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

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Emission Sources At Night!

Cities and human settlements

Boats

Industrial Sites

Gas Flares

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

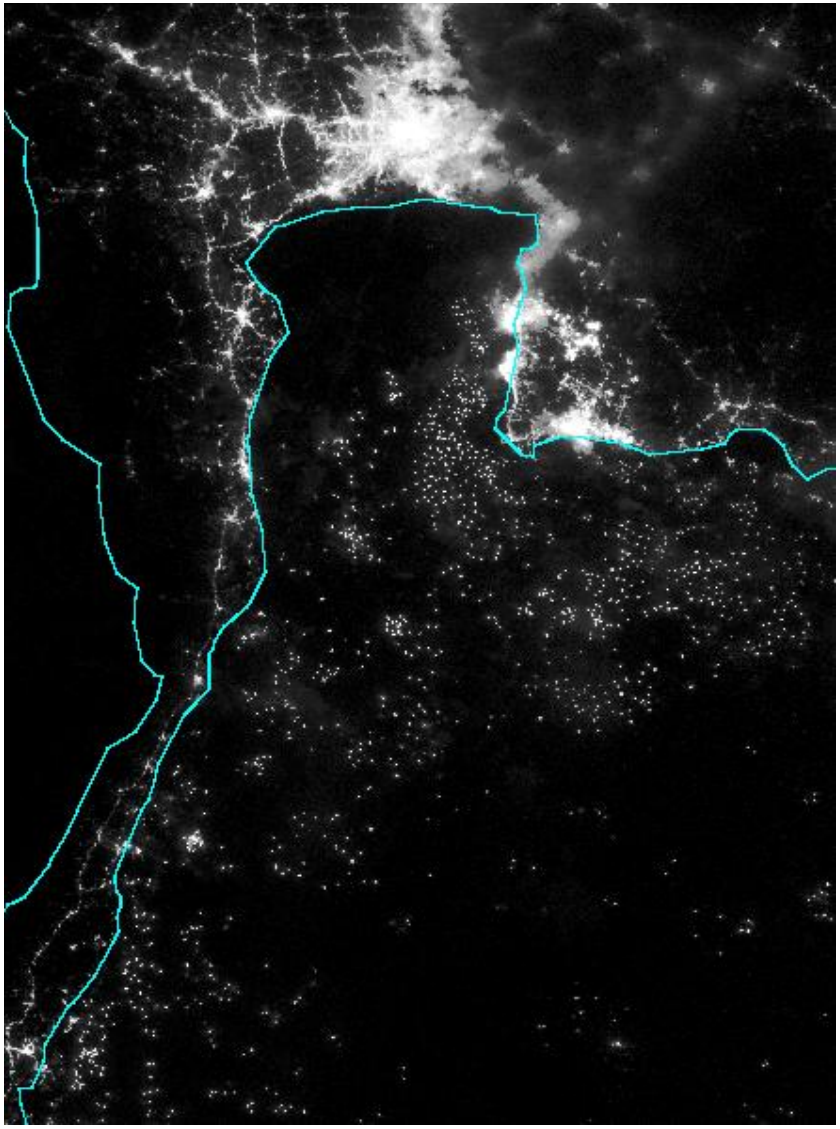
   M11 at 2.25 to be added soon

NOAA produces global monthly cloud-free DNB composites

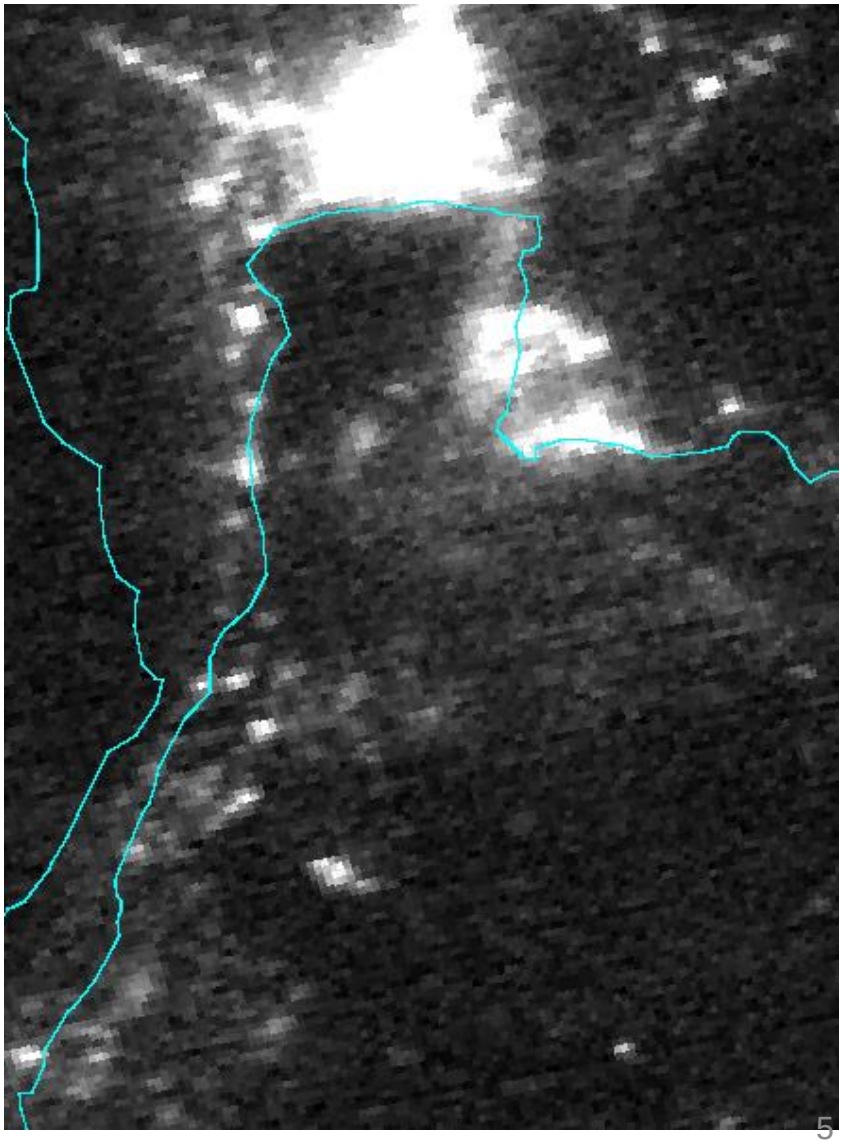
- 75 north to 60 south. 15 arc second grids.
- Dimensions 86400 x 33601. Too large to output as GEOTIFF! Break up into six tiles.
- Original units multiplied by a billion (E9) to yield nanoWatts/(cm2*sr).
- Screened to exclude sunlit data based on solar zenith angle.
- Includes pixels deemed to be confidently 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



