with consistent brightness across all three time steps. Blue areas were bright in 1992 but not in more recent time steps; green areas were bright in 2002 but not in 1992 or 2013, yellow areas were lighted in 2002 and 2013 but not 1992, and red areas are only lighted in the most recent time step.

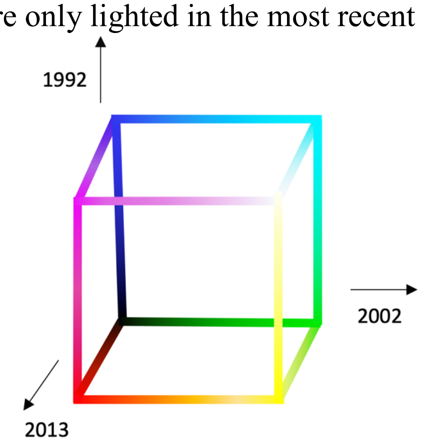

Figure 1: The RGB color space

The map below focuses on the states of the Niger Delta region, where the dLIGHT visualization method captures certain inter-decadal regional dynamics. In the map of the Niger Delta (Figure 2), many settlements exhibit grey cores, which are characteristic of

[1] For more on the RGB additive color model, see https://en.wikipedia.org/wiki/RGB_color_model.

stable lights. Many of these settlements exhibit hues at the periphery, which correspond to the point in time at which the outer extent was brightest, indicative of growth or decline at the edge.

