Progress on Estimation of Global Gas Flaring With VIIRS Data

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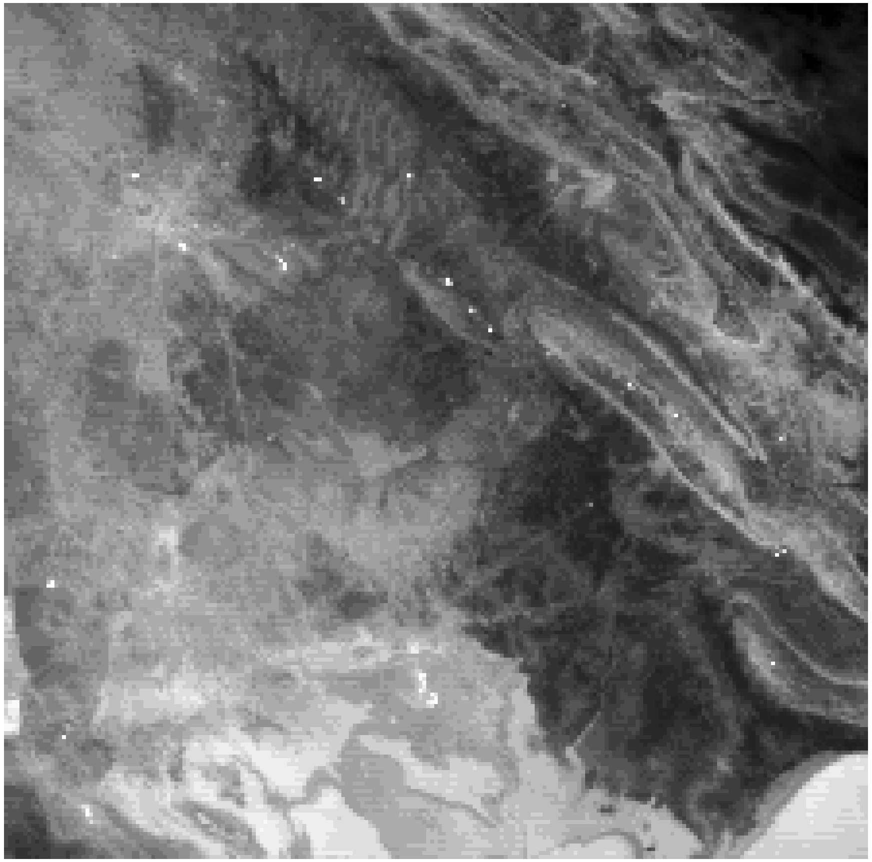
Abstract

- We report on a global map of gas flares and preliminary estimates of flared gas volumes for 2012 and 2014 derived from data collected by the Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS).
- Nighttime VIIRS data were processed to take advantange of clear detections of gas flares in spectral bands designed for daytime imaging of reflected sunlight. At night these spectral channels provide unambiguous observations of combustion sources worldwide.
- The spectral bands utilized span visible, near-infrared (NIR), short-wave infrared (SWIR) and mid-wave infrared (MWIR).
- Planck curve fitting of the hot source and background radiances yield temperature (K) and emission scaling factor. Additional calculations are done to estimate source size (square meters), radiant heat intensity (W/m^2) and radiant heat (MW).
- Nightfire successfully retrieved temperature estimates ranging from 500 to 3000 K. Temperatures derived from Planck curve fitting allow gas flares to be separated from industrial sites and biomass burning
- A calibration for estimating flared gas volumes was developed based on reported data from specific regions.

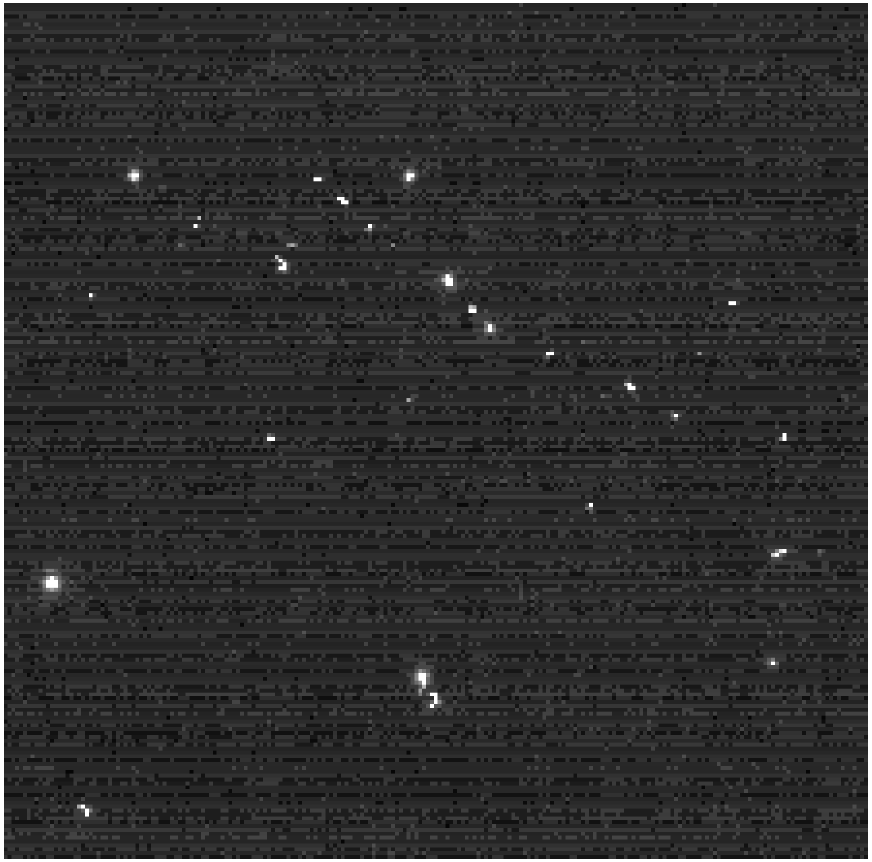
What makes VIIRS data so great?

At night the VIIRS collects data in three daytime imaging bands: M7, M8, and M10.
The nighttime M10 data have a remarkable ability to detect combustion sources!

M13 "Fire Band"

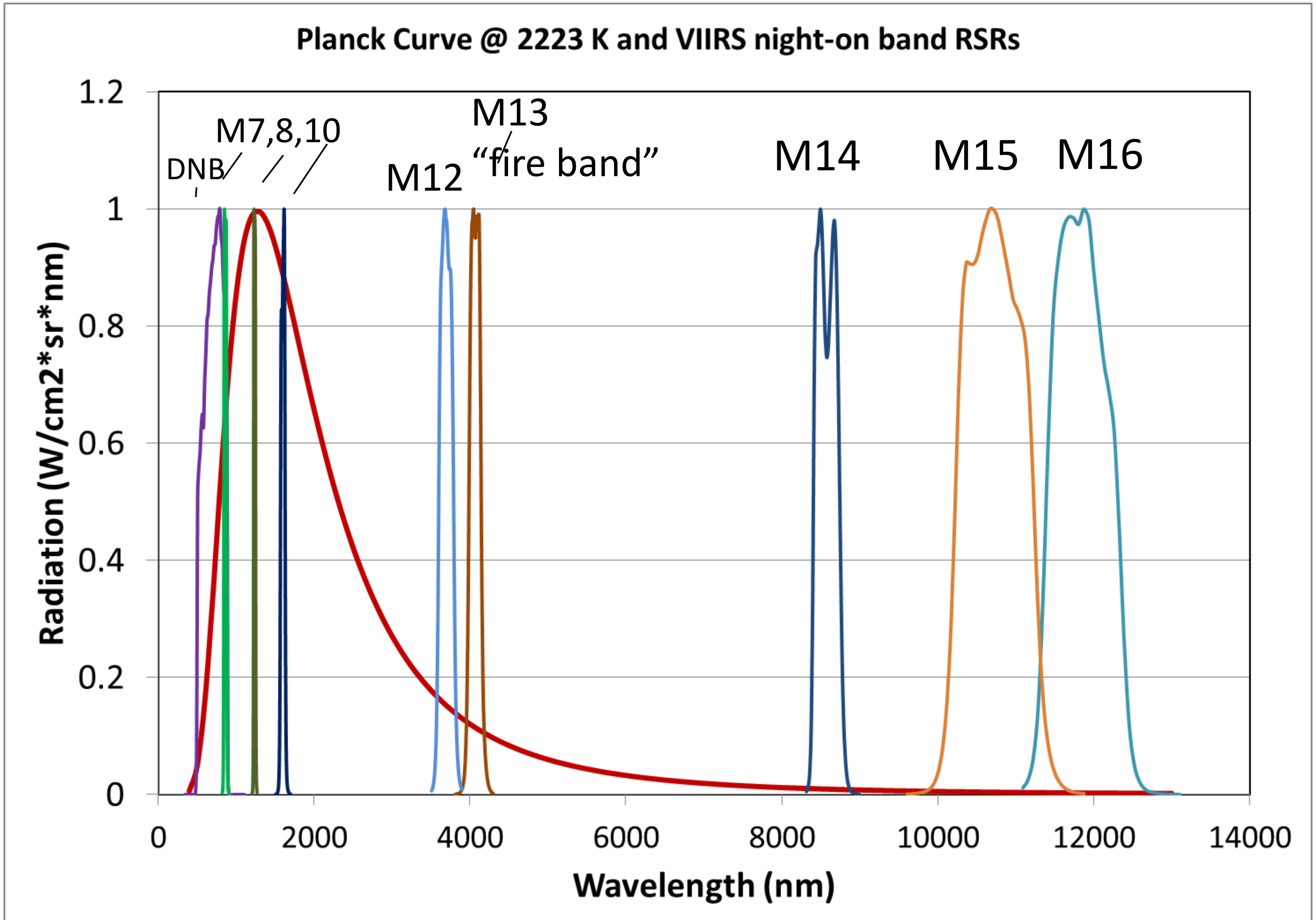


M10



Detection of Combustion Sources Basra, Iraq Region at Night
July 17, 2012

VIIRS collects visible, NIR and SWIR at nights



VIIRS is unique in recording NIR and SWIR channels at night.

Combustion sources stand out clearly against the noise background – with no detection of lights.

Methane burns (in air) at 2223 K.