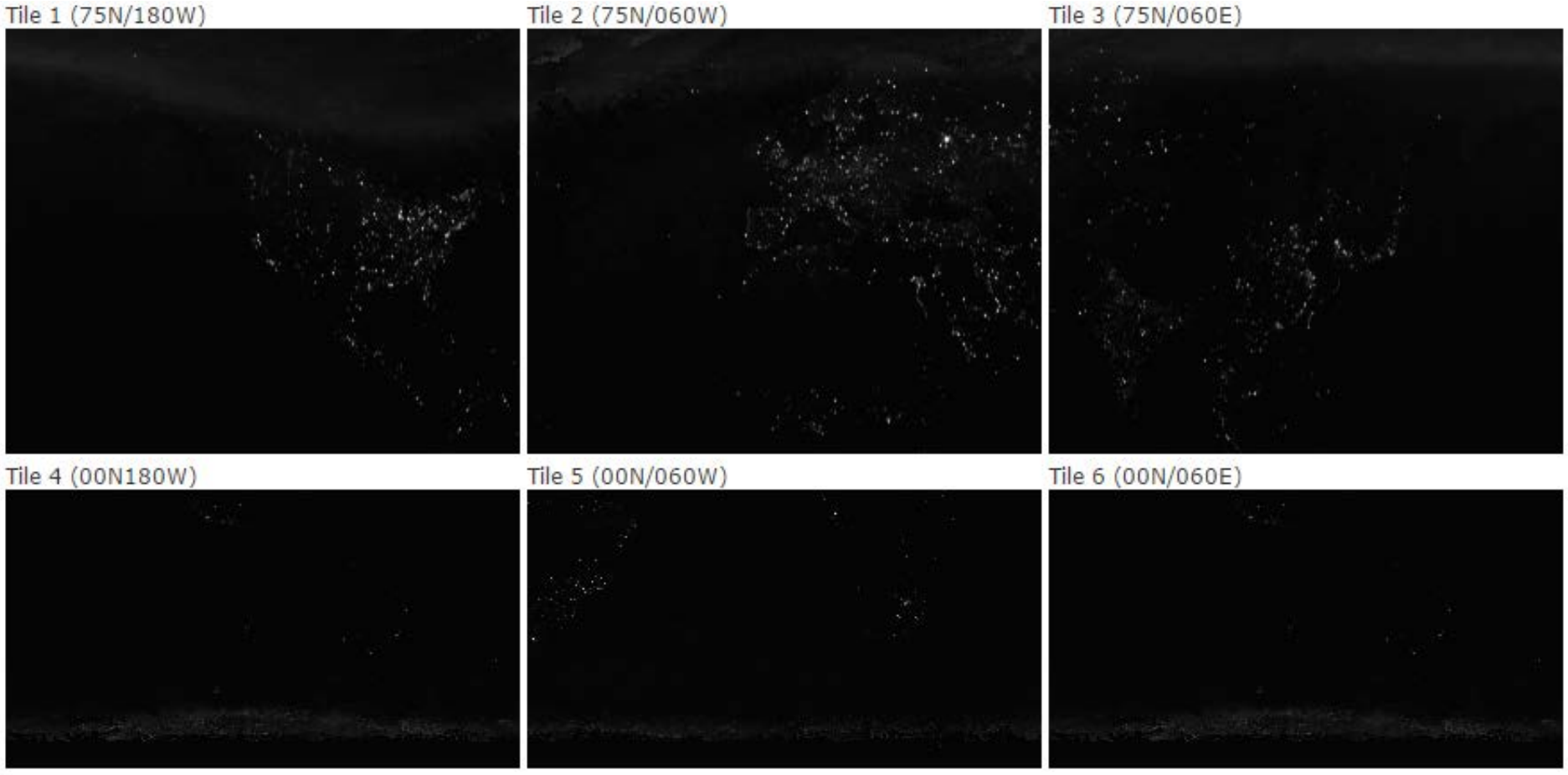
DMSP-OLS October 14, 2012 19:30



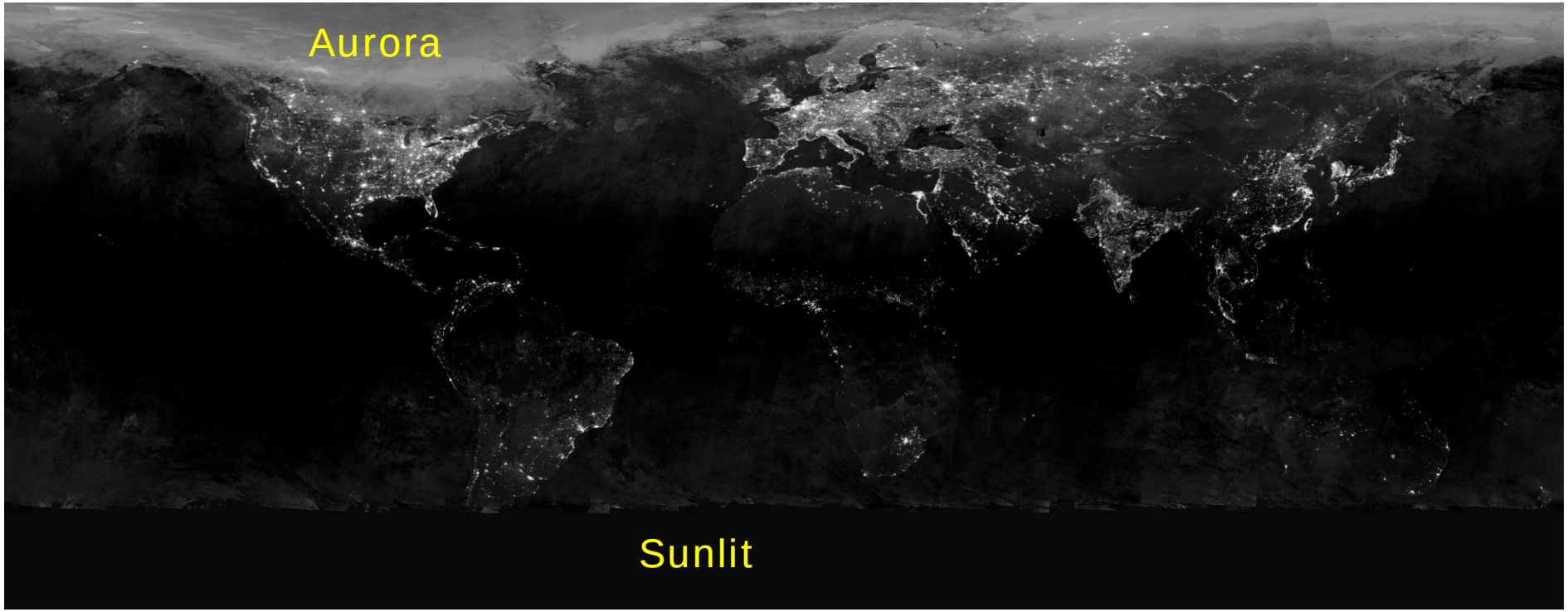
What Makes VIIRS Better Than DMSP?

