Five-year Survey of the U.S. Natural Gas Flaring Observed from Space with VIIRS

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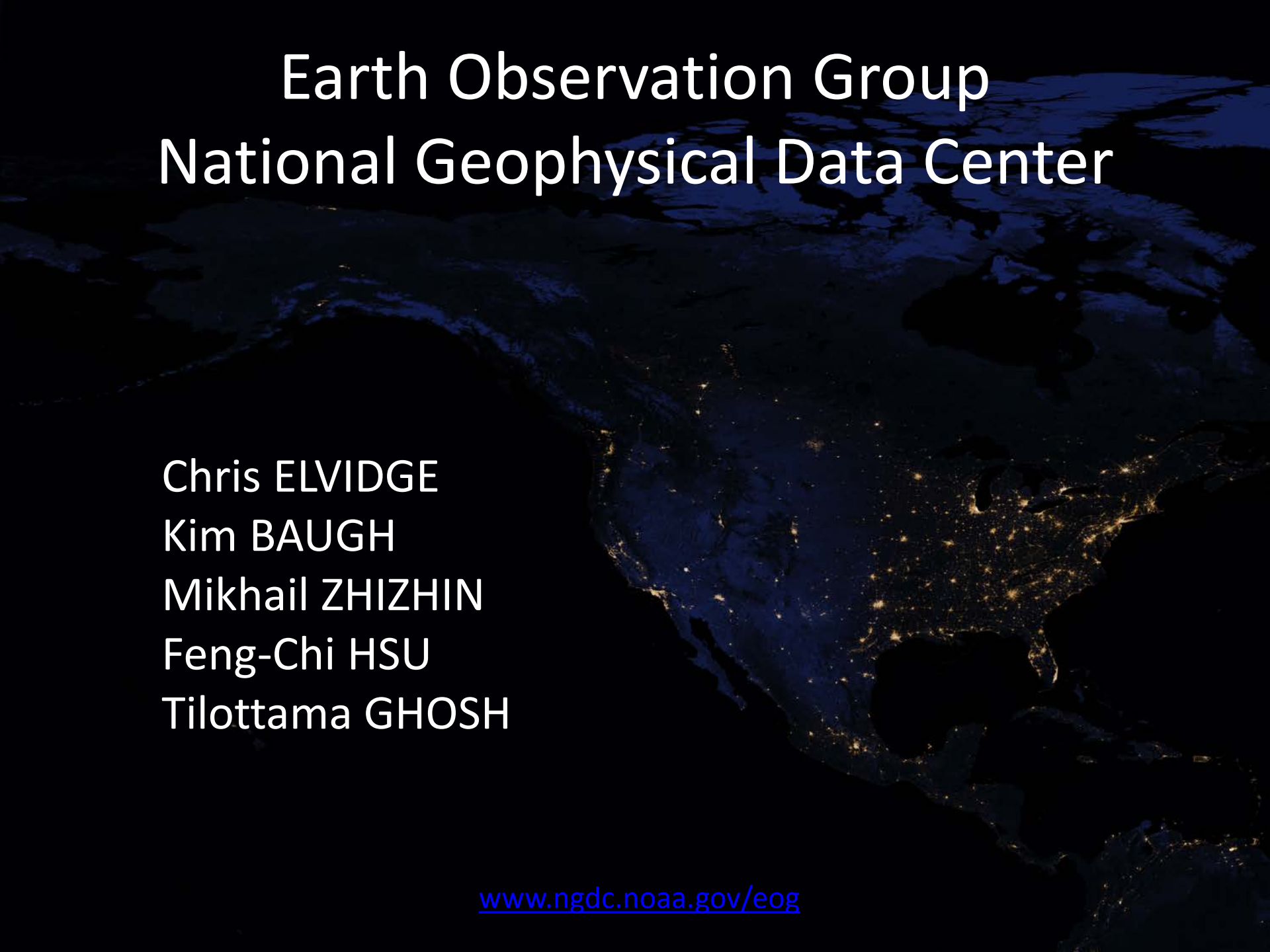