Estimating Radiant Heat

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

$$J = \varepsilon\sigma T^4$$

$$RH = J \times S_{pixel} \sim \sigma T^4 \times S_{source}$$

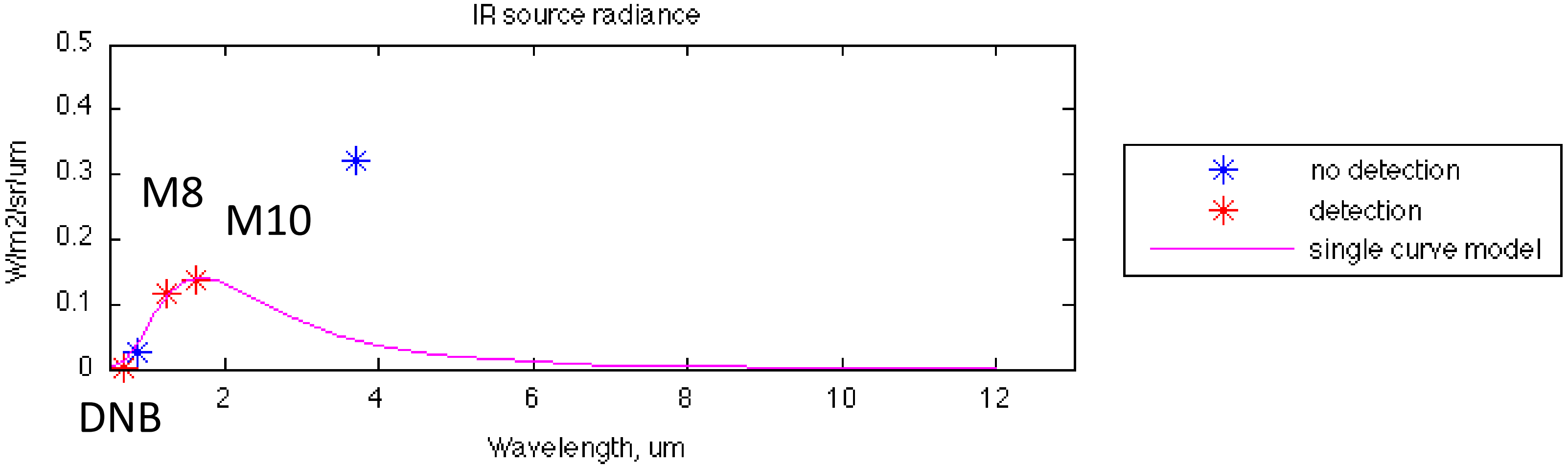
B is the spectral radiance of the black body
λ is wavelength, um
k_B, h, σ are the Boltzmann, Planck, and Stefan-Botzmann constatns
c is the speed of light,
T is its temperature, degrees K
ε is the emission scaling factor (ESF)
J is the radiant heat intensity, Watts/m^2/sec
S is the full pixel or subpixel fire footprint, m^2
RH is the radiant heat, Watts/m^2

Planck curve is fit using a simplex algorithm to match the observed radiances with temperature and emission scaling factor

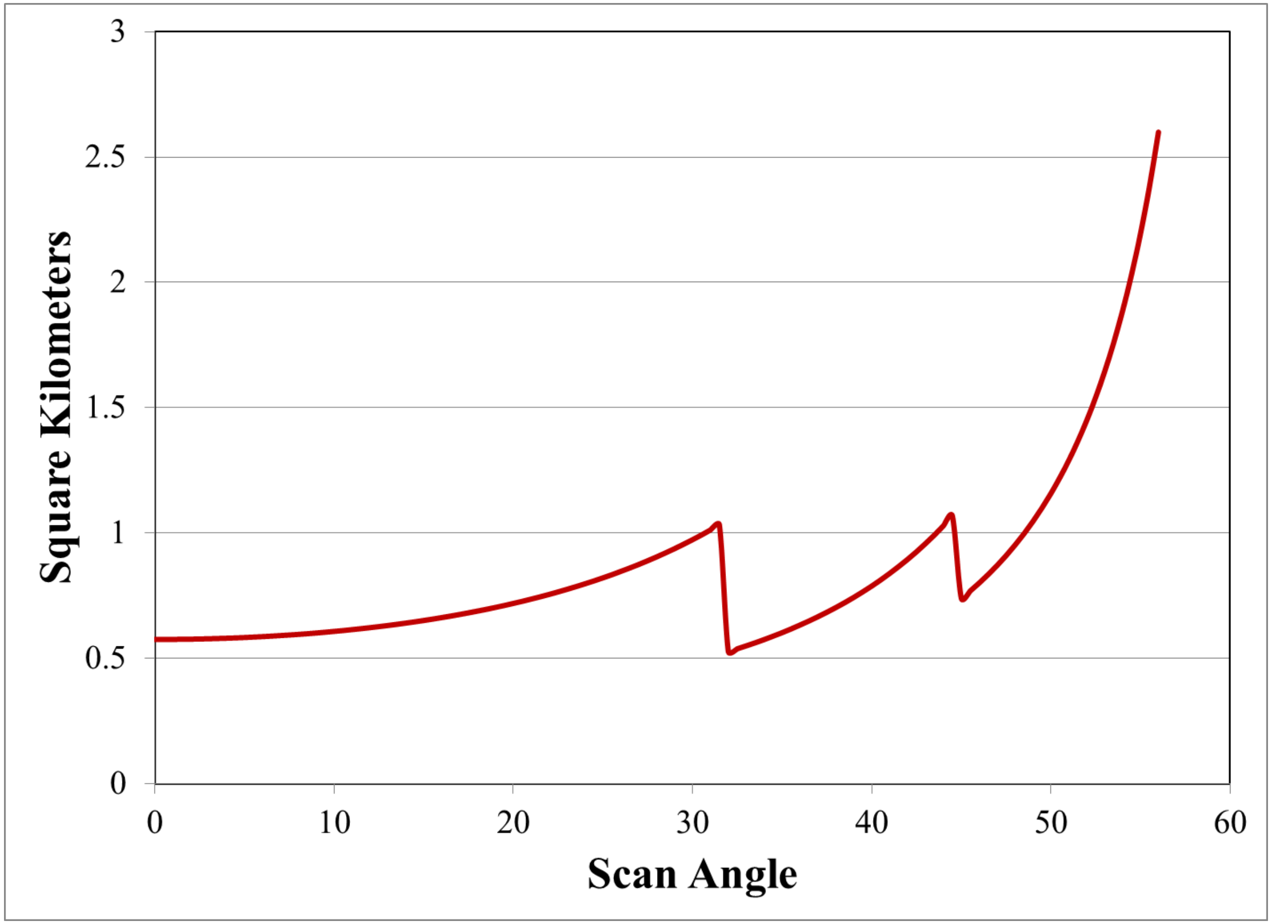
Radiant heat intensity is calculated through application of the Stephan-Bolzmann Law

Radiant heat is intensity multiplied by pixel footprint

Example of the Single Planck Curve Fitting



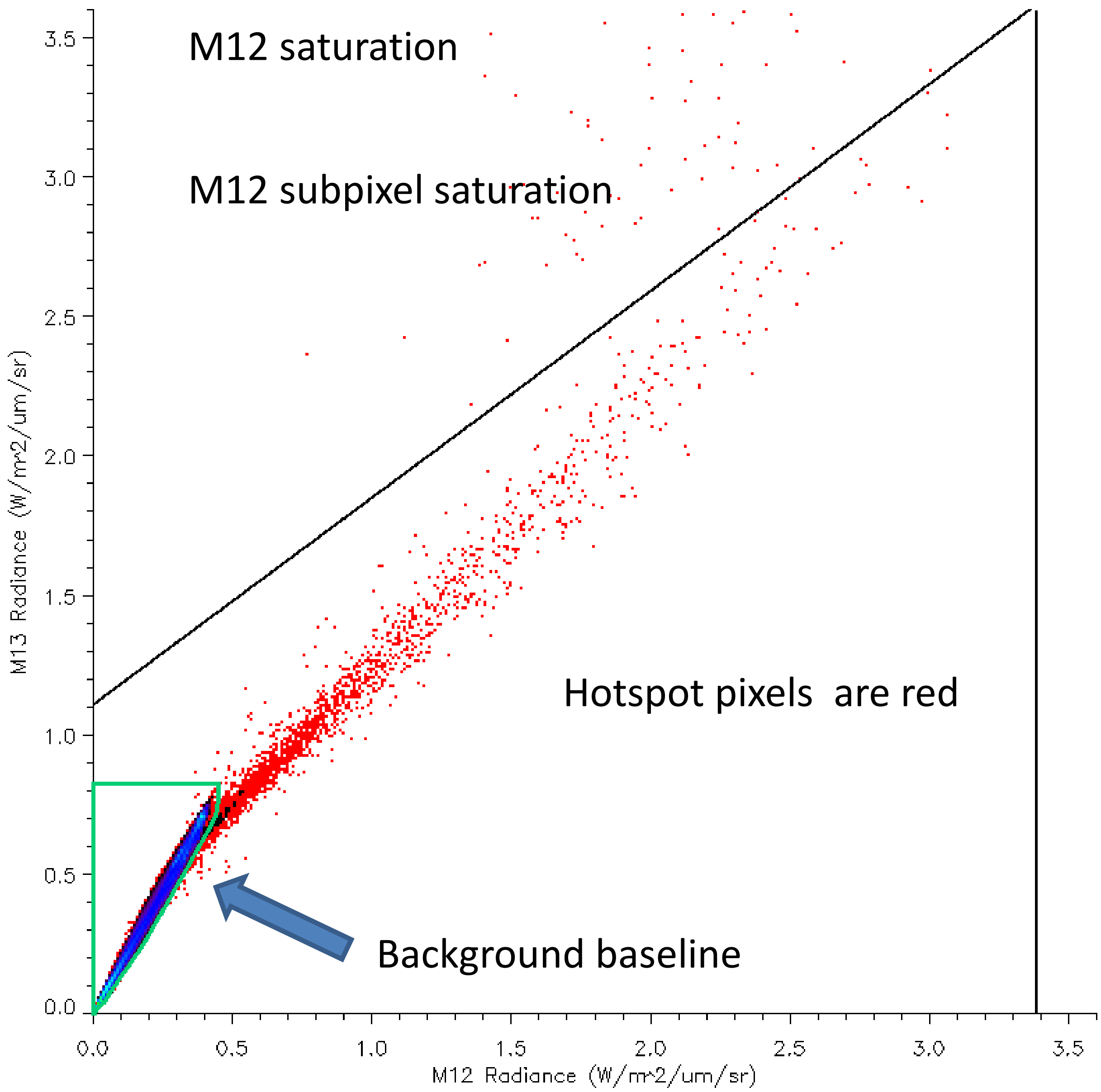
Estimating Subpixel Source Size



Hot objects appear as gray-bodies because they occupy a small fraction of the pixel.

The ESF is multiplied by the pixel footprint size (on the ground) to estimate the size of the hot source in square meters.

M12-M13 Hot Spots Detector



A new algorithm was developed to detect VIIRS pixels containing combustion sources using the mid-wave infrared channels (M12 and M13). The algorithm complements the original M10 detection algorithm.