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

DNB Monthly Composite Tiles

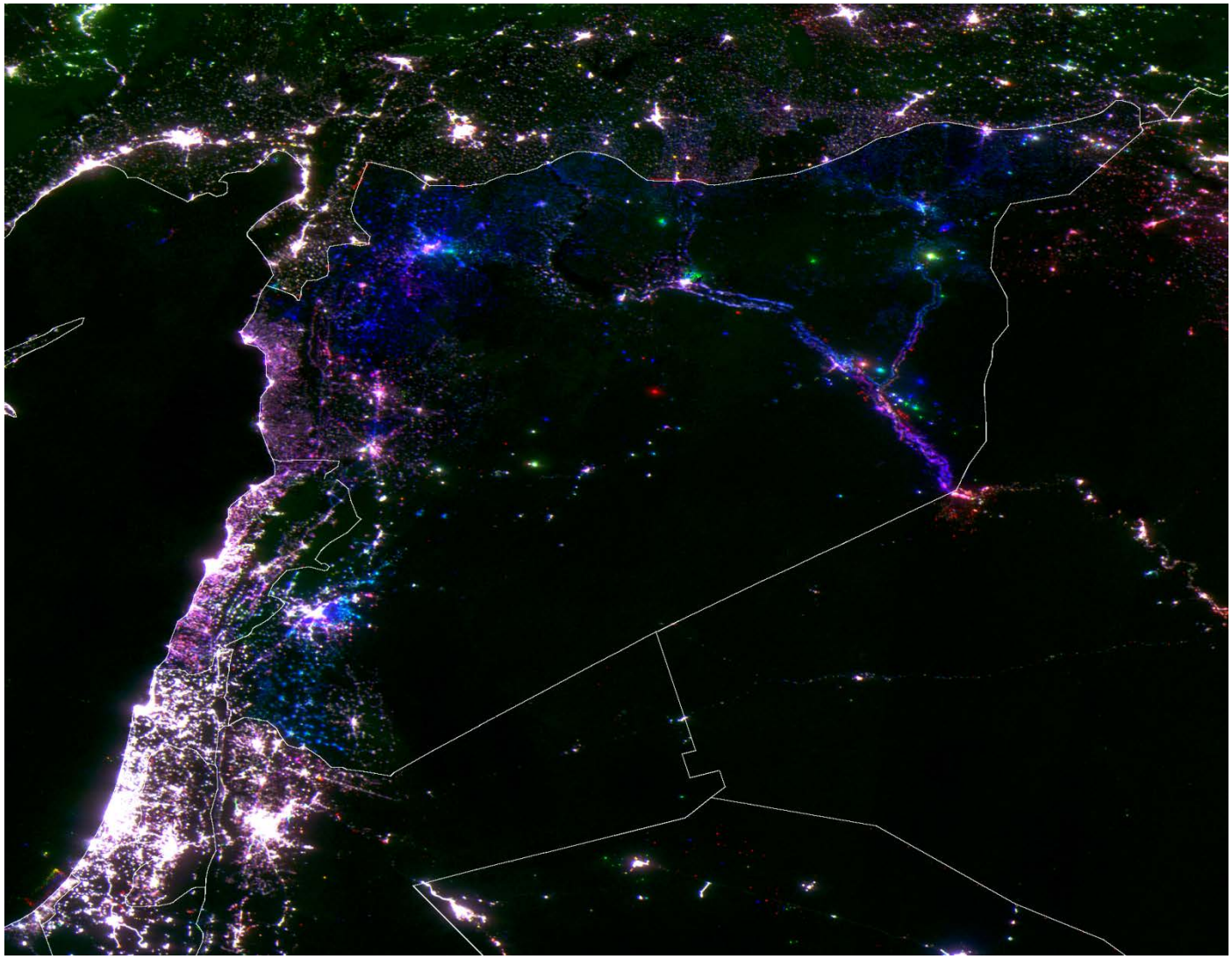


Average VIIRS DNB Composite - January 2013 Contrast Enhanced to Show the Flaws



- Dimensions 86400 x 33601. Too large to output as GEOTIFF!
- Original units multiplied by a billion (E9) to yield nanoWatts/(cm^2·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

Blue indicates power outages in 2013 and 2014. Purple indicates power outage in 2013.

Syria

Nighttime lights are used to model spatially distributed greenhouse gas emissions from human settlements

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2013JD021296

Link to FFDAS data retrieval and visualization: http://hpcg.purdue.edu/FFDAS/index.php

Key Points:
- Gridded high-resolution time series of global fossil fuel CO_2 emissions is generated
- In situ remote sensing data integrated into fossil fuel data assimilation system
- Spatial patterns of recession are analyzed using CO_2 emissions time series

Supporting Information:
- Readme
- Texts S1 and S2
- Figure S1

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A multiyear, global gridded fossil fuel CO_2 emission data product: Evaluation and analysis of results

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Abstract High-resolution, global quantification of fossil fuel CO_2 emissions is emerging as a critical need in carbon cycle science and climate policy. We build upon a previously developed fossil fuel data assimilation system (FFDAS) for estimating global high-resolution fossil fuel CO_2 emissions. We have improved the underlying observationally based data sources, expanded the approach through treatment of separate emitting sectors including a new pointwise database of global power plants, and extended the results to cover a 1997 to 2010 time series at a spatial resolution of 0.1°. Long-term trend analysis of the resulting global emissions shows subnational spatial structure in large active economies such as the United States, China, and India. These three countries, in particular, show different long-term trends and exploration of the trends in nighttime lights, and population reveal a decoupling of population and emissions at the subnational level. Analysis of shorter-term variations reveals the impact of the 2008–2009 global financial crisis with widespread negative emission anomalies across the U.S. and Europe. We have used a center of mass (CM) calculation as a compact metric to express the time evolution of spatial patterns in fossil fuel CO_2 emissions. The global emission CM has moved toward the east and somewhat south between 1997 and 2010, driven by the increase in emissions in China and South Asia over this time period. Analysis at the level of individual countries reveals per capita CO_2 emission migration in both Russia and India. The per capita emission CM holds potential as a way to succinctly analyze subnational shifts in carbon intensity over time. Uncertainties are generally lower than the previous version of FFDAS due mainly to an improved nightlight data set.

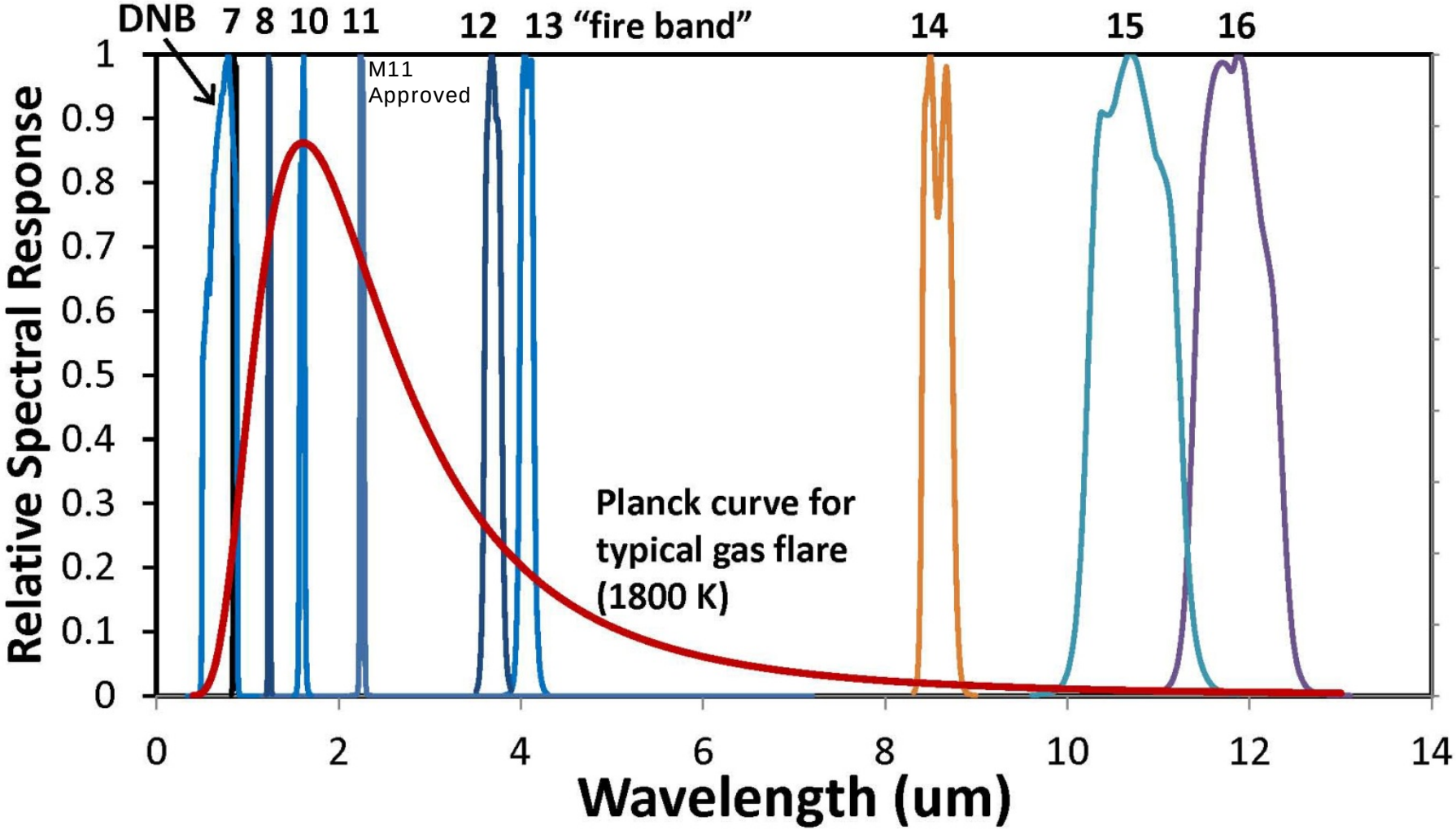
Current Status of NGDC DNB Products

- Nightly mosaics in png and Google Earth Super-overlay formats http://ngdc.noaa.gov/eog/viirs/download_ut_mos.html
- Rough monthly averages. 35 products are available at: 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)