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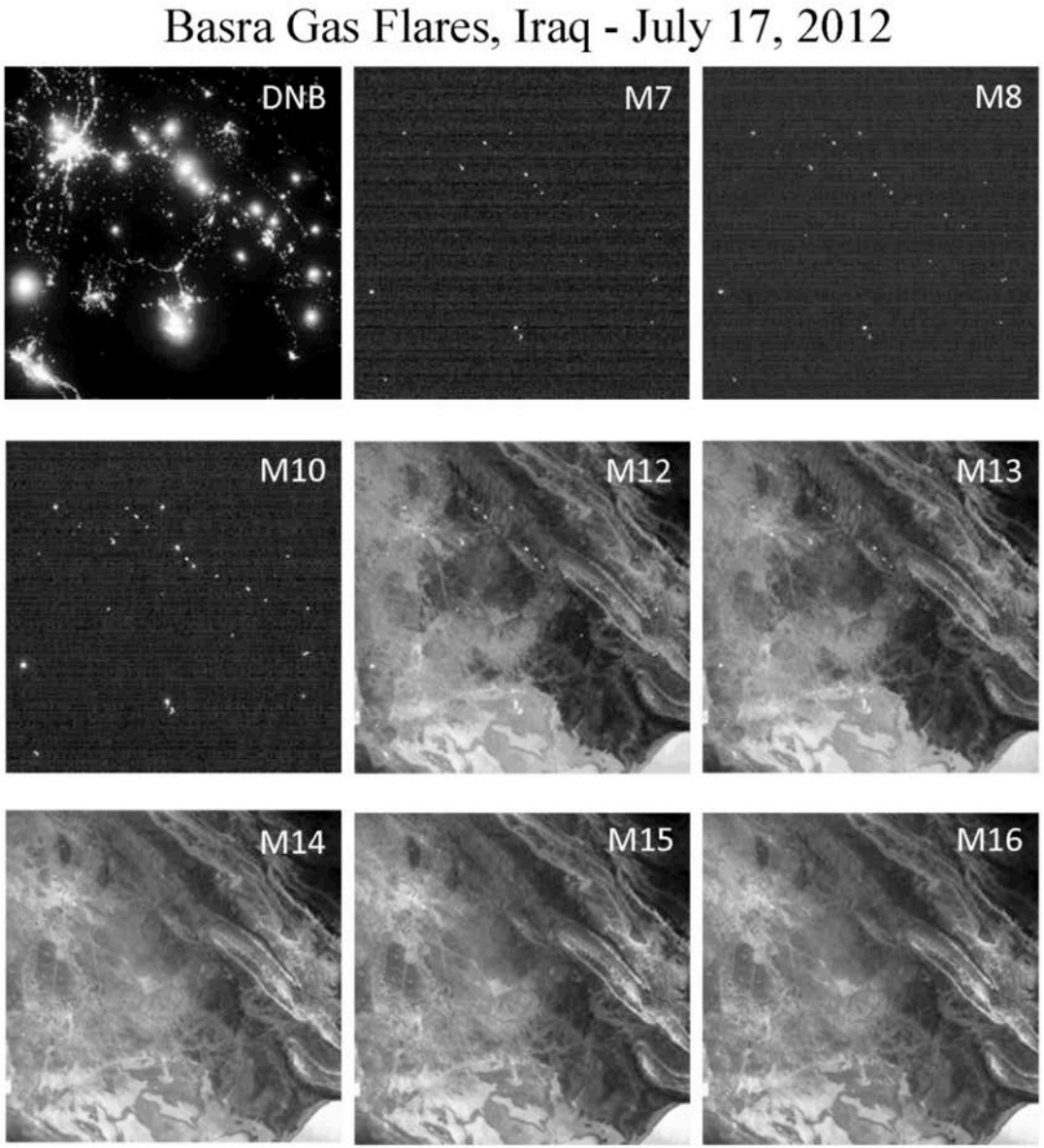
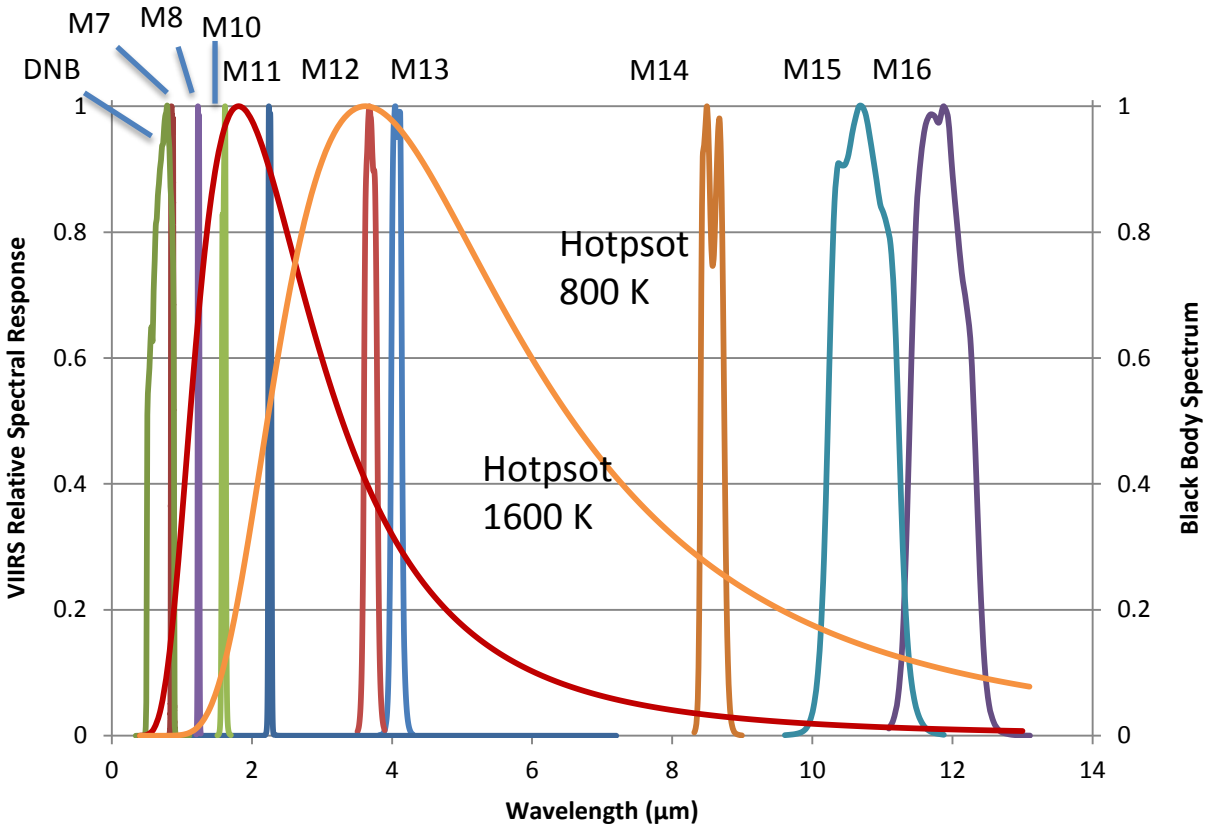
The Nine VIIRS Nighttime Channels