Combustion parameters:

ID=VNF_npp_d20150401_t0831086_e0832328_b17748_x0920423W_y193997N_l0043_s2760_v21

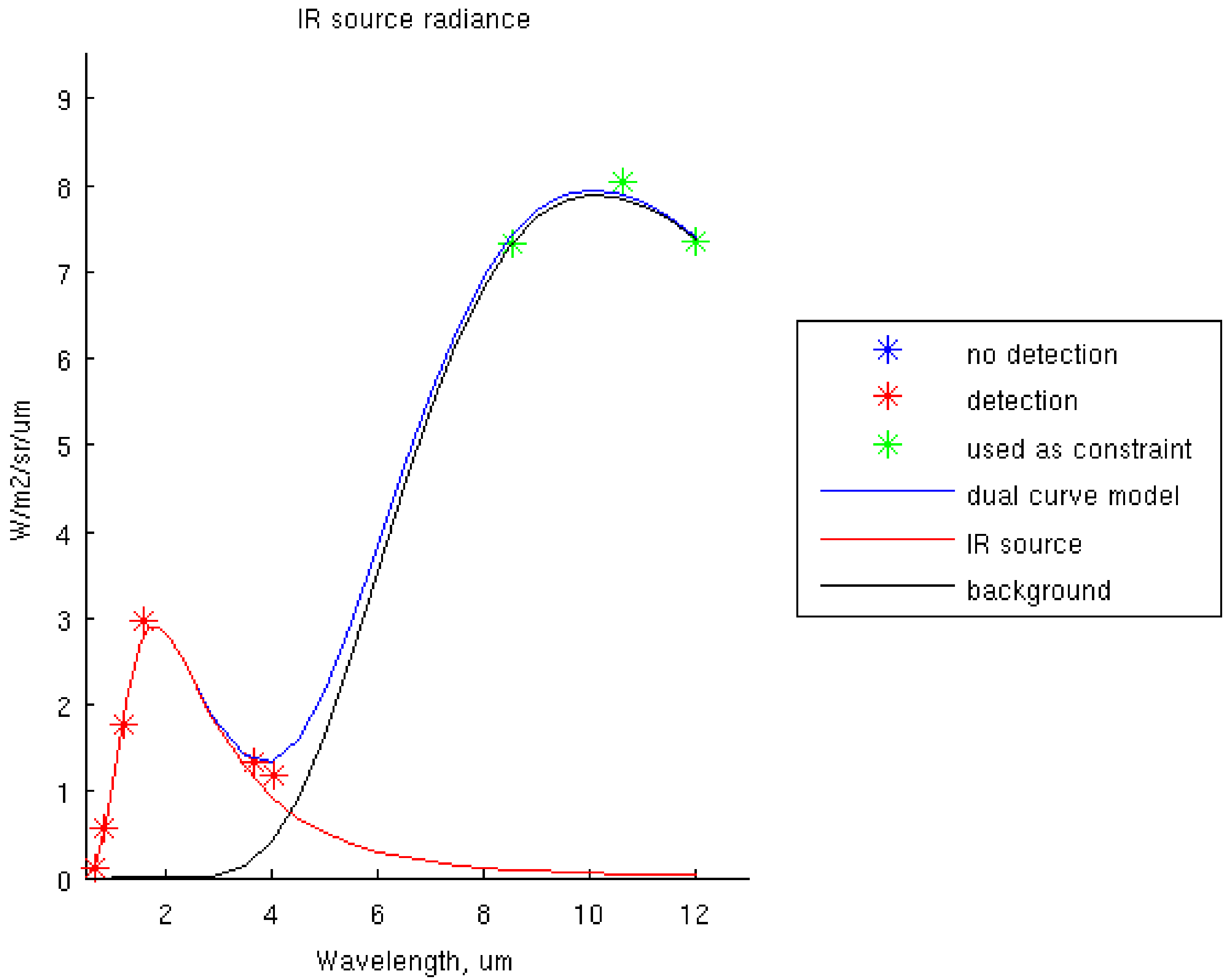
Lat=19.399670 Lon=-92.042252 deg. Time=2015/04/01 08:31:47

Temperature source=1601 deg. K Temperature background=286 deg. K

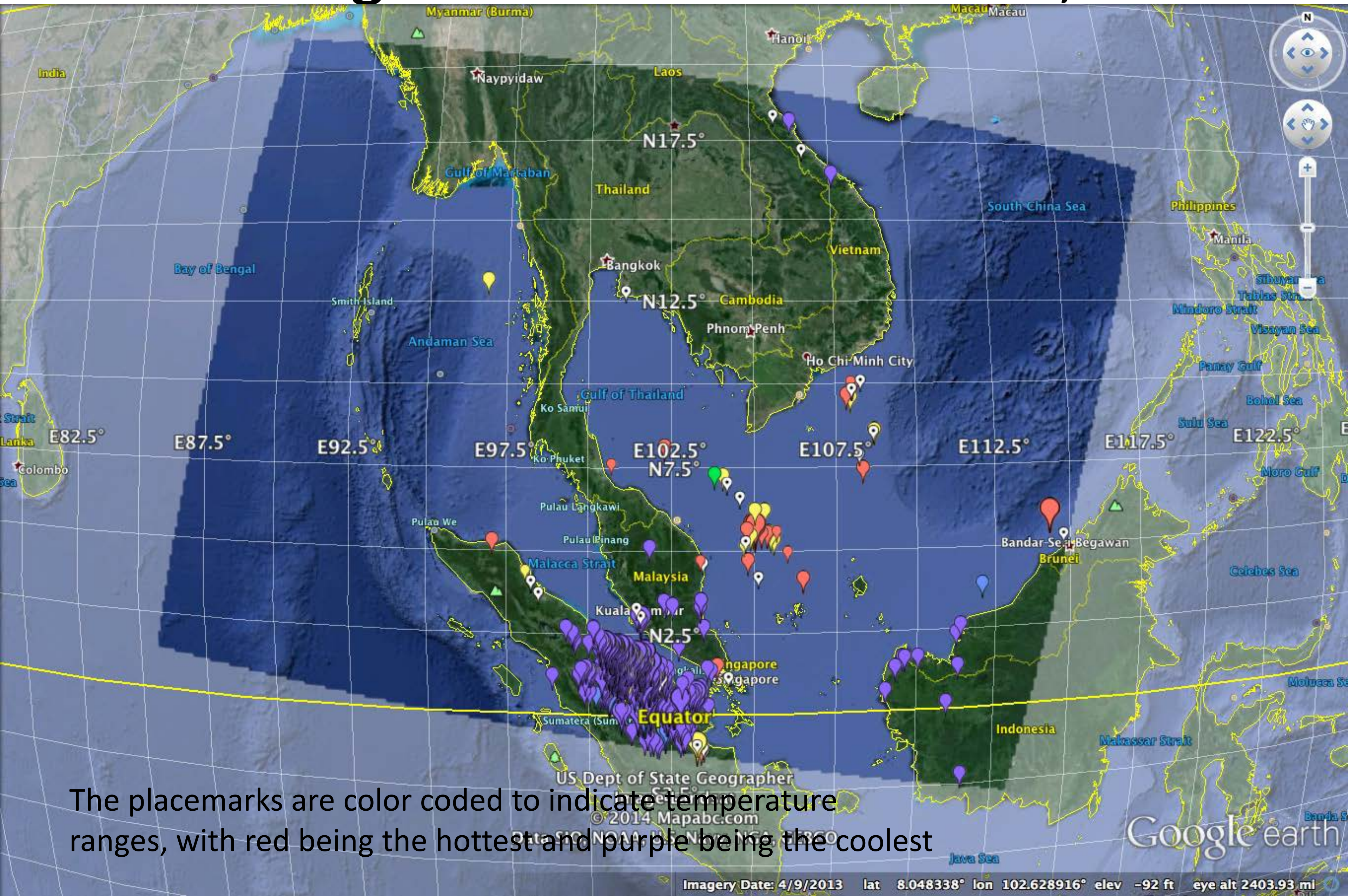
Radiant heat intensity=25.20 W/m2 Radiant heat=24.84 MW