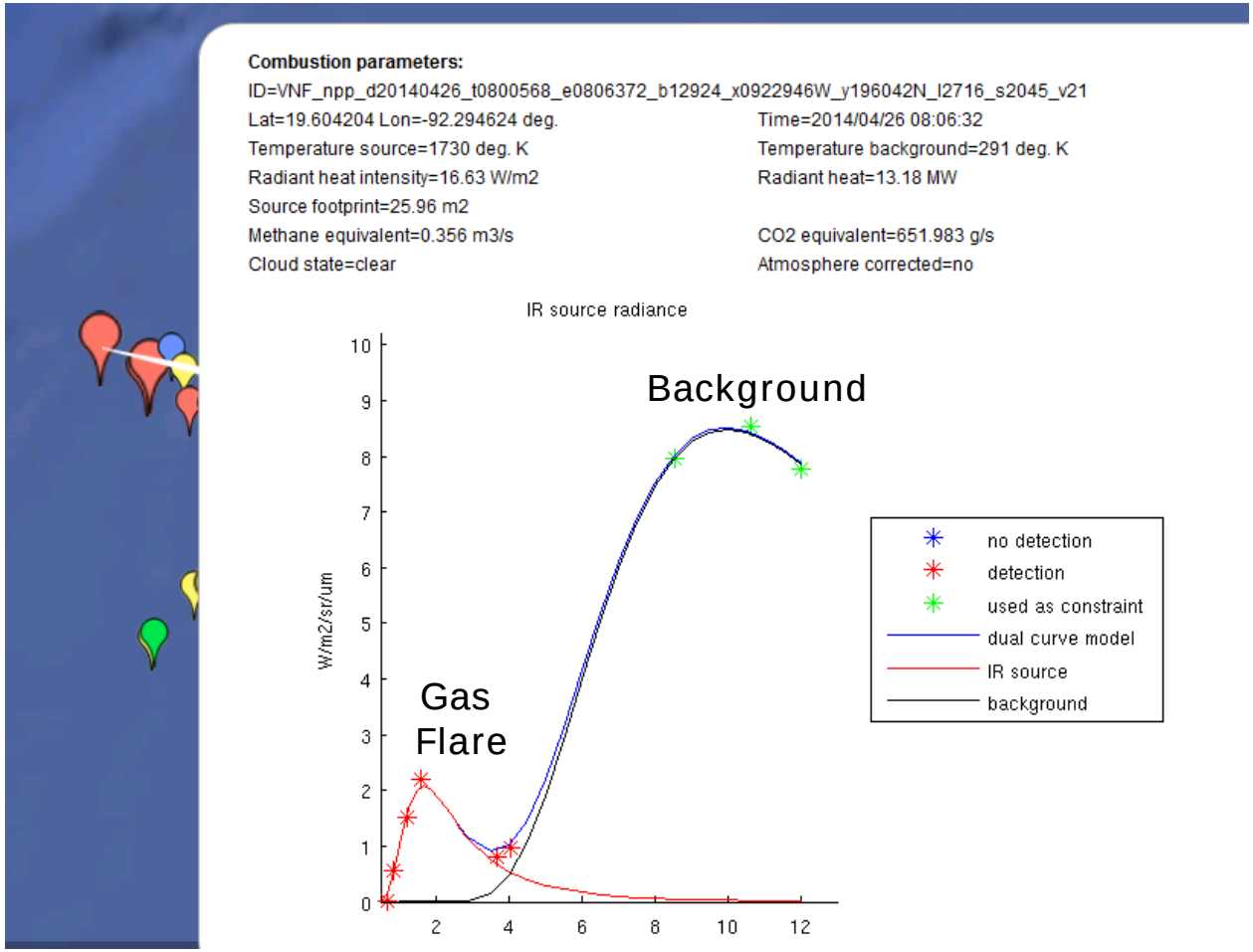
- A multispectral global fire product
- Makes use of near-infrared and shortwave infrared data.
- What is different from other global fire products?
  - Two independent hot source detection algorithms:
    - M10 in the shortwave infrared
    - M12-M13 in the midwave infrared
  - Dual Planck curve fitting (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

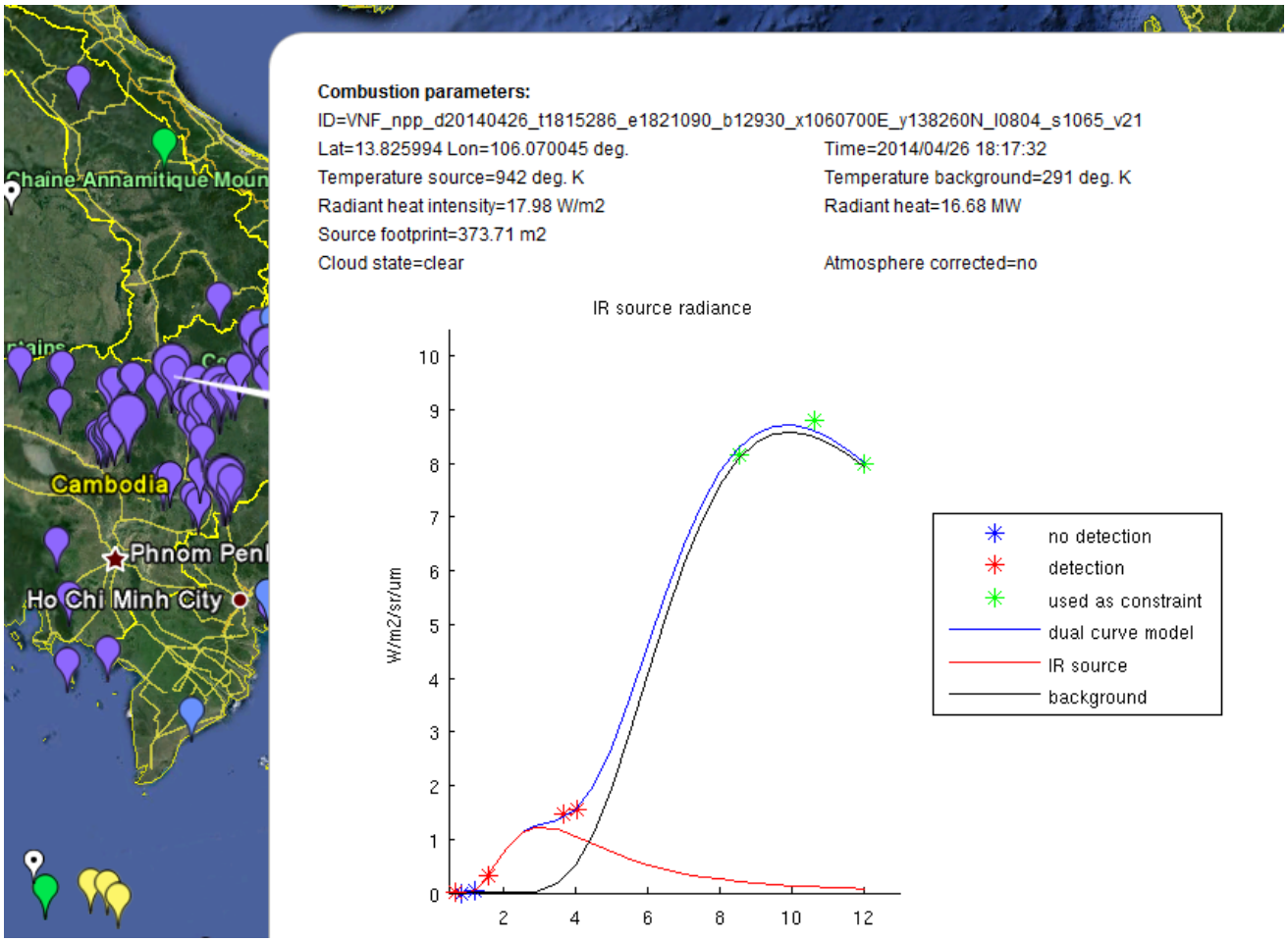
Why Multispectral?



To get at the Planck curves!

Daily files are in csv and kmz formats

Typical Biomass Burning Detection



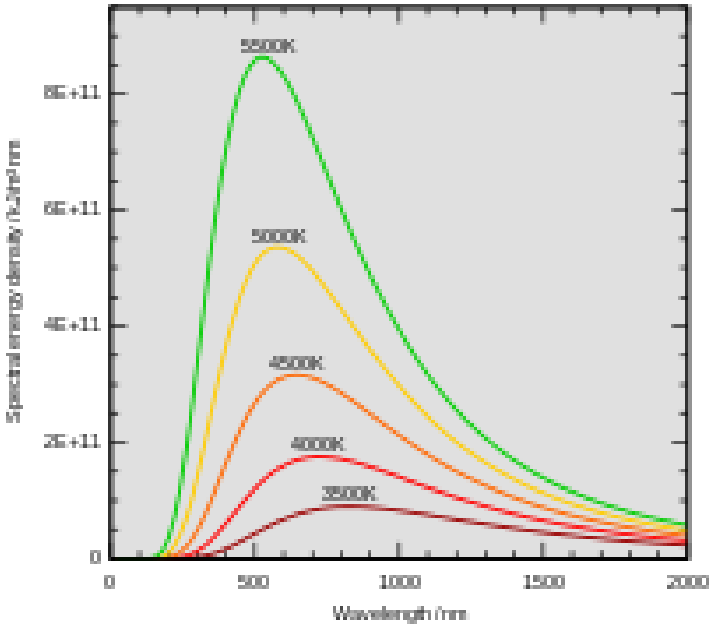
Lower temperature than gas flaring. Often these have larger source size than gas flares.