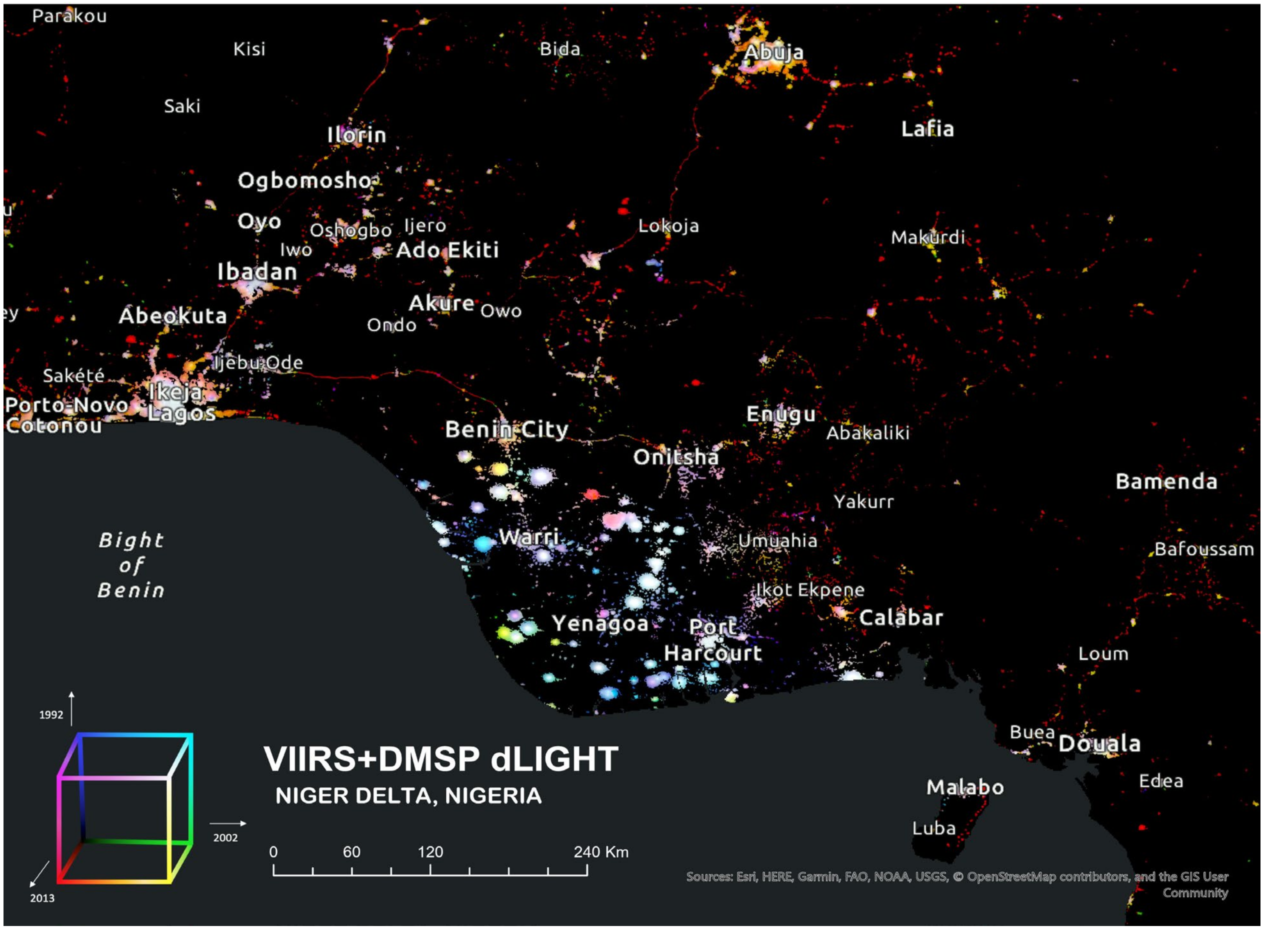

Figure 2: dLIGHT focused on the Niger Delta Region.

For the outer extents in the Niger Delta, the following indicative guidance can be followed.

- Blueish tints indicate outer extents that were brightest in 1992.
- Cyan areas translate to significantly increased brightness in both 1992 and 2002, and dimming post-2002.
- Green-colored hues indicate areas that were brightest in 2002.
- Yellow tinted areas indicate significantly increased brightness in 2002 and 2013.
- Red colored tints indicate areas that were brightest in 2013.
- Magenta tints reflect extents that significantly brighter in both 1992 and 2013.

Monochromatic red, green, or blue lights can be understood as having been substantially brighter, or only lit, in one of the annual composites. This is common in the scattered red settlements of more rural inland states and across the border with neighboring Cameroon. Monochromatic yellow, cyan, or magenta settlements can be understood to have been radically dimmed or as unlit in one of the composites. This is featured most notably in predominantly yellow settlements, such as those in the city of Makurdi. It is important to emphasize that due to co-registration with the 2015 VIIRS composite, areas that may have been lit in 1992, 2002, or 2013, but are not lighted in 2015, will not be represented.

Across the in-brightness can be related to certain dynamics in the Niger Delta. Notable drivers include

- Growth of urban extents, featured most notably in Lagos.
- Local hotspots of economic development, as well as incremental regional economic development.
- Fluctuating industrial development patterns associated with the region's longstanding relationship with transnational oil companies. The region is the site of extractive activities including infrastructural development, oil rigging, and gas flaring.
- The region's extensive extractive activity has been impacted by conflict, including an oil crisis (2004-2006) and periodic production ramp-downs induced by insurgency and violence.

II. Data and Methodology

For more information on the methodology, see:

- Small, C. 2020. Spatiotemporal Network Evolution of Anthropogenic Night Light 1992-2015. arXiv:2005.12197 [physics.soc-ph] (2020), 1-25. Available at https://arxiv.org/abs/2005.12197.
- Small, C., D. Sousa, G. Yetman, C. Elvidge, and K. MacManus. 2018. Decades of Urban Growth and Development on the Asian Megadeltas. *Global and Planetary Change* 165: 62-89. https://doi.org/10.1016/j.gloplacha.2018.03.005.
- Small C., S. van der Linden, A. Okujeni, B. Waske. 2018. Remote Sensing of Urban Environments, Ch. 6.07 in *Comprehensive Remote Sensing*, vol. 6, pp. 96-127. Oxford: Elsevier. ISBN: 9780128032206. https://doi.org/10.1016/B978-0-12-409548-9.10380-X. The procedure stipulated in this paper is applied to imaging data that covers the global extent.

Input data

The main data inputs are DMSP-OLS NTL Stable Lights Composite - Version 4 and VIIRS Day-Night Band (DNB) Night Light Composites.