Gas flares are readily detected in the VIIRS M10 spectral band

VIIRS Nightfire (VNF):

A global fire product created from nighttime multispectral satellite data



VIIRS data is available from March 2012 – present.

Nine channels of data are collected at night.

VIIRS M-band spatial resolution is 742m at nadir.

Nighttime collection of channel 11 is expected to start in 2017

Flare Array in Basra

2017-05-23 22:14 UTC

T = 1572K, S = 115 m2

Combustion parameters:

ID=VNF_npp_d20170523_t2209303_e2215089_b28865_x0473925E_y302177N_l2490_s1016_v21

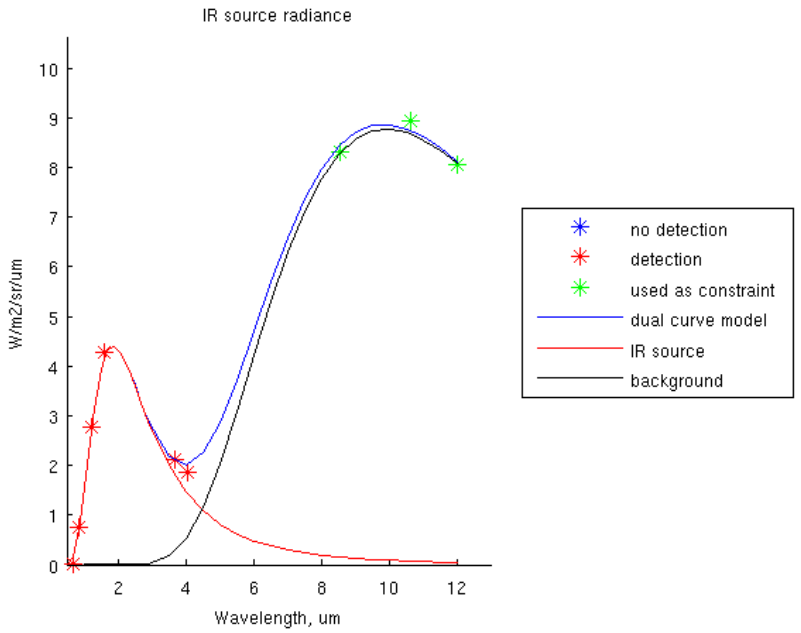
Lat=30.217733 Lon=47.392509 deg. Time=2017/05/23 22:14:41