Temperature Calculation

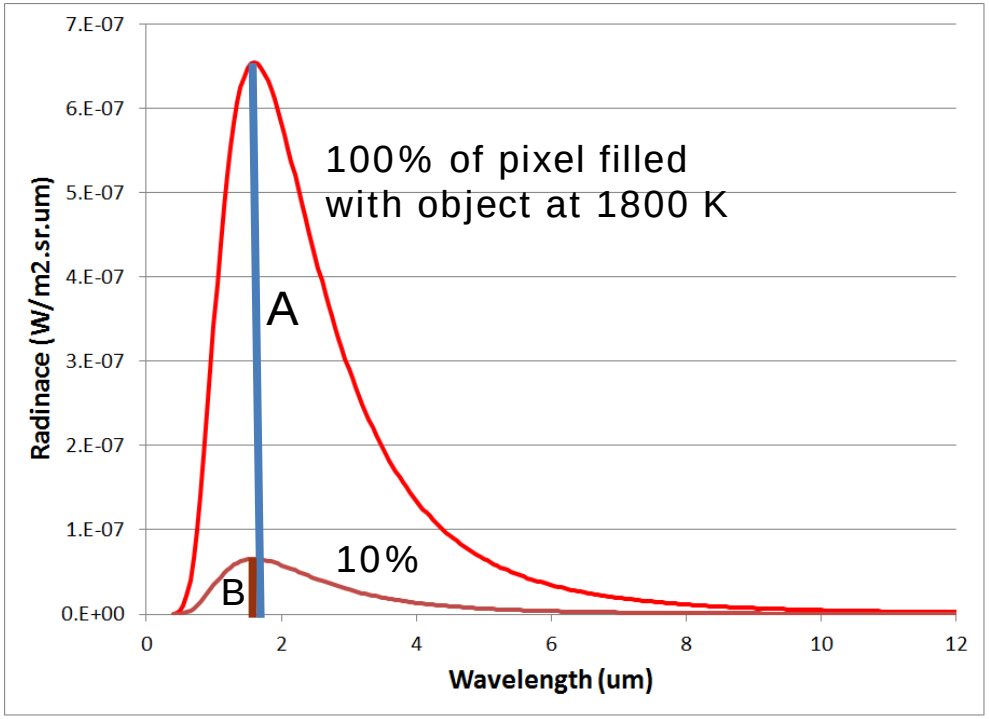
Wien's displacement law states that the black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature.

$$\lambda_{max} = C/T$$

where C is a constant equal to 2897
and T is the temperature in Kelvin

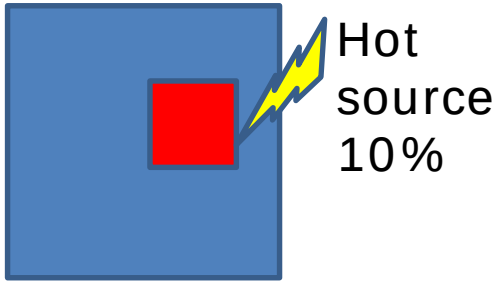


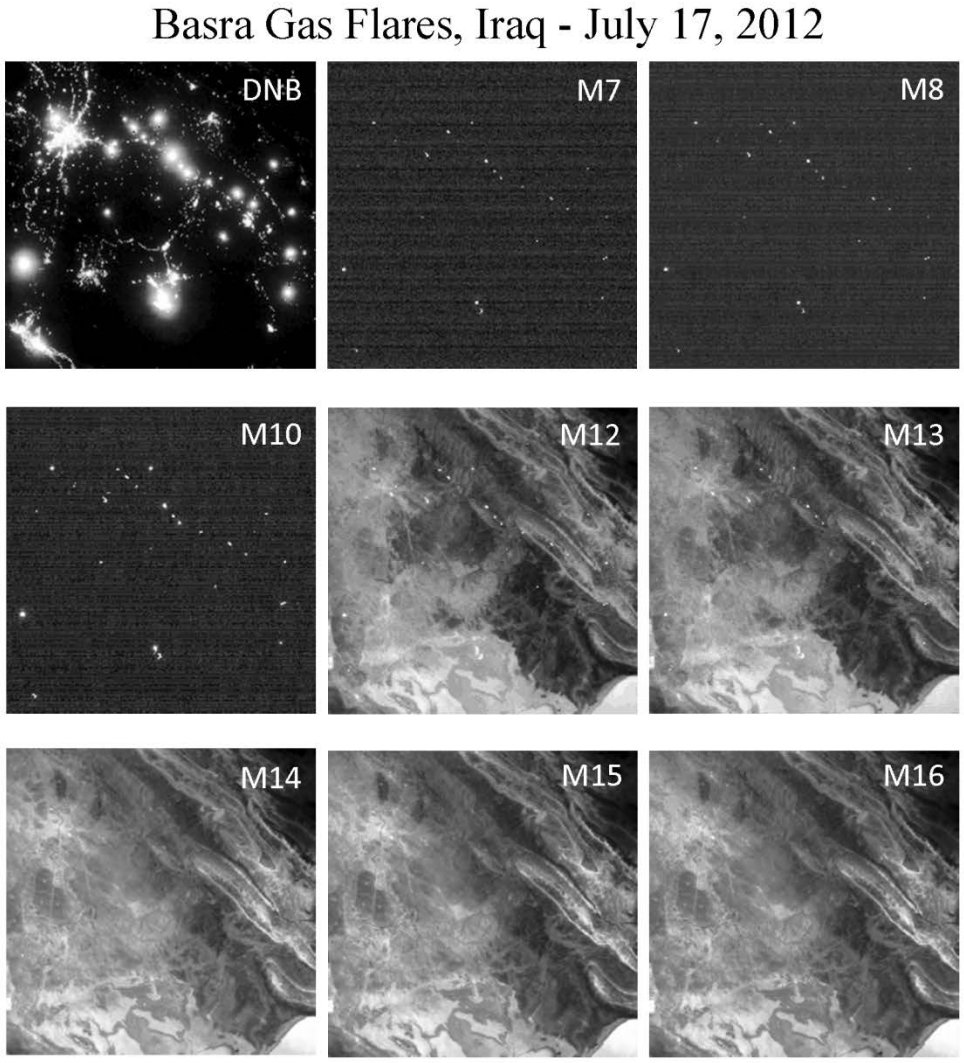
Subpixel source area calculation



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.