Source footprint=66.64 m2

Cloud state=uknlown Atmosphere corrected=no

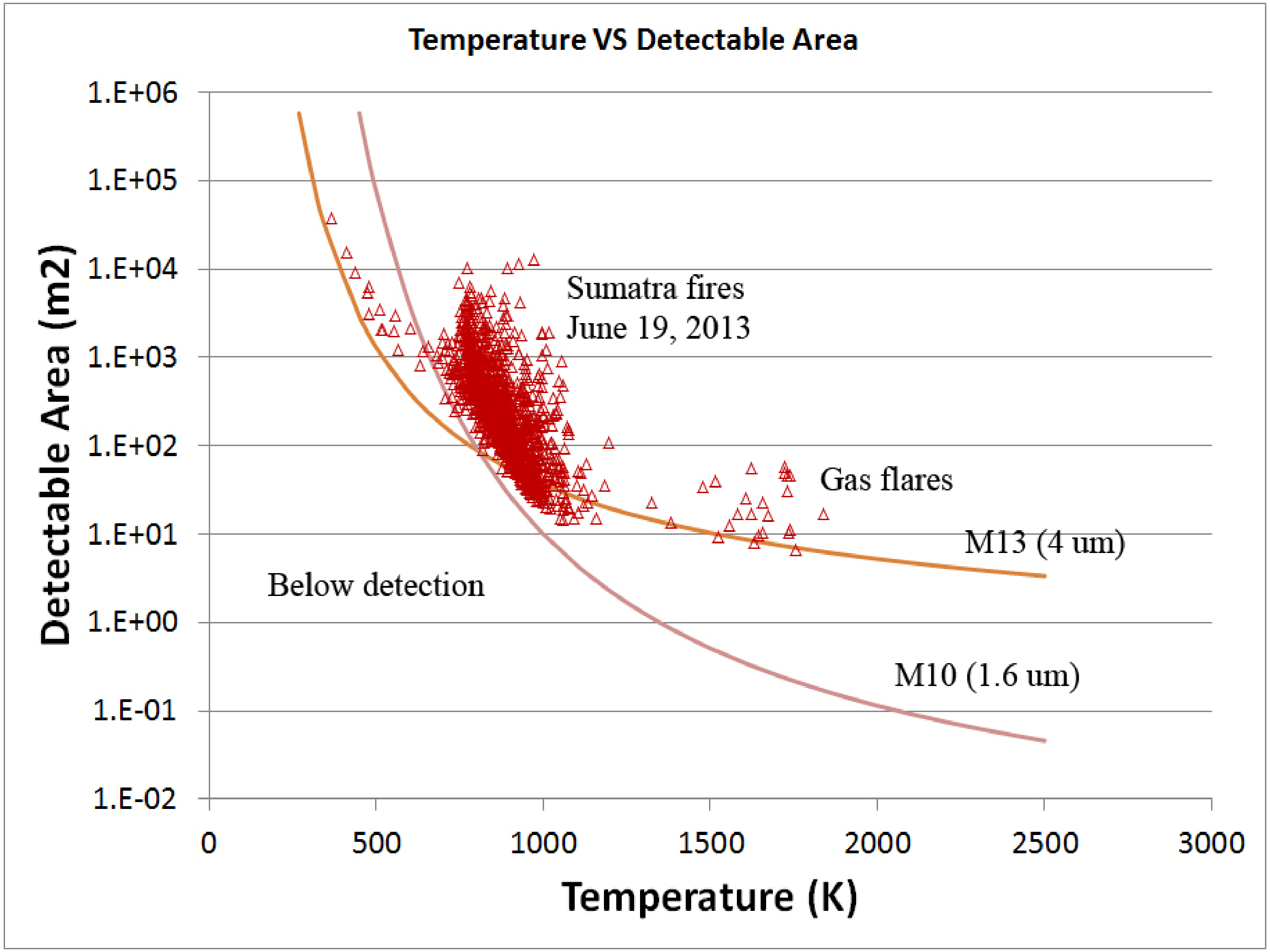


VIIRS Nightfire KMZ for June 19, 2013

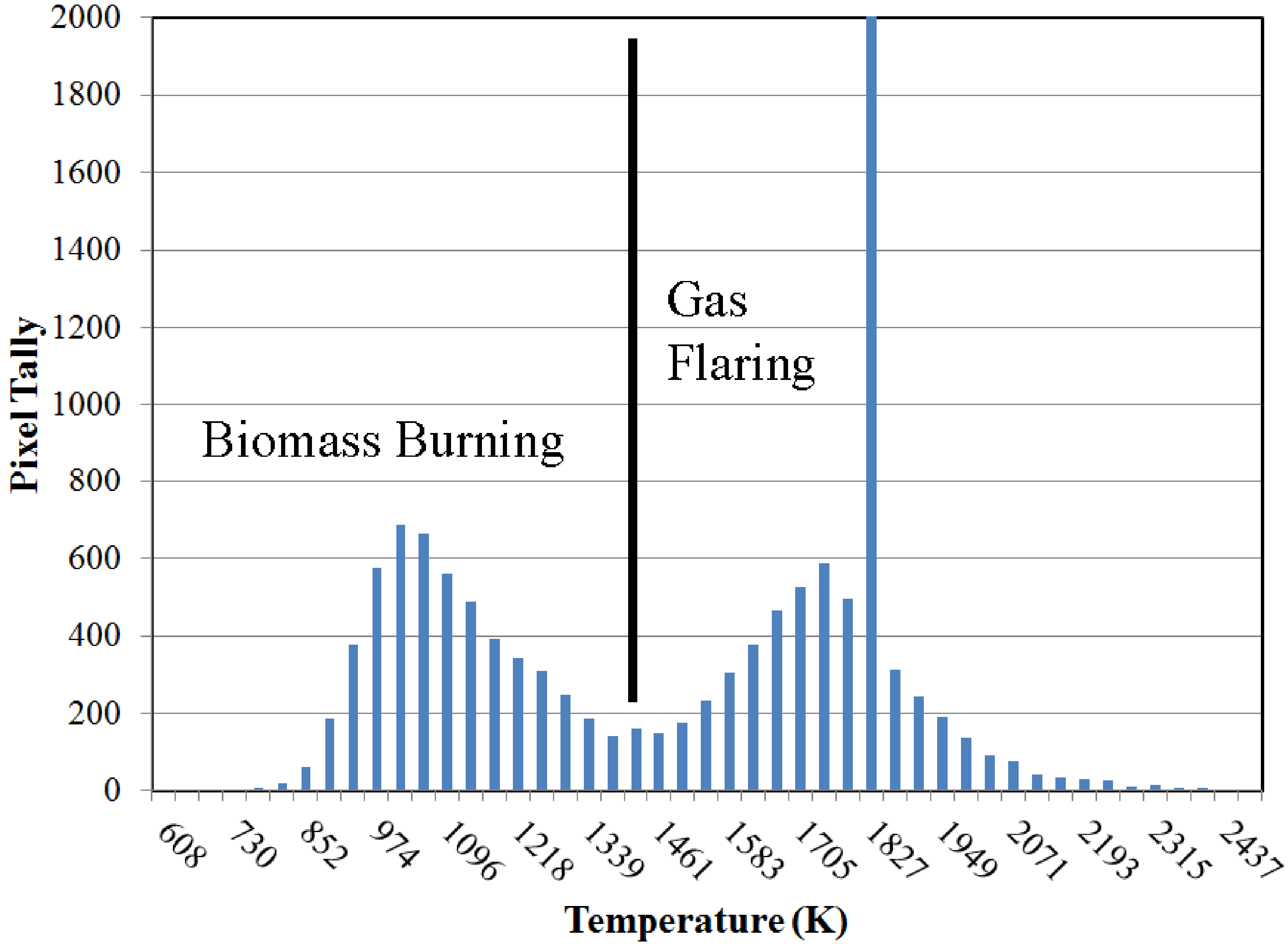


The placemarks are color coded to indicate temperature ranges, with red being the hottest and purple being the coolest

Sensitivity of Dual-Curve Fit



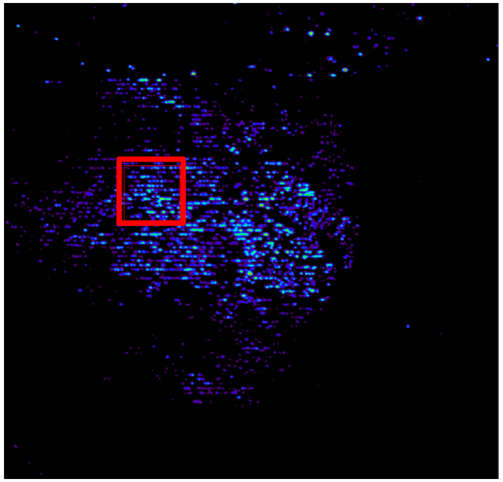
Bimodal Temperature Distribution

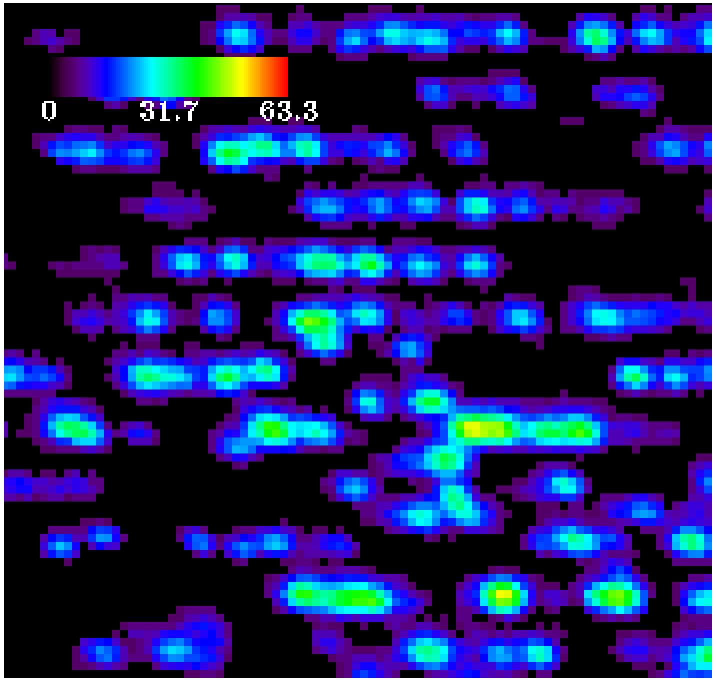


Global Mapping of Gas Flares

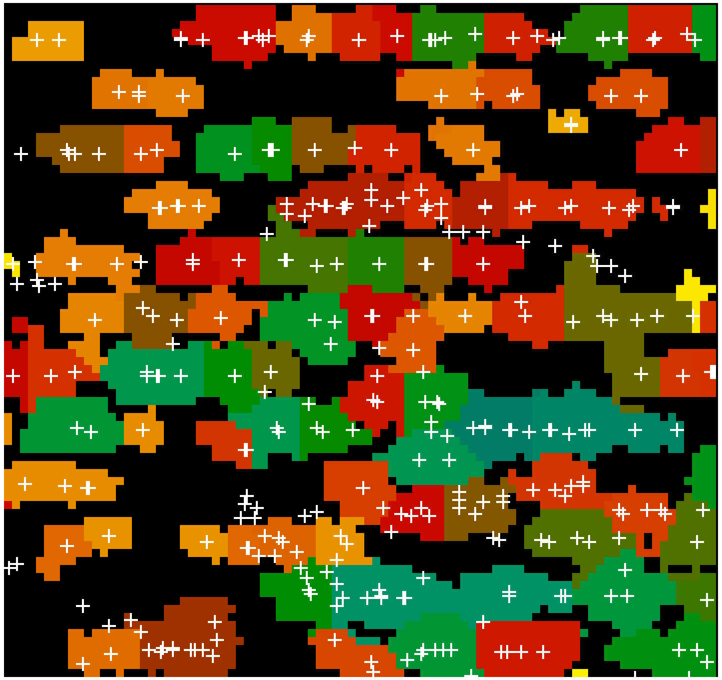
- The extended records of local maxima detections are composited into a global 15 arc second grid:
  - Number of detections (n)
  - Percent frequency of detection (pct)
  - Average temperature (K)
- Filtering to remove fires (biomass burning), volcanoes and non-flaring industrial sites:
  - Remove sites with $n < 3$.
  - Remove sites with $K < 1500$.
- Manual editing to clean out residual fires.
- Watershed to identify separable features and mark centroid locations: 10 000 flares worldwide

Watershed Cluster Analysis
Percent frequency of detections
North Dakota





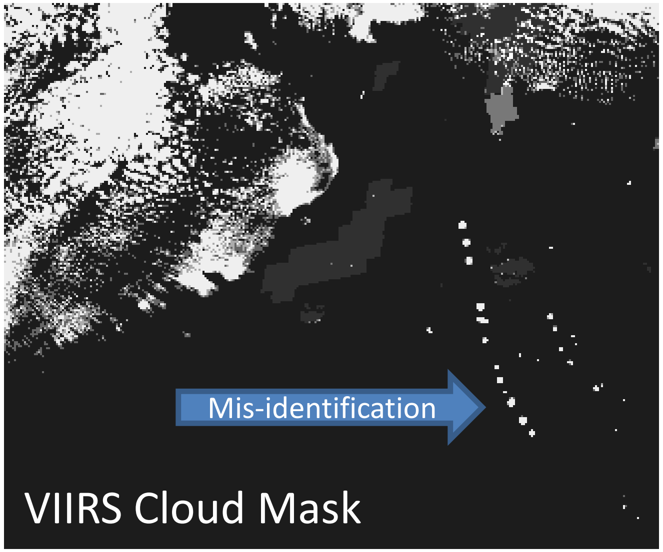
2012 Feb. ~ 2014 Dec.
Fire observation percentage