Temperature source=1572 K Temperature background=293 K

Radiant heat intensity=38.84 W/m2 Radiant heat=39.83 MW

Source footprint=114.98 m2

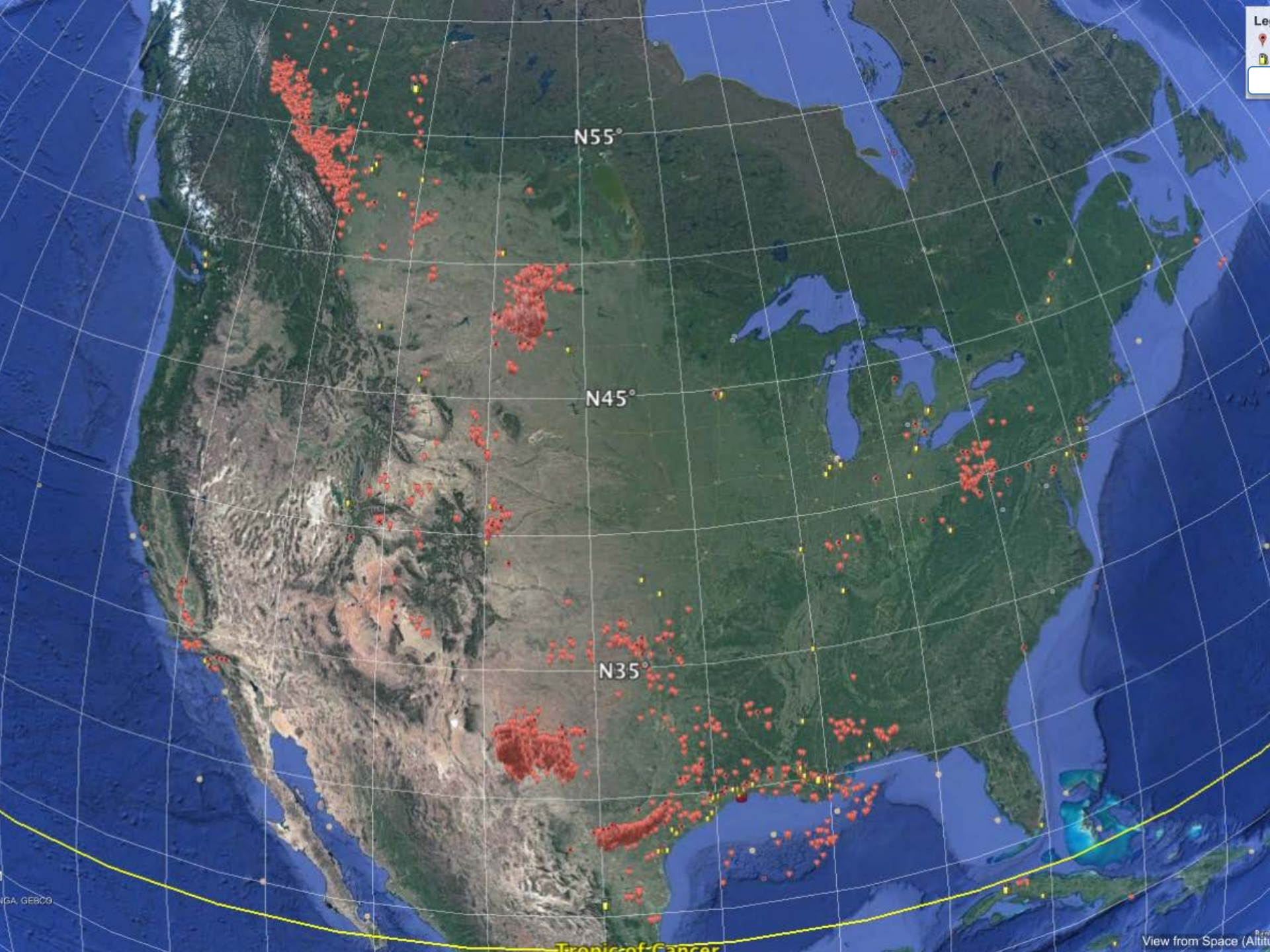
Cloud state=cloudy Atmosphere corrected=no