Full pixel footprint

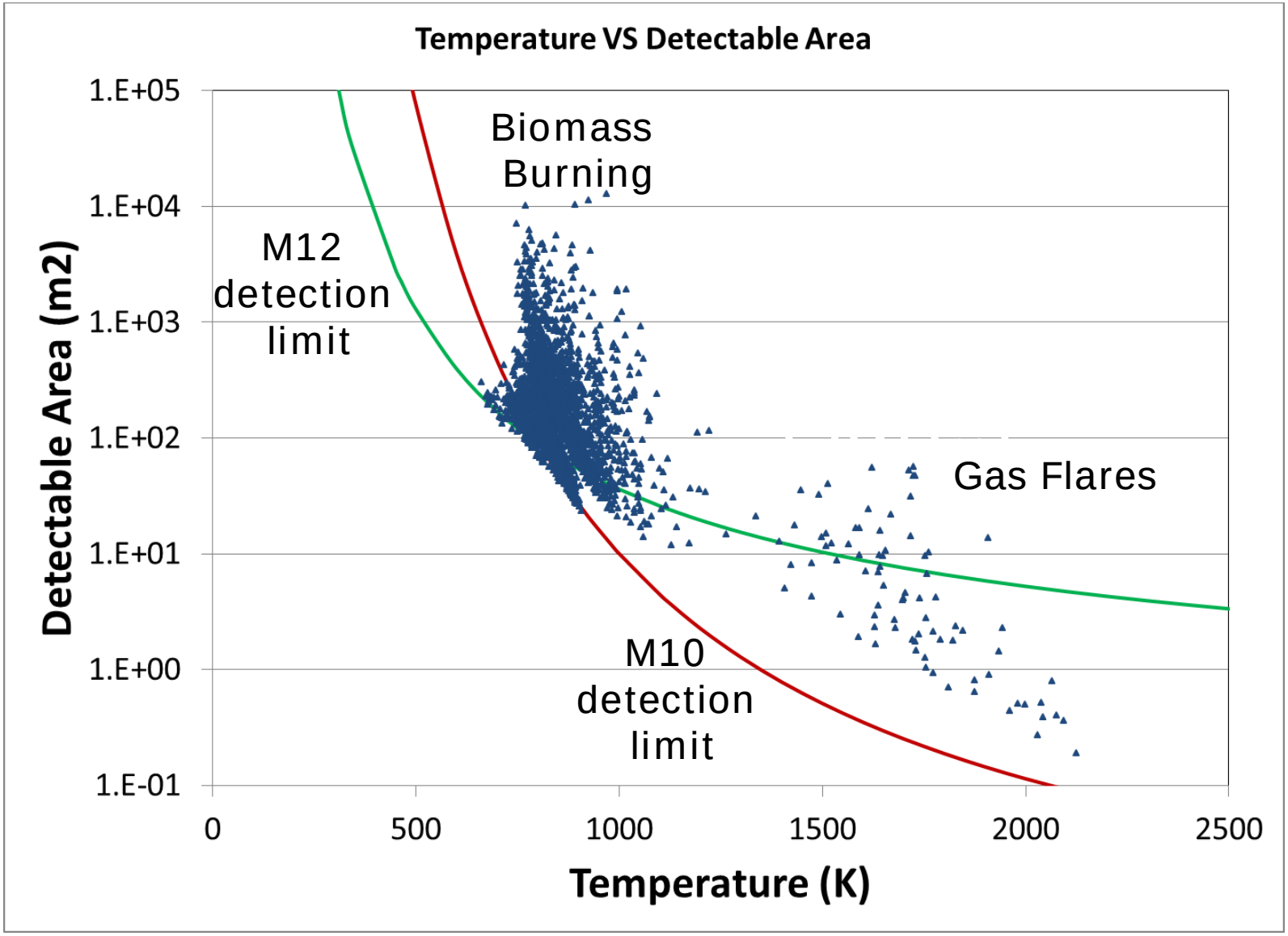




Gas flares are readily detected in the VIIRS M10 spectral band

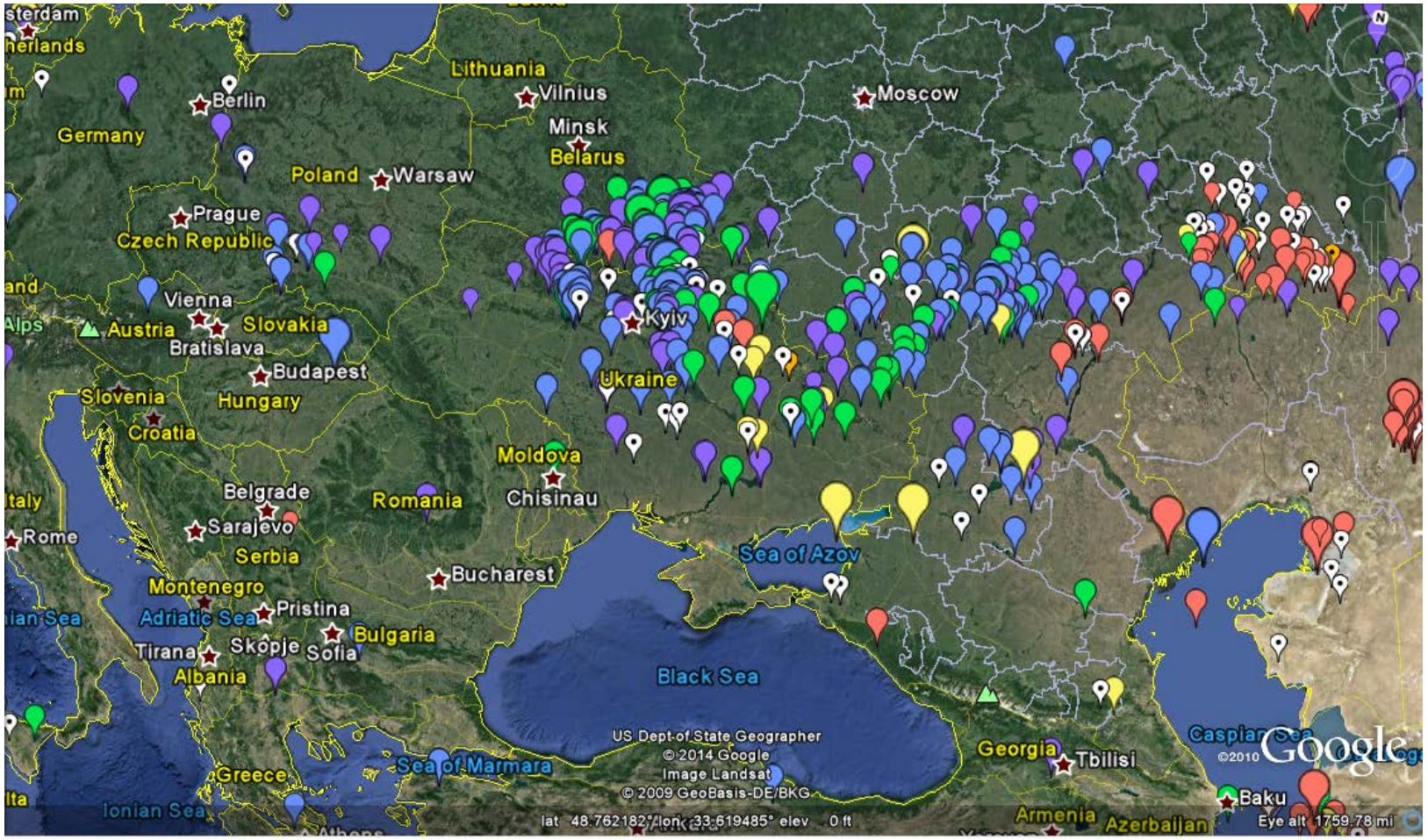
Detection Limits

At 1800 K flares as small as 0.25 m^2 are detectable



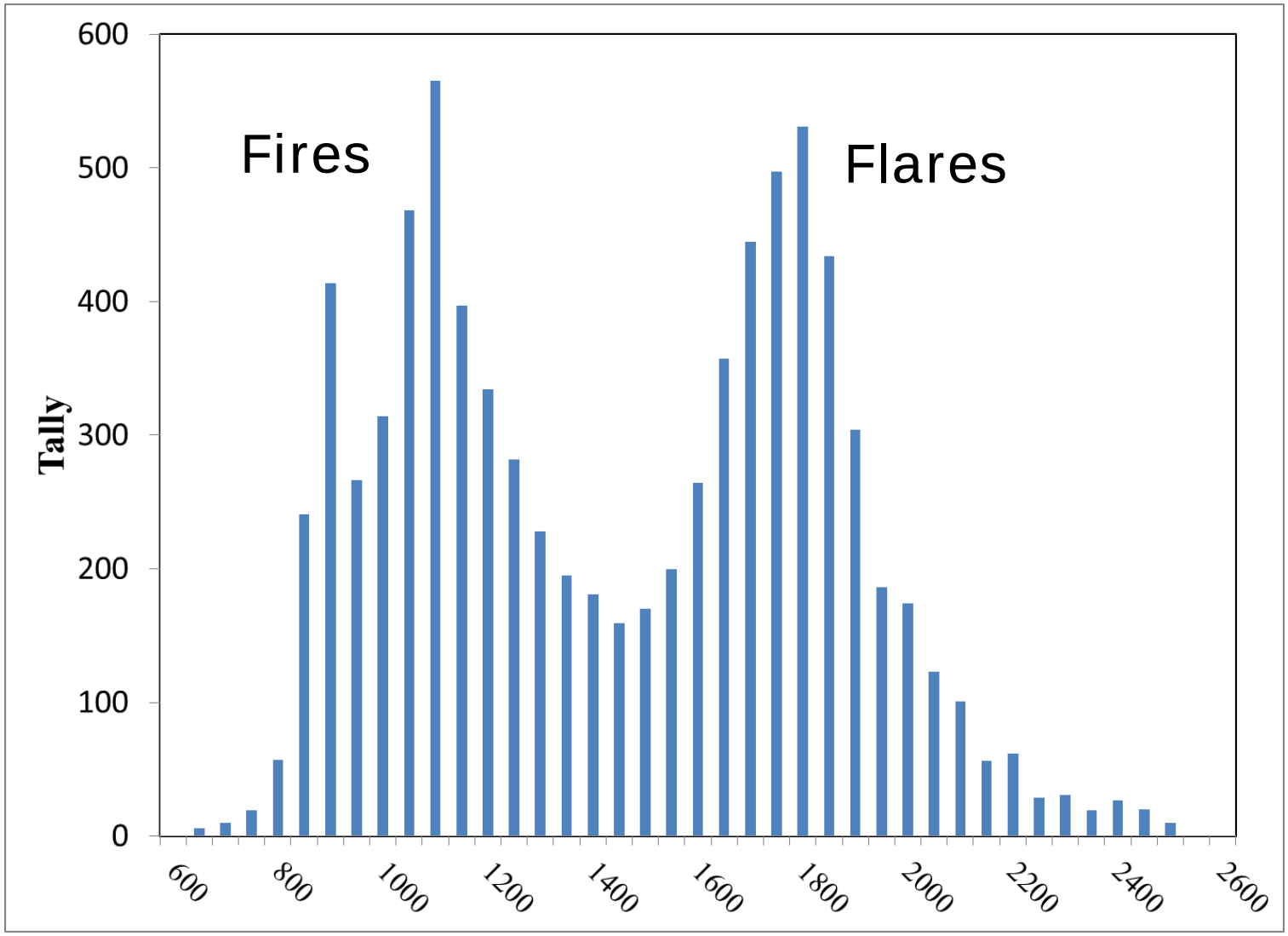
Daily VNF data are available at:

http://ngdc.noaa.gov/eog/viirs/download_viirs_fire.html



Current processing typically runs with a four hour delay

Temperatures are bimodal



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” inititative.

UN Initiative to end routine flaring by 2030