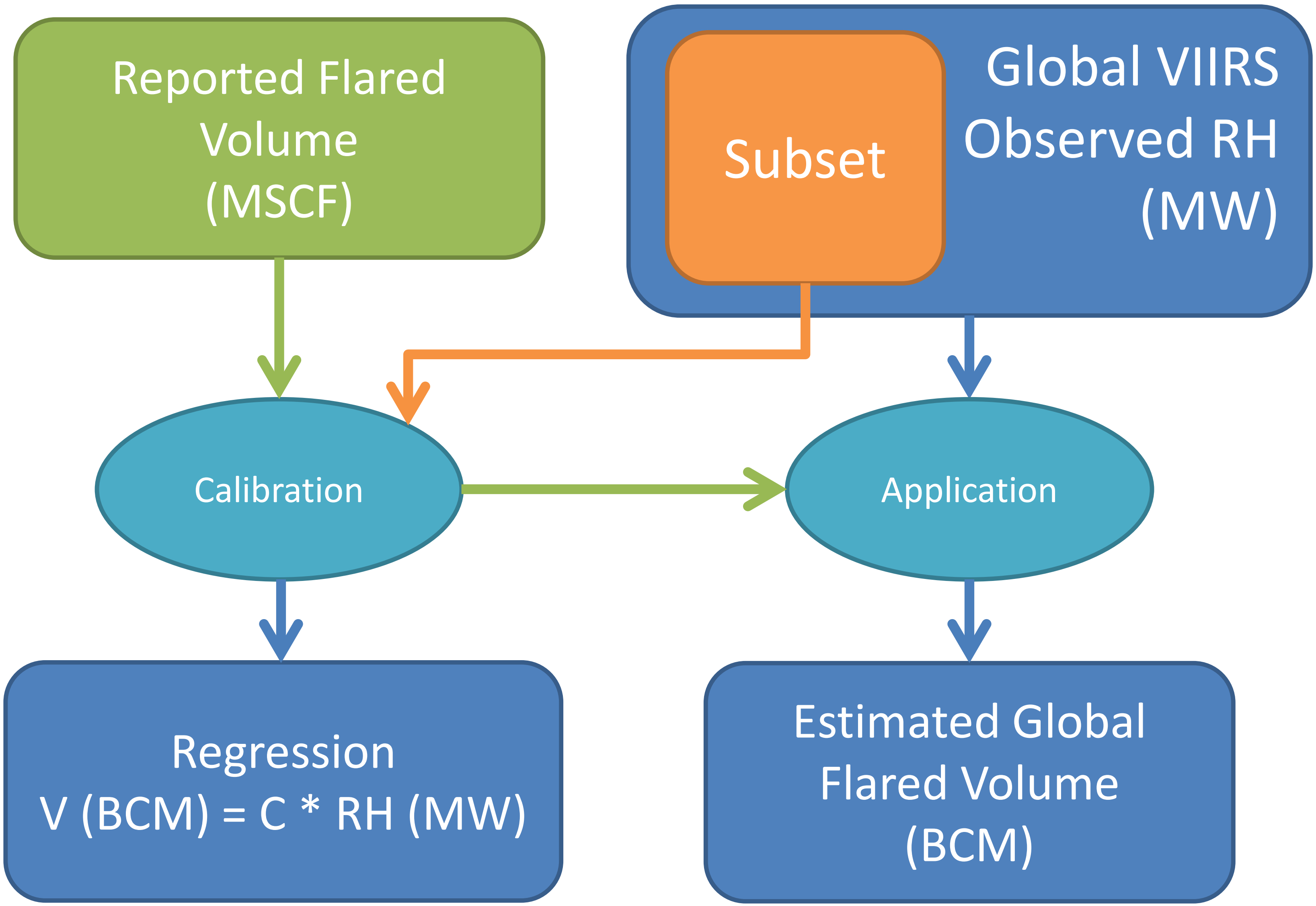
Identified clusters w/
Reported well location

Cloud state filtering

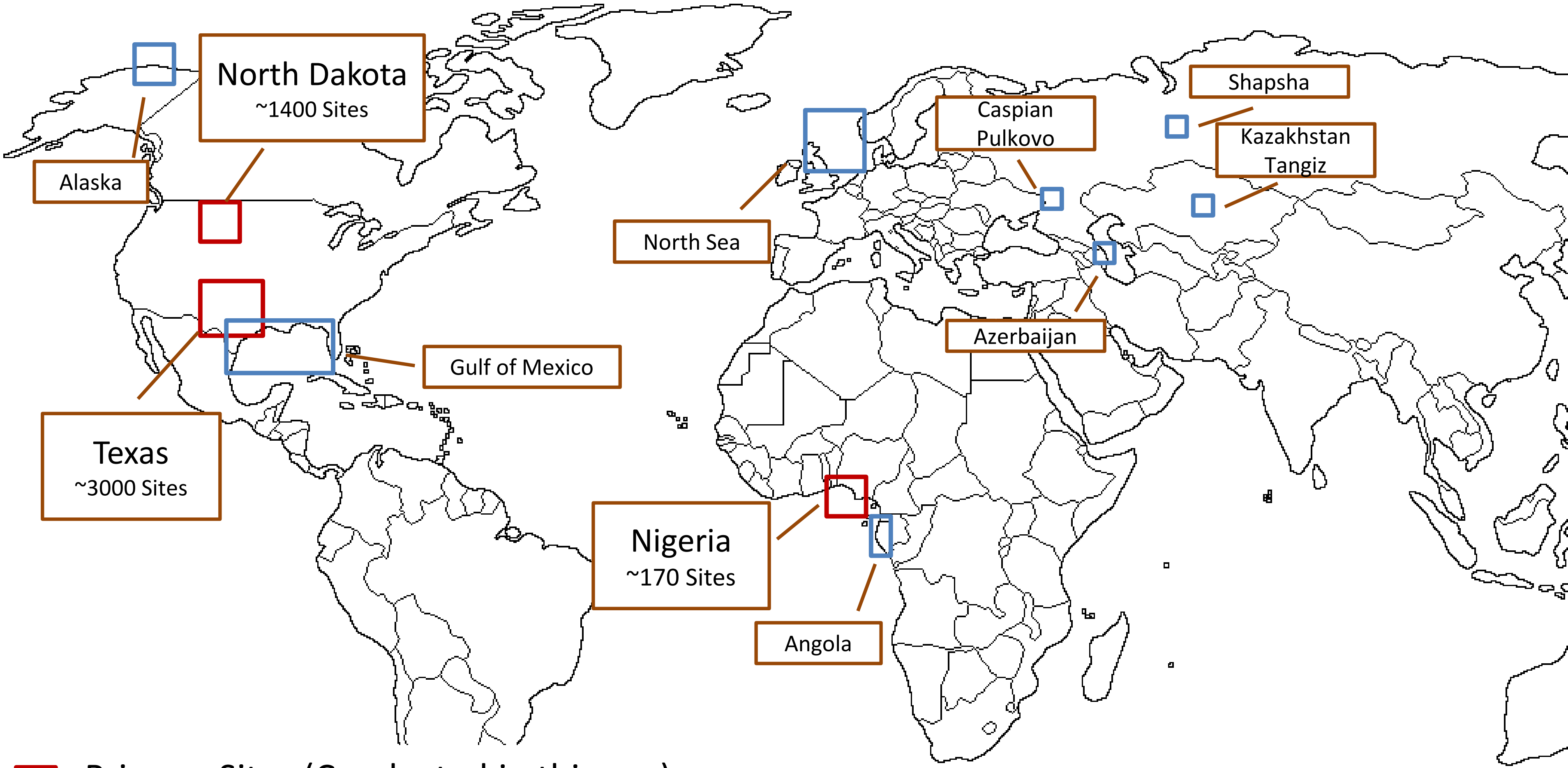
- For each separable flare cluster, cloud-state is retrieved for each overpass from the VIIRS Cloud Mask product (VCM).
- The VCM often mis-identifies gas flares as clouds. An algorithm clears isolated clouds co-located with M10 detections.
- If for a given overpass, there is no VNF detection and the flare site is NOT cloudy, this overpass will be used as a valid observation and it will be assumed the flare was not active (RH=0).



How to Calibrate



Calibration Sites



Primary Sites (Conducted in this run)

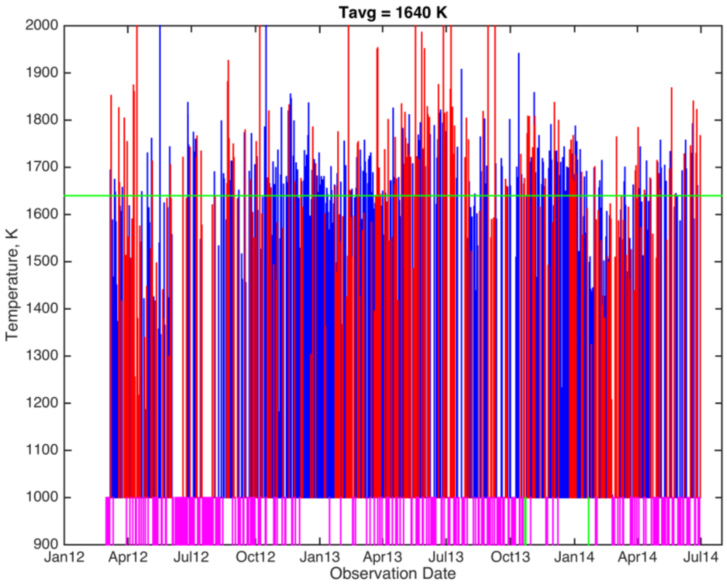
Chosen considering data volume / processing burden

Secondary Sites (To be added)