DMSP-OLS NTL Stable Lights Composite - Version 4

The DMSP-OLS satellite series has been collecting thermal infrared and visible emissions from the Earth's surface, formally intended for meteorological and cloud-cover observation. Low-light imaging capabilities are induced with an onboard photomultiplier tube. Since 1992, NOAA has archived continuous imaging of nighttime lights from a series of five satellites whose coverage ranges from 180 degrees West to 180 degrees East longitude. Inter-calibration coefficients and procedures have been developed to facilitate quantitative consistency between satellites. The stable lights v4 product undergoes filtering to eliminate extraneous and temporally-unstable light emissions and reduce cloud-contamination in annual composites. The final composites are gridded at a resolution of 30 arc-seconds. In these composites, digital numbers are used to represent luminance data, zero being the minimum value and 63 being the upper-bound saturation value. Other than detected negligible emission, the minimum value of 0 is assigned to extraneous and ephemeral lights. A value of 63 is given to all values over which the satellite's view is saturated. The sensor's limited dynamic range results in saturation of bright sources when the gain is set high enough to detect dim sources. In addition, the combination of geolocation uncertainty, atmospheric scattering, and sensor point spread function creates a blurring effect, known as overglow that causes lighted extents to appear larger than they are. While low-light thresholding can reduce overglow effects, it also attenuates low luminance sources, considerably reducing the information content of the DMSP-OLS observations. The combined effects of bright saturation, spatial resolution, and overglow pose challenges for spatiotemporal change analyses using OLS.

VIIRS DNB Night Light Composites

DMSP-OLS composites were co-registered with the annual VIIRS Day-Night Band (DNB) cloud-free brightness composite from 2015, and resampled to VIIRS resolution. VIIRS composites have a 15 arc-second resolution, improved quantization from DMSP's 6 bit to 14 bits, lower detection limits, and a wider dynamic range. The VIIRS sensors have onboard in-flight calibration. The basic procedure used to make VIIRS nighttime lights composites is described in detail by Elvidge et al., 2017.

Methodology

1. DMSP-OLS and VIIRS NTL data were procured from the NOAA Earth Observation Group (https://ngdc.noaa.gov/eog/).
2. DMSP-OLS Annual Composites for the years 1992-2013 were inter-calibrated using updated inter-calibration coefficients developed for the version 4 product by the NOAA Earth Observation Group. Three inter-calibrated composites for the years 1992, 2002, and 2013 act as inputs to a tri-temporal RGB composite. Spatial correlations among all annual composite pairs were computed to assure inter-annual continuity and avoid using composites with lower correlation due to reduced numbers of cloud-free coverages.
3. The RGB tri-temporal composite was co-registered with a VIIRS 2015 monthly composite, and resampled to the VIIRS 15 arc-second resolution.
4. The dOLS+VIIRS image fusion process uses a Hue Saturation Value (HSV) transformation to the resampled 15 arc-second tri-temporal composite.
5. The value channel of the HSV transformed composite is replaced by the unit-normalized brightness from the co-registered VIIRS composite. This has the

effect of retaining the spatial detail of the VIIRS luminance, while fusing this to the chrominance derived from the tri-temporal composite.

6. The fused HSV image is inversely transformed to RGB space. Due to the improved dynamic range and reduced overglow in the VIIRS DNB product, only the much brighter VIIRS pixels retain the color-coded change information from the Hue and Saturation channels of the transformed OLS product. This effectively masks out most of the OLS overglow, while retaining the higher spatial resolution and brightness structure in areas with oversaturation.
7. The final product is a single 3-channel GeoTIFF, which shows the decadal change information in higher spatial resolution, no bright saturation, and greatly reduced overglow.

The resulting change map acts as a projection of the relative brightness changes from 1992-2013 onto the lighted areas in 2015. One implication of this is that areas that may have been lit in 1992, 2002, or 2013, but are not lighted in 2015, will not be represented. However, these intermittent lights are relatively rare compared to the monotonic increasing brightness, which is widespread across lighted areas. Additionally, due to the change map's depiction of relative brightnesses, this product is not suitable for quantitative analysis. Instead, this product represents relative changes in brightness, grounded in the Digital Numbers (0-63) of the DMSP-OLS sensor.

III. Data Set Description(s)

This data set includes one global raster file that shows the extent of nighttime lights change at a resolution of 15 arc-seconds:

- Band 1: The red band represents data derived from the 2013 annual composite.
- Band 2: The green band represents data derived from the 2002 annual composite.
- Band 3: The blue band represents data derived from the 1992 annual composite.