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Zero Routine Flaring by 2030

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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
Read More »

Initiative | Q&A | Quick Facts | Endorsers | Get Involved | Related Information

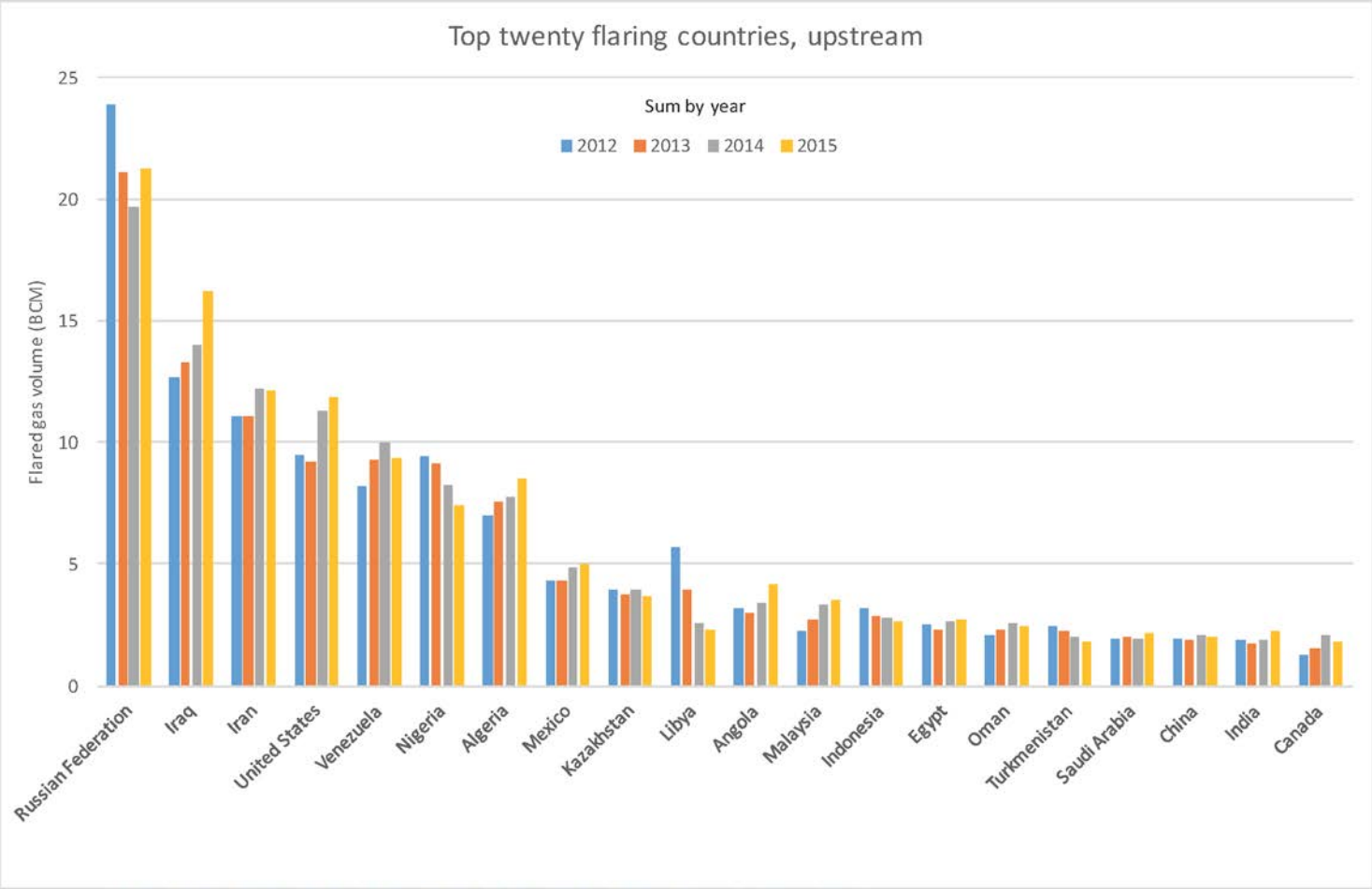
Flaring in the News

During oil production, associated gas is produced from the reservoir together with the oil.

How will progress be tracked? VIIRS!

Upstream flaring 2012-2015

Units = billion cubic meters (BCM)



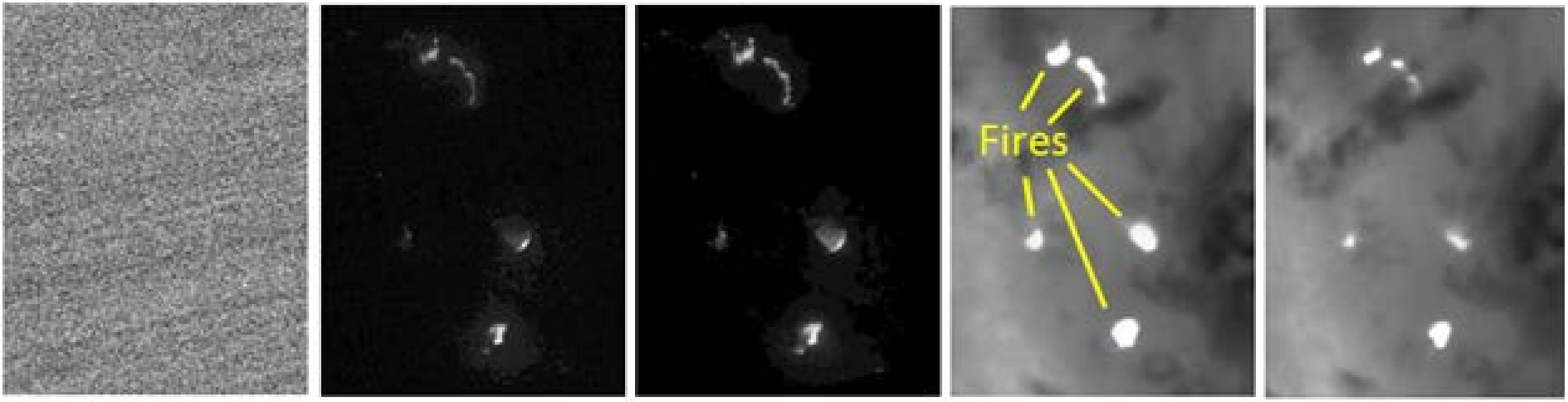
Distinguishing flaming and smoldering combustion with nighttime Landsat 8