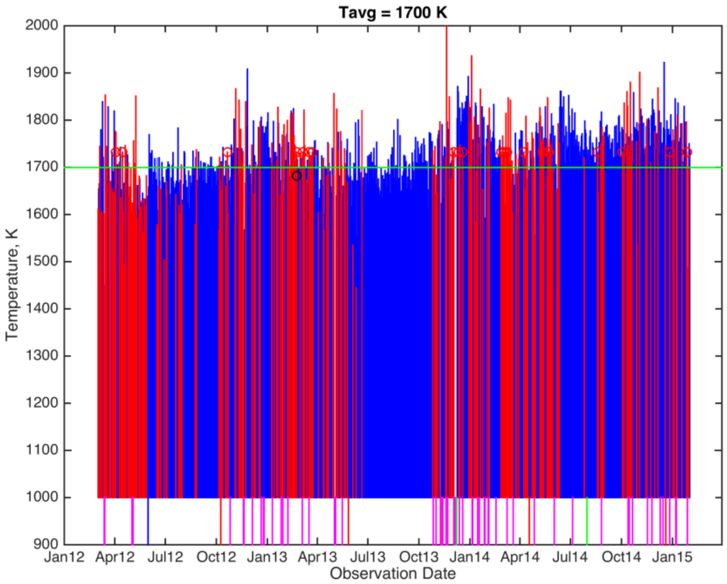
Nigeria flares used in calibration

Temperature Time Series

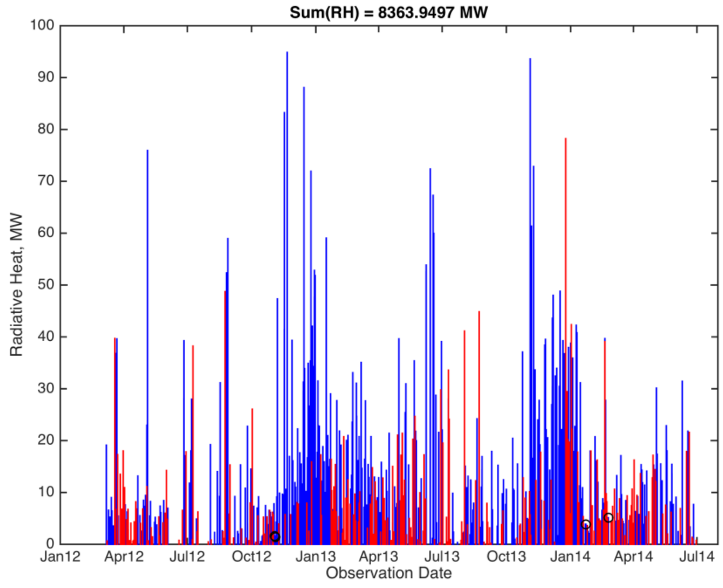
Example from Nigeria

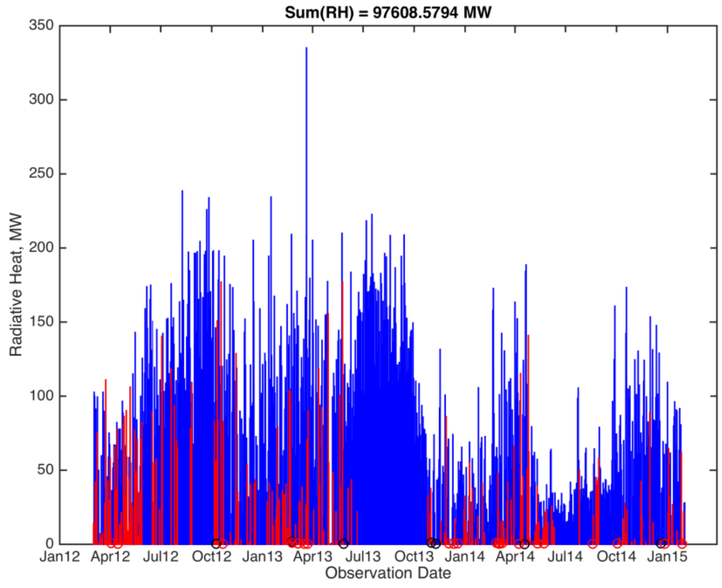


Example from Iraq

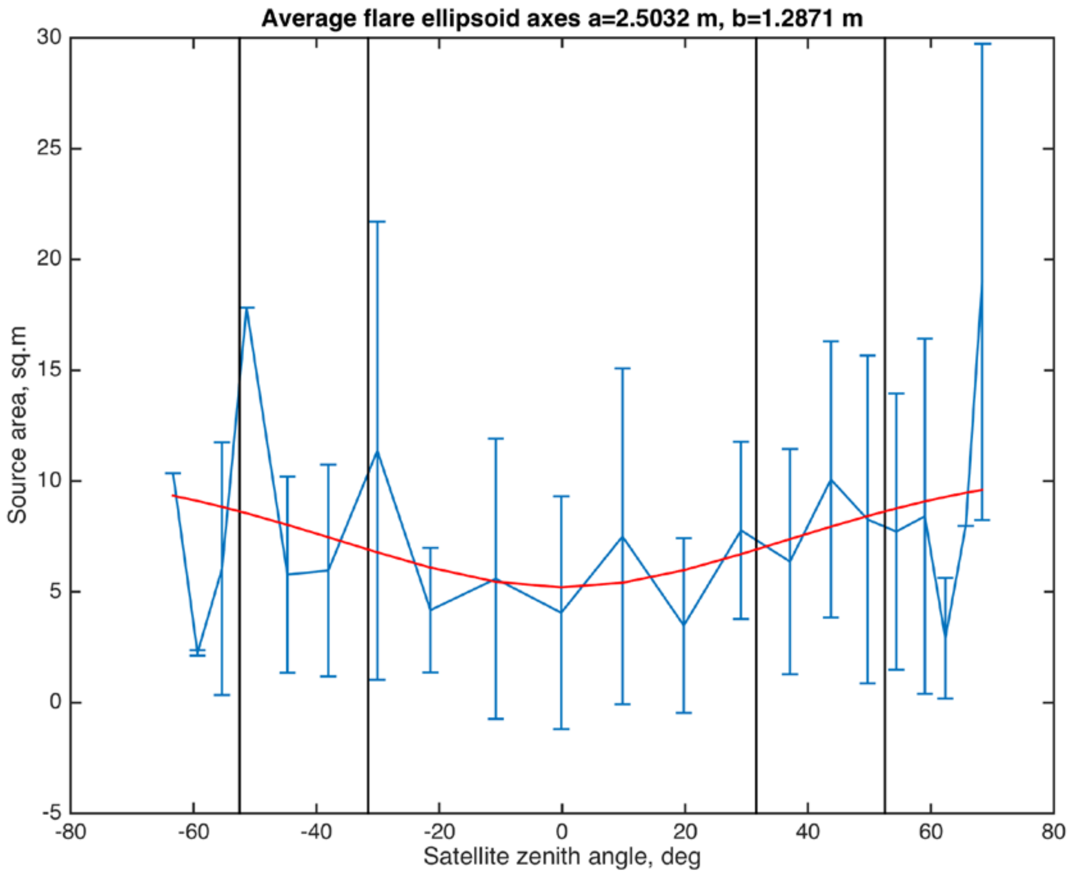


Radiant heat Nigeria vs Iraq

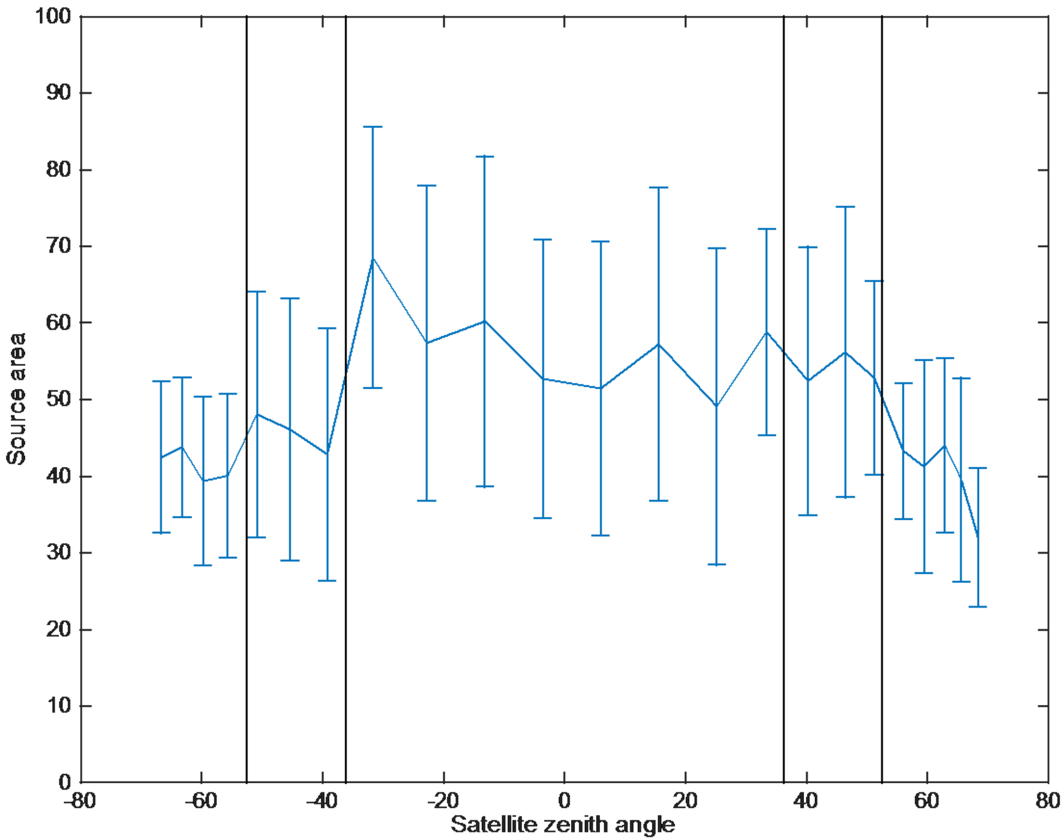


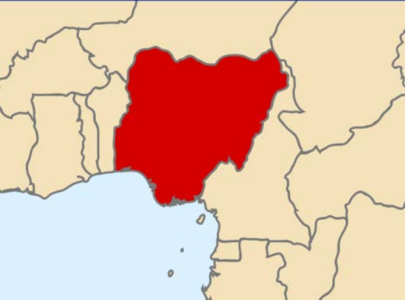


SATZ Correction
Gas flare in Basra



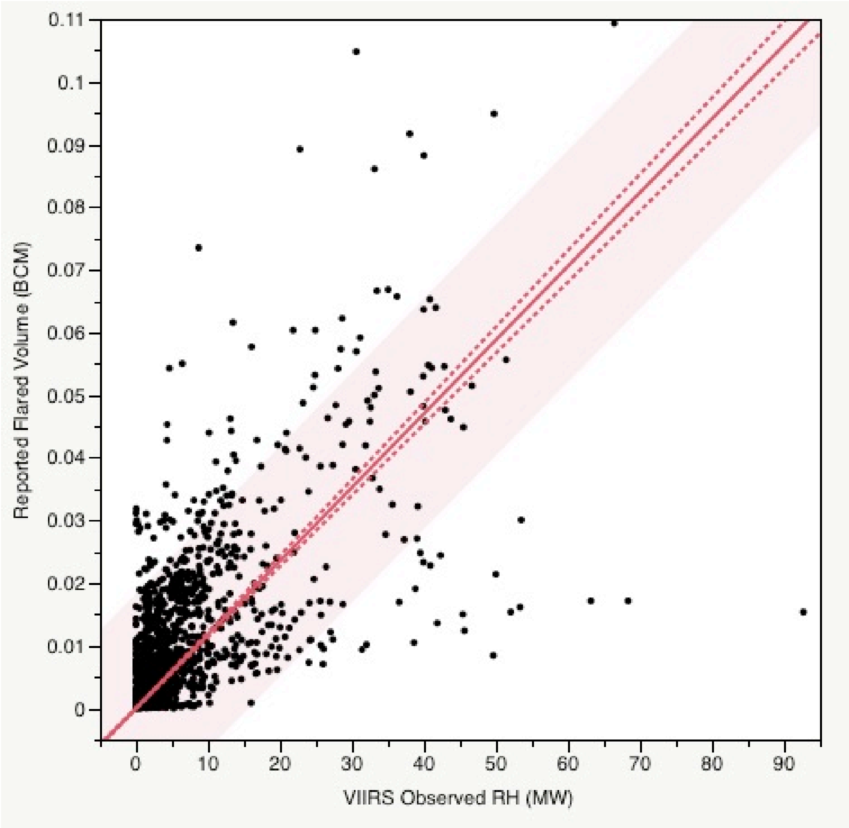
Door to Hell: Derweze, Turmenistan

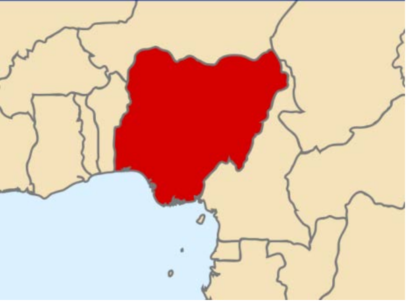




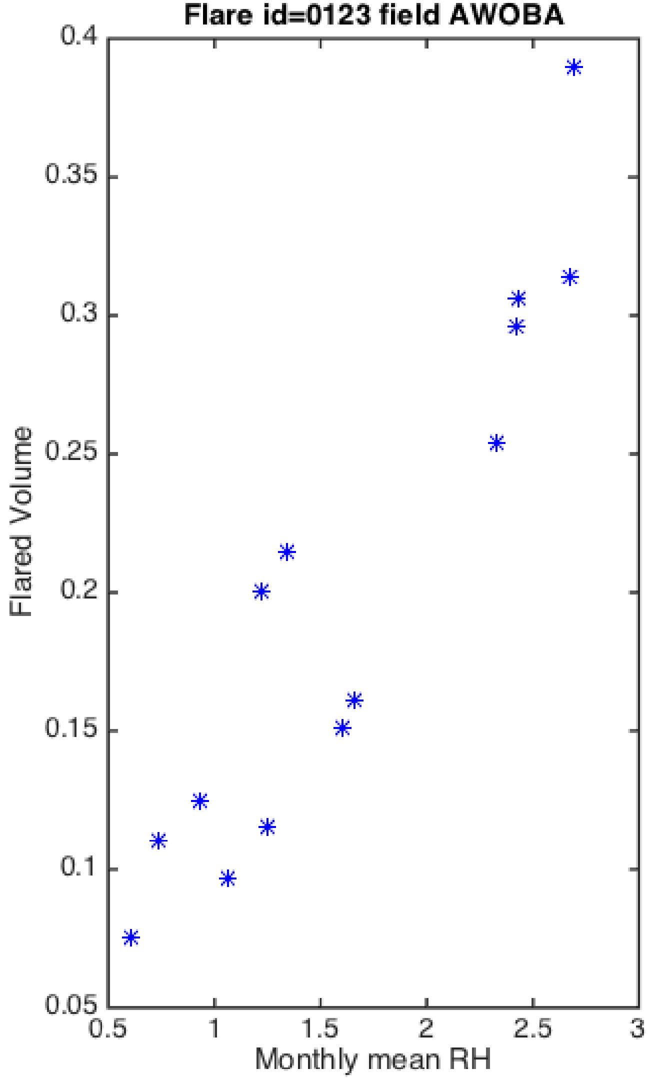
Calibration for Nigeria

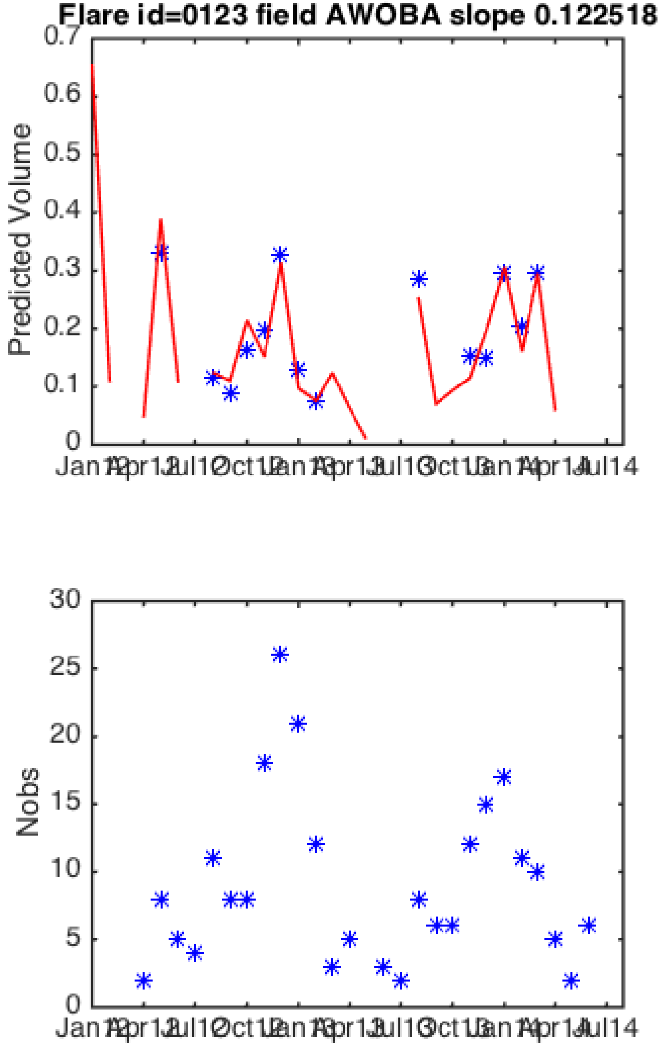
- Reported flared volume
  - Monthly, field-wise
  - NNPC
- Aggregation unit: field (flare site)
  - Temp > 1300K