Data set web page:
SEDAC URL: https://sedac.ciesin.columbia.edu/data/set/sdei-viirs-dmsp-dlight
Permanent URL: https://doi.org/10.7927/9ryj-6467

Data set format:
The data are available in GeoTIFF format as a downloadable zip file. The downloadable is a compressed zip file, containing: 1) global raster, 2) Readme, and 3) PDF documentation.

Data set download:
sdei-viirs-dmsp-dlight-geotiff.zip

IV. How to Use the Data

This data set includes one multi-banded raster that depicts the spatial extent of night light changes in much greater detail than is provided by DMSP-OLS composites. As such, the image depicts emergent growth and relative decline in lighted settlements and development networks across the globe. The following information can be used to guide product interpretation.

Band 1: The Red Band represents the HSV-transformed DMSP-OLS composite from 2013.

Band 2: The Green Band represents the HSV-transformed DMSP-OLS composite from 2002.

Band 3: The Blue Band represents the HSV-transformed DMSP-OLS composite from 1992.

Hence, warmer colors can be interpreted as indicating local brightening and cooler colors indicating local dimming. The most common are yellow (lighted in 2002 and 2013) and red (lighted post 2002).

V. Potential Use Cases

Spatiotemporal NTL change data offers wide-reaching potential use cases across varied socioeconomic and scientific studies and applications. This product offers a unique perspective on the global trajectory of an artificially lit settlement over an extended time frame. NTL data has been utilized as a proxy for economic growth, Gross Domestic Product (GDP), urban development, population dynamics, greenhouse gas emissions, and light pollution. Some applications for this product include:

- Comparing regional development
- Evaluating electrification policies and progress
- Evaluating economic modernization policies
- Monitoring changes in the urban extent & development networks
- Visualizing the effects of conflict, disaster, or social upheaval
- Monitoring infrastructure development
- Monitoring some extractive practices or industries

VI. Limitations

This data set is not suitable for quantitative analysis, as the values are based on the relative nature of the Digital Number values in the DMSP-OLS Satellite Suite. There are no quantitative values provided at the pixel level. This product aims to qualitatively illustrate NTL change in much greater detail than would be demonstrated by an OLS-only product.

VII. Acknowledgments

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VIII. Disclaimer

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IX. Use Constraints

X. Recommended Citation(s)

Data set(s):

Small, C., and Center for International Earth Science Information Network (CIESIN), Columbia University. 2020. VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/9ryj-6467. Accessed DAY MONTH YEAR.

Scientific publication:

Small, C., D. Sousa, G. Yetman, C. Elvidge, and K. MacManus. 2018. Decades of Urban Growth and Development on the Asian Megadeltas. *Global and Planetary Change* 165: 62-89. https://doi.org/10.1016/j.gloplacha.2018.03.005.

XI. Source Code

No source code is provided for this data set.

XII. References

Doll, C. 2008. *CIESIN Thematic Guide to Night-time Light Remote Sensing and its Applications*. Palisades NY: NASA Socioecnomic Data and Applications Center (SEDAC). Available at https://sedac.ciesin.columbia.edu/binaries/web/sedac/thematic-guides/ciesin_nl_tg.pdf.

Small, C. 2020. Spatiotemporal Network Evolution of Anthropogenic Night Light 1992-2015. arXiv:2005.12197 [physics.soc-ph] (2020), 1-25. Available at https://arxiv.org/abs/2005.12197.

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Elvidge, C. D., K. Baugh, Z. Mikhail, F. C. Hsu, and T. Ghosh. 2017. VIIRS Night-time Lights, *International Journal of Remote Sensing*, 38:21, 5860-5879, https://doi.org/10.1080/01431161.2017.1342050.

XIII. Documentation Copyright and License

Appendix 1. Data Revision History

No revisions have been made to this data set.

Appendix 2. Contributing Authors & Documentation Revision History

Revision Date	ORCID	Contributors	Revisions
June 18, 2020	0000-0001-5045-1932	Chris Small, Mairead Milan, Kytt MacManus	This document is the 1st instance of documentation.