- 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



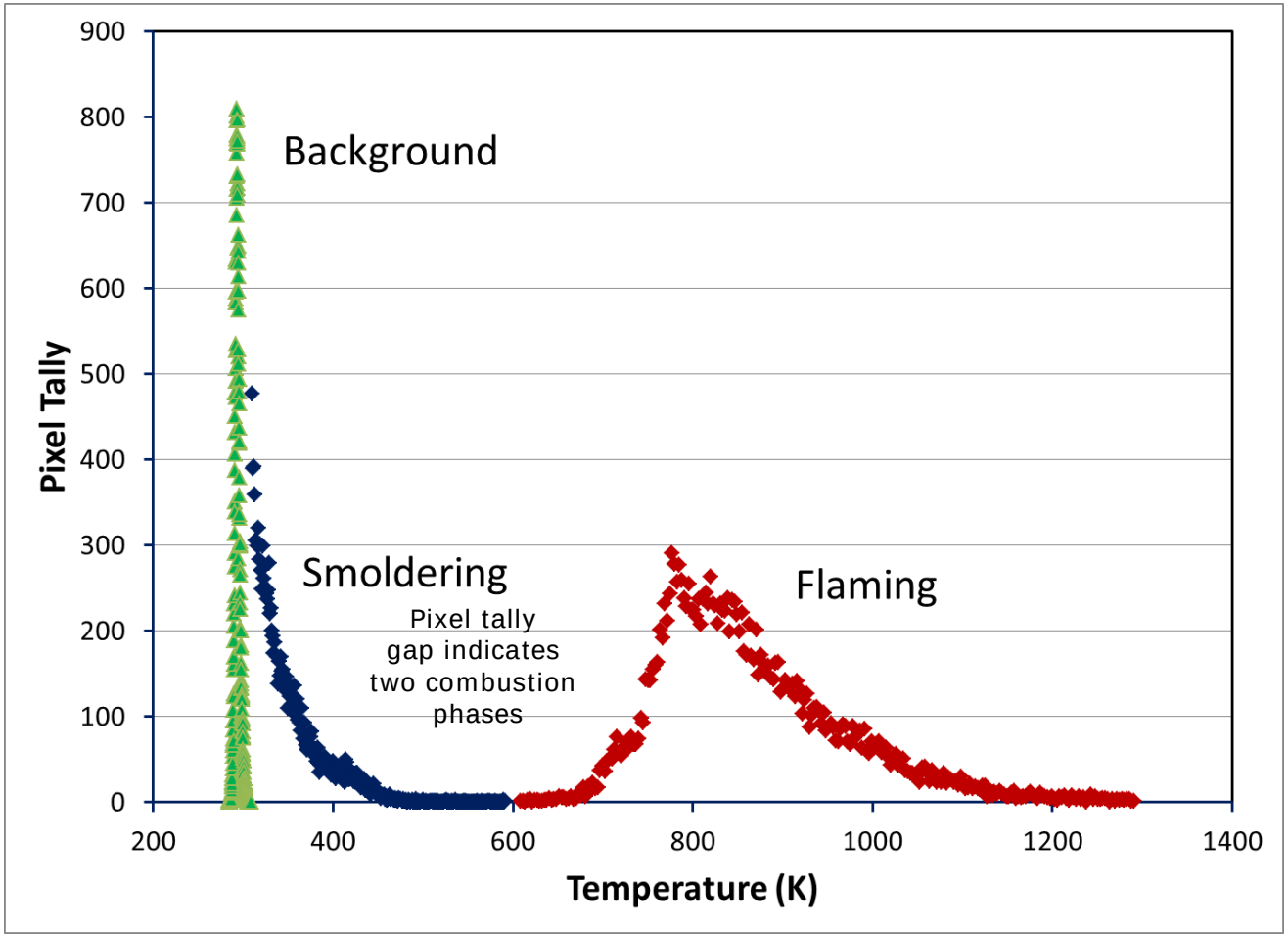
Band 5 = 0.86 um | Band 6 = 1.6 um | Band 7 = 2.2 um | Band 10 = 11 um | Band 11 = 12 um

Flaming

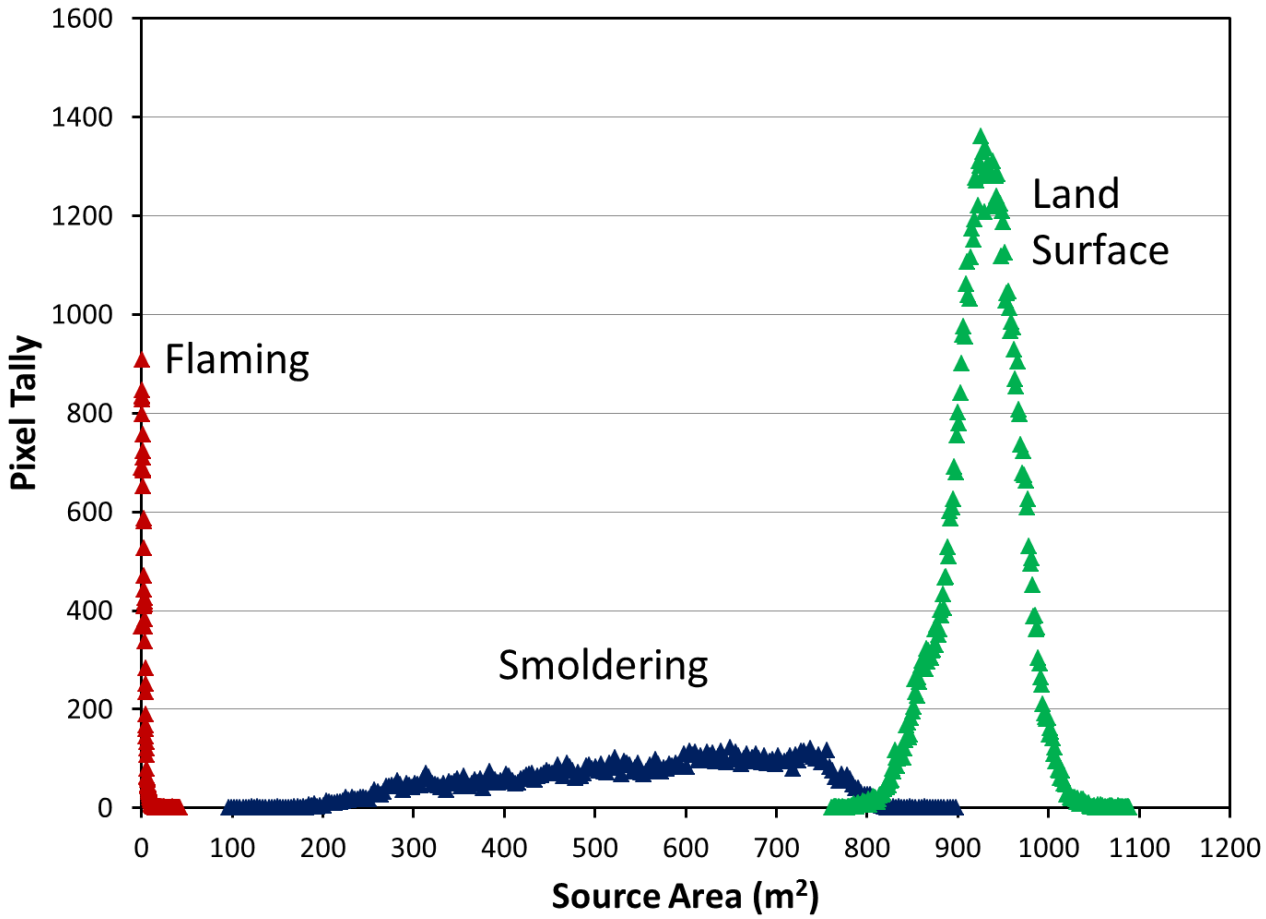
Smoldering

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