  - Only account site with single flare feature (identified as local max?)
  - Filter for site-months
    - None
  - 2221 site-months
- BCM = 0.00117*MW

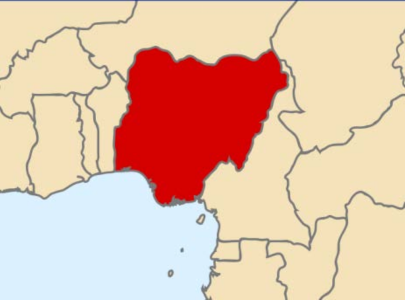




Nigeria
site-months AWOBA

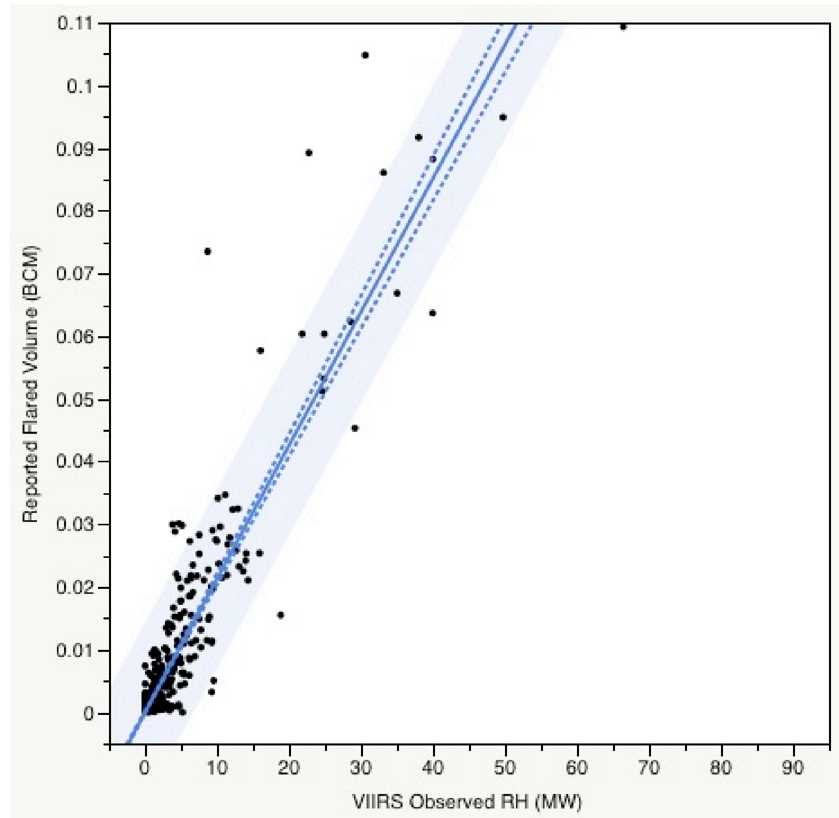






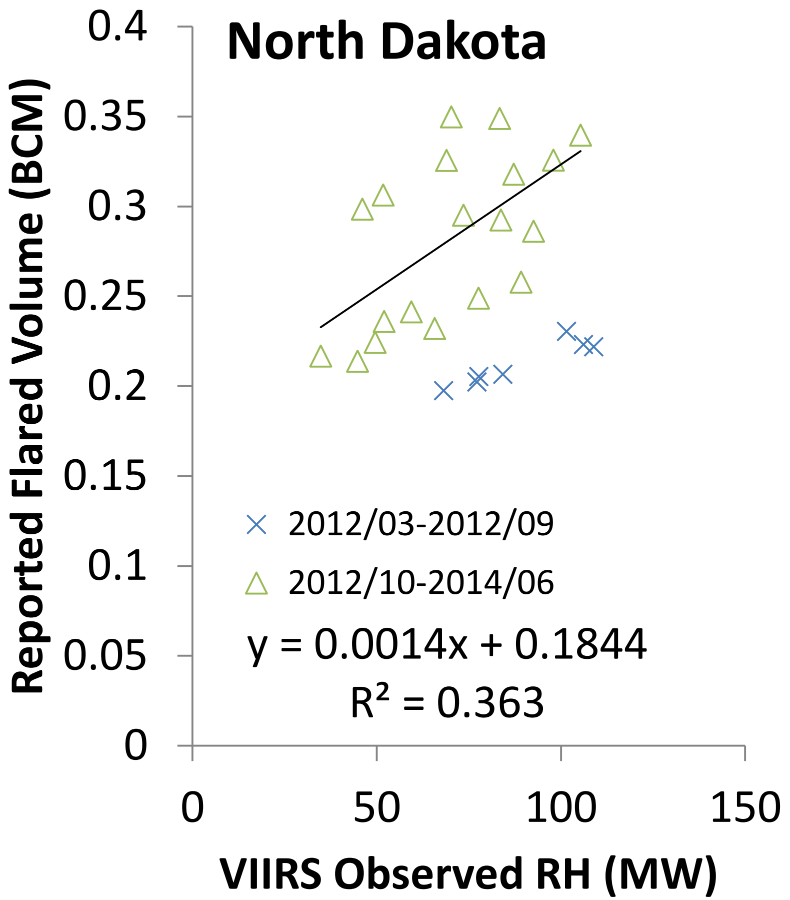
Nigeria, filtered

- Filter for site-months with
  - Nobs > 7
  - $R^2 > 0.5$
- 379 site-months
- BCM=0.0213(±8.8E-5)*MW
  - 95% confidence



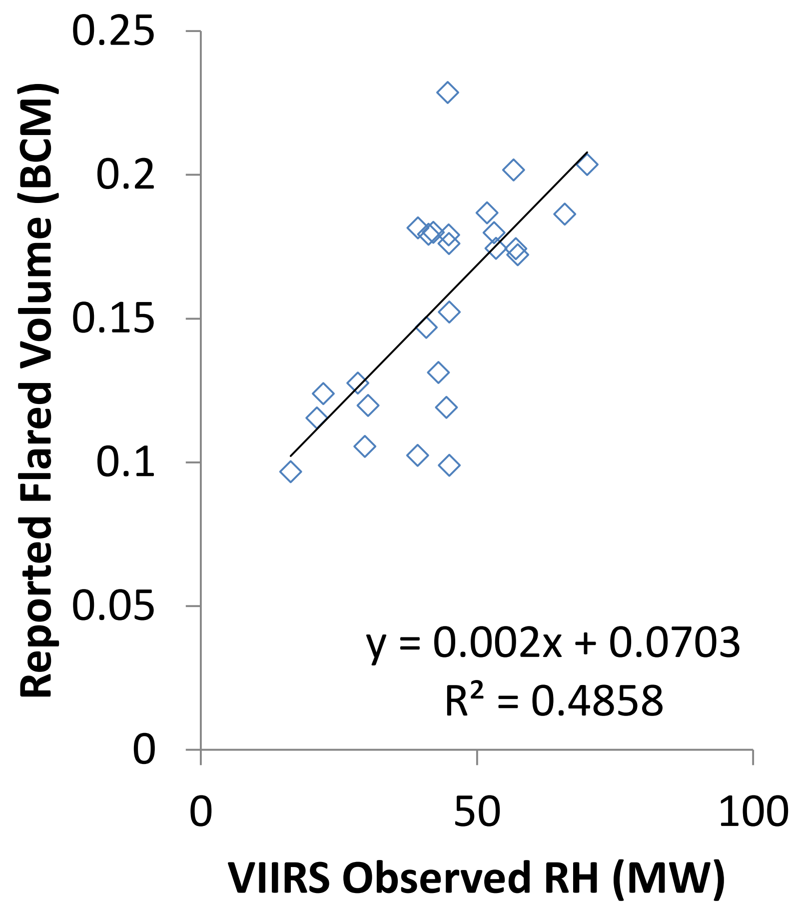
Calibration for North Dakota

- Reported Flare Volume
  - Monthly, state-wide
  - North Dakota Industrial Commission, Dept. of Mineral Resources, Oil and Gas Division
- Aggregation unit: State
  - Temp > 1300K
  - 2 patterns, take the later half (2012/10~2014/06)
    - Regulation change?
  - 13 months
    - Removed one outlier: 2013/12