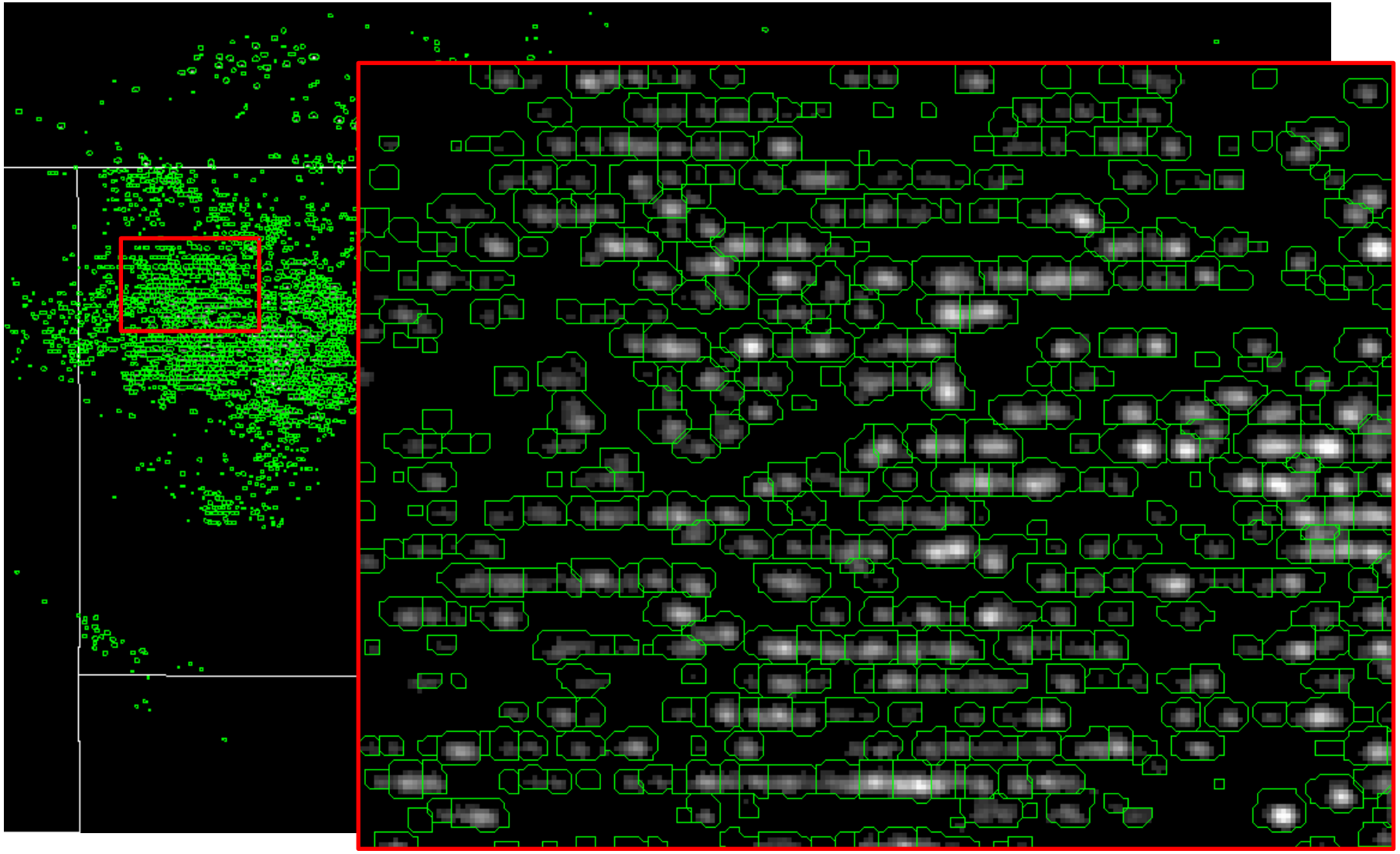
Directions: To here - From here

Time Series Analysis of VNF Detections

- Run VIIRS Nightfire Algorithm for and save in a PostgreSQL database (130 GB for global coverage 3/2012 – 12/2016)
- Accumulate detections with T > 1300K into a 15 arc-second grid
- Remove noise and fires, mask out grid cells < 3 detections
- Use “watershed” algorithm to separate flare sites
- Manually label flare types based on the Google Earth images
- Accumulate annual detection statistics within each flare site
- For each site, estimate average lat-lon location, temperature T, surface area S, shape and radiant heat RH


