Fires, Flares and Lights: Mapping Anthropogenic Emission Sources with Nighttime Low-light Imaging Satellite Data

Christopher D. Elvidge, Ph.D.
Earth Observation Group
NOAA National Geophysical Data Center
Boulder, Colorado USA
chris.elvidge@noaa.gov

Kimberly Baugh, Feng-Chi Hsu, Mikhail Zhizhin, Tilottama Ghosh
Cooperative Institute for Research in the Environmental Sciences
University of Colorado

October 18, 2016
Emission Sources At Night!

Cities and human settlements

Industrial Sites

Gas Flares

Boats

Fires
VIIRS Collects Two Styles of Low Light Imaging Data

1. Signal intensification to detect faint radiant emissions in the visible and near infrared – the Day Night Band (DNB).

2. Daytime channels at night – enabling the detection of radiant emissions that are obscured by reflected sunlight. VIIRS collects the following at night:
   - M7 at 0.865 um
   - M8 at 1.24 um
   - M10 at 1.61 um
   - M11 at 2.25 to be added soon
NOAA produces global monthly cloud-free DNB composites

- 75 north to 60 south. 15 arc second grids.
- Dimensions 86400 x 33601. Too large to output as GEOTIFF! Break up into six tiles.
- Original units multiplied by a billion (E9) to yield nanoWatts/(cm2*sr).
- Screened to exclude sunlit data based on solar zenith angle.
- Includes pixels deemed to be confidently clear based on the VIIRS cloud-mask.
- EOG is working on algorithms to make research quality nighttime lights: removal of background noise, aurora, high energy particle hits, lightning, fires, fuzzy lights.
VIIRS Provides Improved Spatial Resolution

Fishing Boat Detections

VIIRS October 15, 2012  01:30
DMSP-OLS October 14, 2012   19:30
What Makes VIIRS Better Than DMSP?

• The VIIRS DNB footprint is 45 times smaller than the DMSP pixel footprint!

DMSP OLS
5 km² footprint

VIIRS Day / Night Band
742 m² footprint
DNB Monthly Composite Tiles
Average VIIRS DNB Composite - January 2013
Contrast Enhanced to Show the Flaws

- Dimensions 86400 x 33601. Too large to output as GEOTIFF!
- Original units multiplied by a billion (E9) to yield nanoWatts/(cm² sr)
- NGDC is working on algorithms to make research quality nighttime lights: removal of background noise, aurora, ionospheric detector hits, lightning, fires, fuzzy lights.
Nighttime lights should be used with some caution due to their plasticity.

Color composite of three monthly average DNB products.
201204 = blue
201301 = green
201405 = red


Syria
Nighttime lights are used to model spatially distributed greenhouse gas emissions from human settlements
Current Status of NGDC DNB Products

- Rough monthly averages. 35 products are available at: [http://ngdc.noaa.gov/eog/viirs/download_monthly.html](http://ngdc.noaa.gov/eog/viirs/download_monthly.html)
- Monthly and annual cleaned nighttime lights still in development
  - Outlier filtering to remove aurora, lightning, biomass burning, and high energy particle hits on detectors
  - Background noise removal
  - First global annual nighttime lights product expected release date is early December, 2016
VIIRS Nightfire (VNF)

- A multispectral global fire product
- Makes use of near-infrared and shortwave infrared data.
- What is different from other global fire products?
  - Two independent hot source detection algorithms:
    - M10 in the shortwave infrared
    - M12-M13 in the midwave infrared
  - Dual Planck curve fitting (background and hot source) followed by calculations using physical laws
  - Temperature calculation based on Wien’s Displacement Law
  - Source area estimation based on Planck’s Law
  - Radiant heat (W/m²) calculated using the Stefan-Boltzmann Law
- Nightly global data are available at: http://ngdc.noaa.gov/eog/viirs/download_viirs_fire.html
- Global gas flaring data are available at: http://www.ngdc.noaa.gov/eog/viirs/download_global_flare.html
VIIRS Nightfire (VNF): A global multispectral fire product
Nine channels of data collected at night

Nighttime collection of channel 11 is expected to start in 2017
Why Multispectral?

To get at the Planck curves!

Daily files are in csv and kmz formats
Typical Biomass Burning Detection

Lower temperature than gas flaring. Often these have larger source size than gas flares.
Temperature Calculation

Wien's displacement law states that the black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature.

$$\lambda_{\text{max}} = \frac{C}{T}$$

where $C$ is a constant equal to 2897 and $T$ is the temperature in Kelvin.
Subpixel source area calculation

B/A = 0.1 Therefore the hot source is filling 10% of the pixel footprint. Multiply the pixel footprint by 0.1 to calculate to size of the hot source.