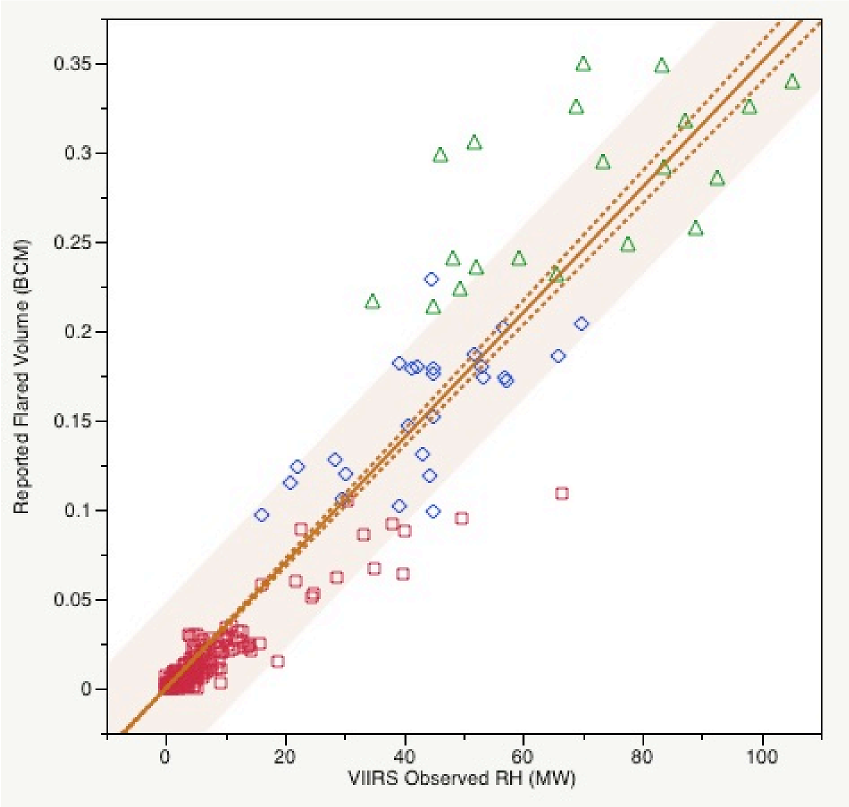
Calibration for Texas

- Reported Flare Volume
  - Monthly, state-wide
  - Texas Rail Road Commission
- Aggregation unit: State
  - Temp > 1300K
  - Only sites confirmed by reported records are accounted.
  - 26 months



Overall Result

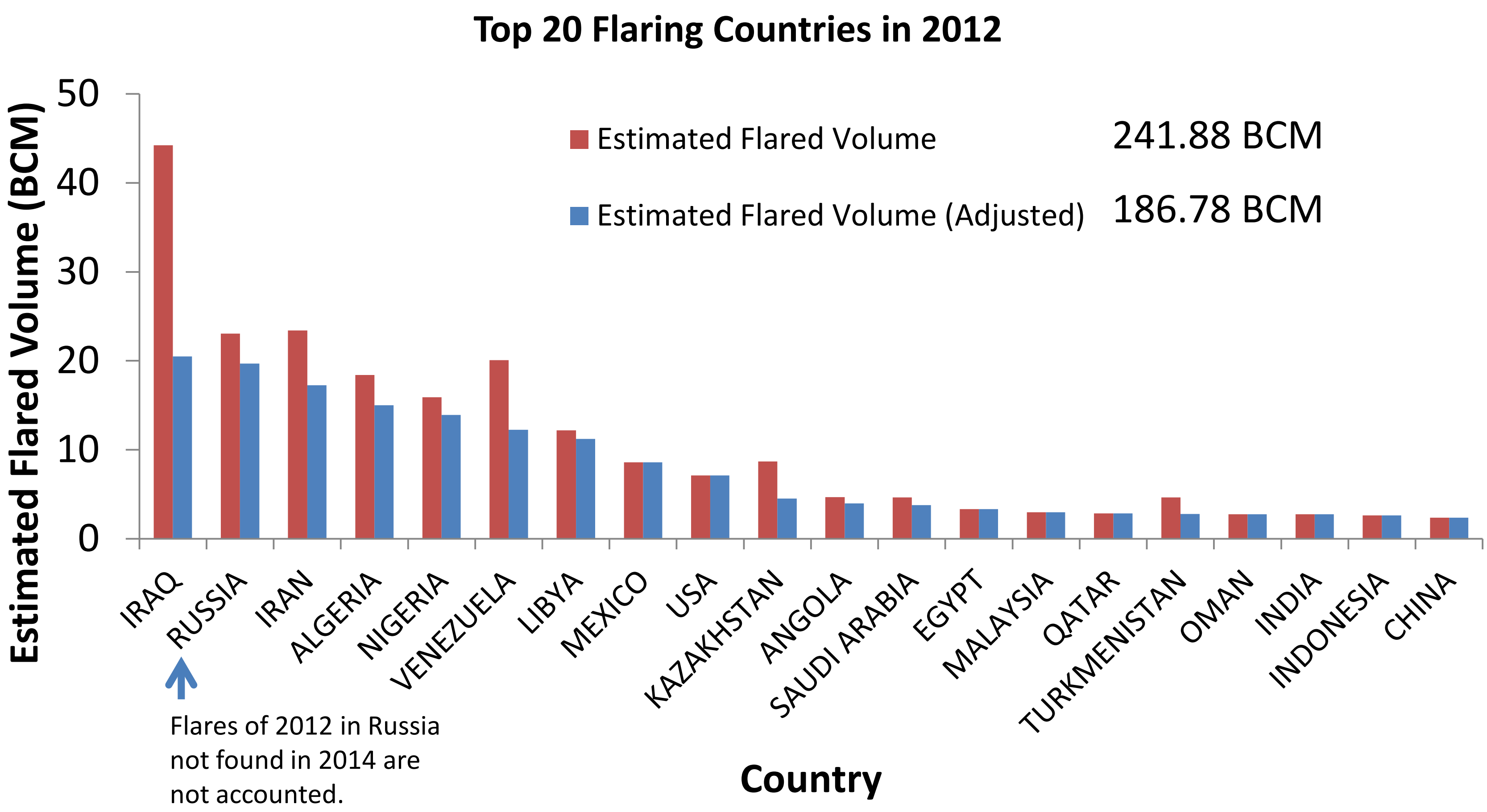
- North Dakota & Texas SATZ corrected
- BCM=0.0035(±1.1E-4)*MW
- R^2=0.905



Known Issues

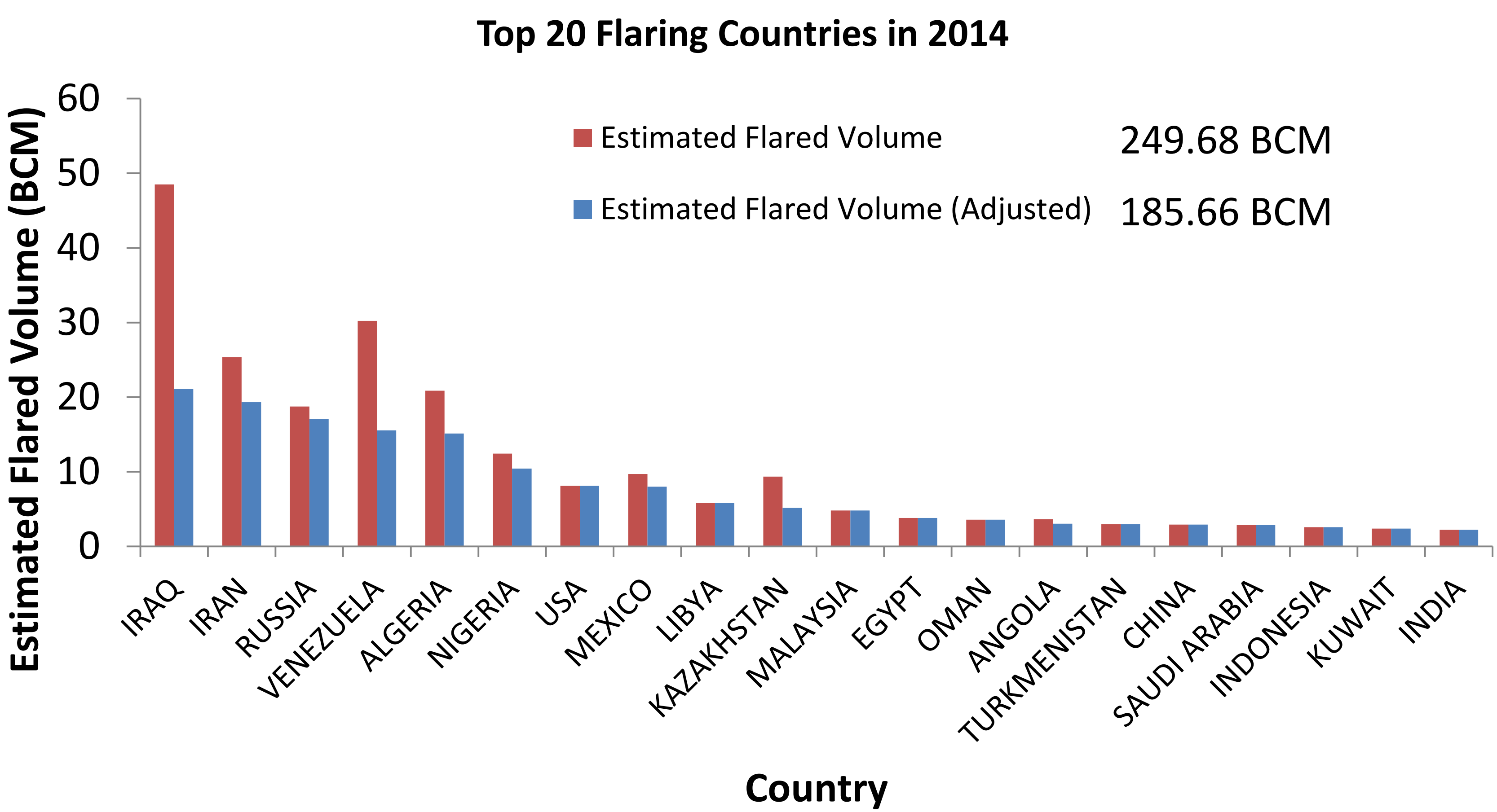
- Wide spread on merged data (with Texas and North Dakota SATZ corrected).
- Partial annual estimation
  - (2014 6 months, 2012 10 months)
- Solar outage at higher latitude
  - Some sites might not be detected due to sunlight.
- North Dakota Regulation Change?
- HP/LP Flare?
  - Observed secondary cluster exhibits 3 times higher RH than majority.
  - LP flares radiate 3 time more energy than HP flares.
- Bias on compiled instantaneous observe vs. monthly summation of flared volume.
- SATZ correction is not yet fully verified.

Top 20 Countries (2012)



Adjust: Top 50 flares are discounted 75% of their estimated flared volume due to high possibility of being LP flares.

Top 20 Countries (2014)



Adjust: Top 50 flares are discounted 75% of their estimated flared volume due to high possibility of being LP flares.

John Zink Test Laboratory
Tulsa, OK

Future

- Include more calibration areas?
- Add test flare facility data from John Zink?
- Regional SATZ correction?
- Study non-linear model $V = C * RH^D$
- Improve ID of refineries and industrial sites