N55°
N45°
N35°
Tropic of Cancer
View from Space (Altit

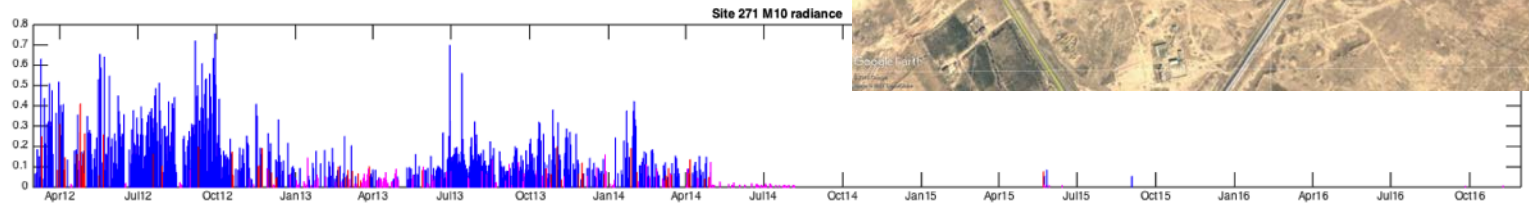
Gridded VNF Detections in North Dakota
Temperature > 1300K, Ndetect > 3



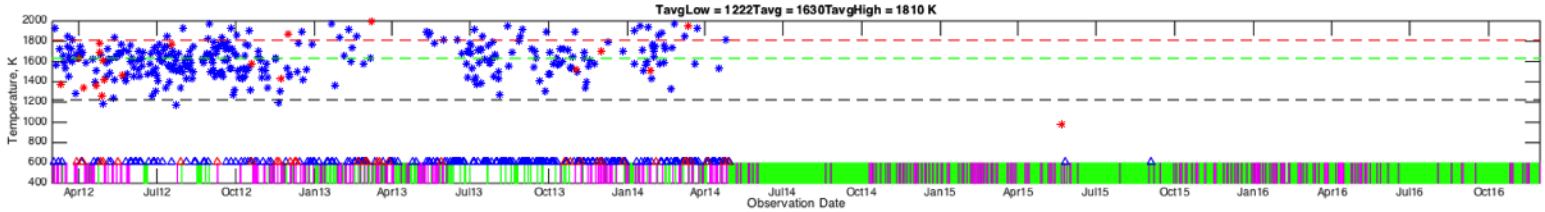
Syria, site #271

Lat=34.911244 Lon=43.432322 deg.