100% of pixel filled with object at 1800 K

Full pixel footprint

Hot source 10%
Gas flares are readily detected in the VIIRS M10 spectral band.
Detection Limits
At 1800 K flares as small as 0.25 m² are detectable.
Daily VNF data are available at:
http://ngdc.noaa.gov/eog/viirs/download_viirs_fire.html

Current processing typically runs with a four hour delay
Temperatures are bimodal

[Bar chart showing two peaks labeled "Fires" and "Flares"]
Gas Flaring

- A widely used practice to dispose of natural gas that cannot be utilized or brought to market due to lack of infrastructure.
- VNF is ideally suited for detecting and estimating flare volumes because the M10 band covers the peak radiant emissions for flares.
- Using VNF data we have identified 18,129 flares from 2012-2015.
- Russia has the largest flare volume.
- USA has the largest number of flares.
- VIIRS data can be used for Monitoring, Reporting, and Verification (MRV) of gas flaring reductions:
  - Greenhouse gas emission reduction commitments under the Paris Climate Agreement
  - UN & Worldbank “Zero routine flaring by 2030” initiative.
UN Initiative to end routine flaring by 2030

How will progress be tracked? VIIRS!

Zero Routine Flaring by 2030

The Zero Routine Flaring Initiative
May 22, 2015 — The initiative was launched by UNSG Ban Ki-moon and WBG President Jim Yong Kim with governments, oil

During oil production, associated gas is produced from the reservoir together with the oil.
Upstream flaring 2012-2015
Units = billion cubic meters (BCM)
Distinguishing flaming and smoldering combustion with nighttime Landsat 8

- There is a 400 K temperature gap between flaming and smoldering. Flaming 800-1000 K. Smoldering 400 K.
- Smoldering shows up as thermal anomalies in the longwave infrared.
- Flaming shows up well in the shortwave infrared.
- VNF style calculations discriminate flaming from smoldering combustion phases. Two shortwave spectral bands are used to model the flaming phase Planck curves. Two longwave infrared bands are used to model the smoldering phase Planck curves.
- This is important because the two combustion phases differ dramatically in their greenhouse gas and black carbon emissions.
- The presence of smoldering combustion was confirmed in field inspection done by NOAA and LAPAN the day after a nighttime Landsat collection.
Landsat Path 2, Row 185
Nighttime data collected March 28, 2014
over active fires in Riau, Sumatra
Fire Detection in Nighttime Landsat 8 Data

Band 5 = 0.86 um  Band 6 = 1.6 um  Band 7 = 2.2 um  Band 10 = 11 um  Band 11 = 12 um

Flaming    Smoldering
Temperatures of flaming versus smoldering

Note the temperature gap from 450 to 650 K
Two distinct phases!
Modeling the flaming phase with SWIR and smoldering with LWIR
Summary

• Nighttime remote sensing enables the detection of radiant emissions from greenhouse gas sources worldwide.
• VIIRS nighttime lights are used to model spatially distributed greenhouse gas emissions from cities, towns, and villages.
• VNF data are used to catalog gas flaring sites and track flared gas volumes over time.
• VNF data of biomass burning have not been widely utilized to date.
• NASA and NOAA have a commitment to continue flying VIIRS instruments into the future.
EOG Publications

• Methods for global survey of natural gas flaring from Visible Infrared Imaging Radiometer Suite data. doi:10.3390/en9010014
• Automatic boat identification system for VIIRS low light imaging data. doi:10.3390/rs70303020
• VIIRS Nightfire: Satellite pyrometry at night http://www.mdpi.com/2072-4292/5/9/4423
• What is so great about nighttime VIIRS data for the detection and characterization of combustion sources? http://dx.doi.org/10.7125/APAN.35.5
• Using the short-wave infrared for nocturnal detection of combustion sources in VIIRS data. http://dx.doi.org/10.7125/APAN.35.6
• Why VIIRS data are superior to DMSP for mapping nighttime lights. http://dx.doi.org/10.7125/APAN.35.7
• Nighttime lights compositing using the VIIRS day-night band: Preliminary results. http://dx.doi.org/10.7125/APAN.35.8
• Illuminating the capabilities of the Suomi NPP VIIRS day/night band. http://dx.doi.org/10.3390/rs5126717