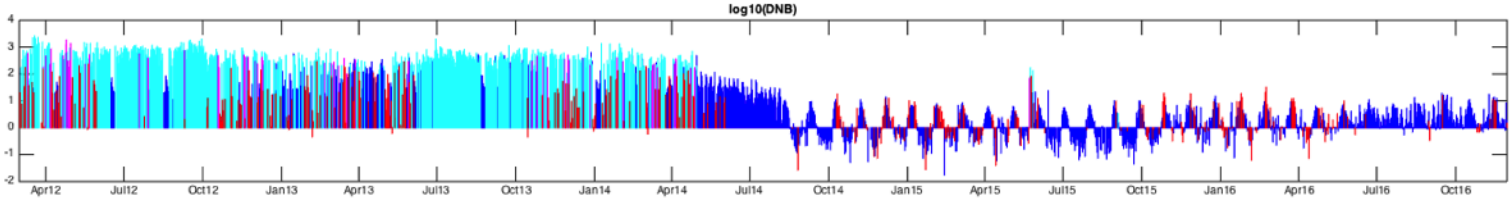
M10 Radiance



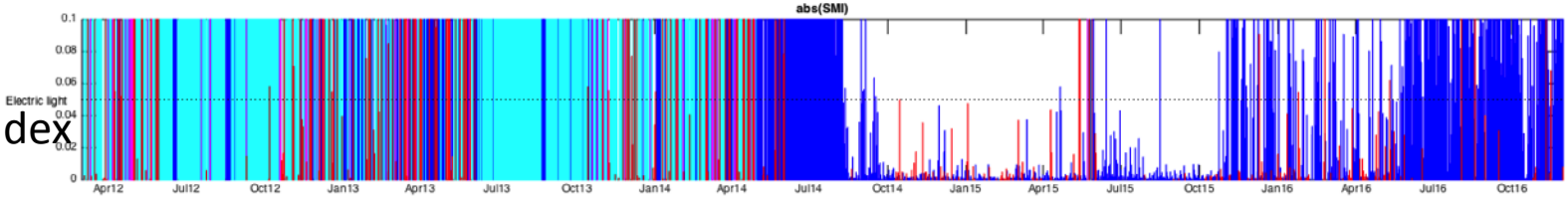
Temp. K



DNB Radiance



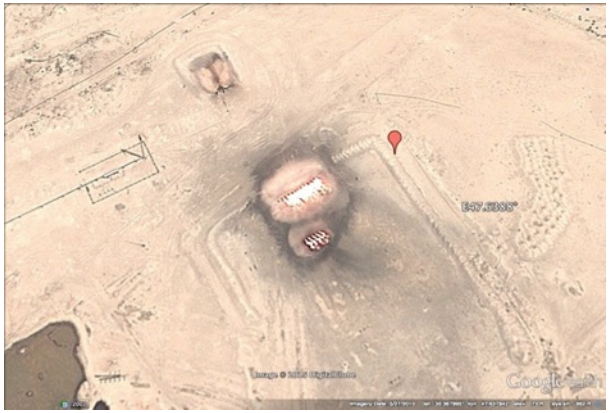
DNB Spike Index



Flare Shapes: Heat vs View Angle

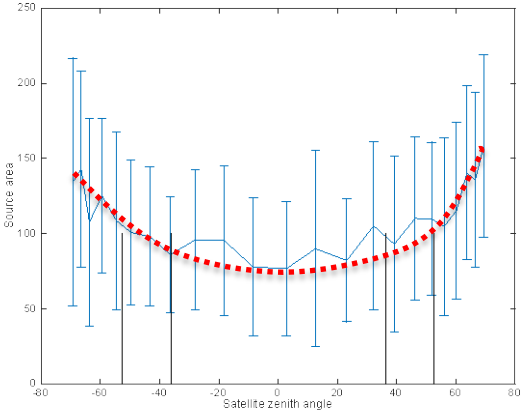
Flare in Northern Iraq

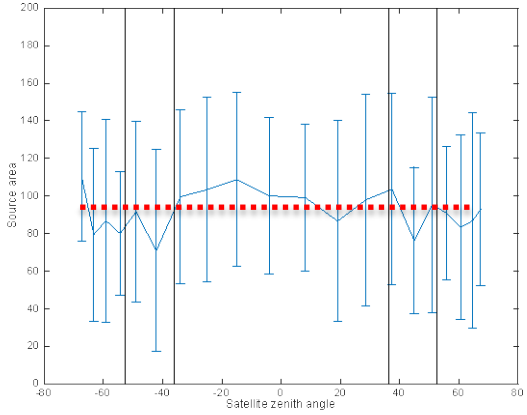
Flare Array in Basra

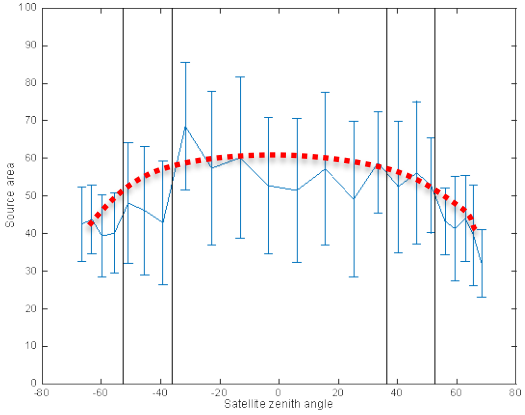


Door to Hell in Tadzhikistan

Radiant Heat







Satellite view angle

Calibration

Sum of flare “radiant heat “ RH’ = T^4 x S^D (no clouds) in proportion to the percent of detections (PCT). Here D is nonlinear correction factor, S is surface area.

Flared volume is given by the Regression Through the Origin (RTO) relating the CEDIGAZ reported country level BCM and RH’

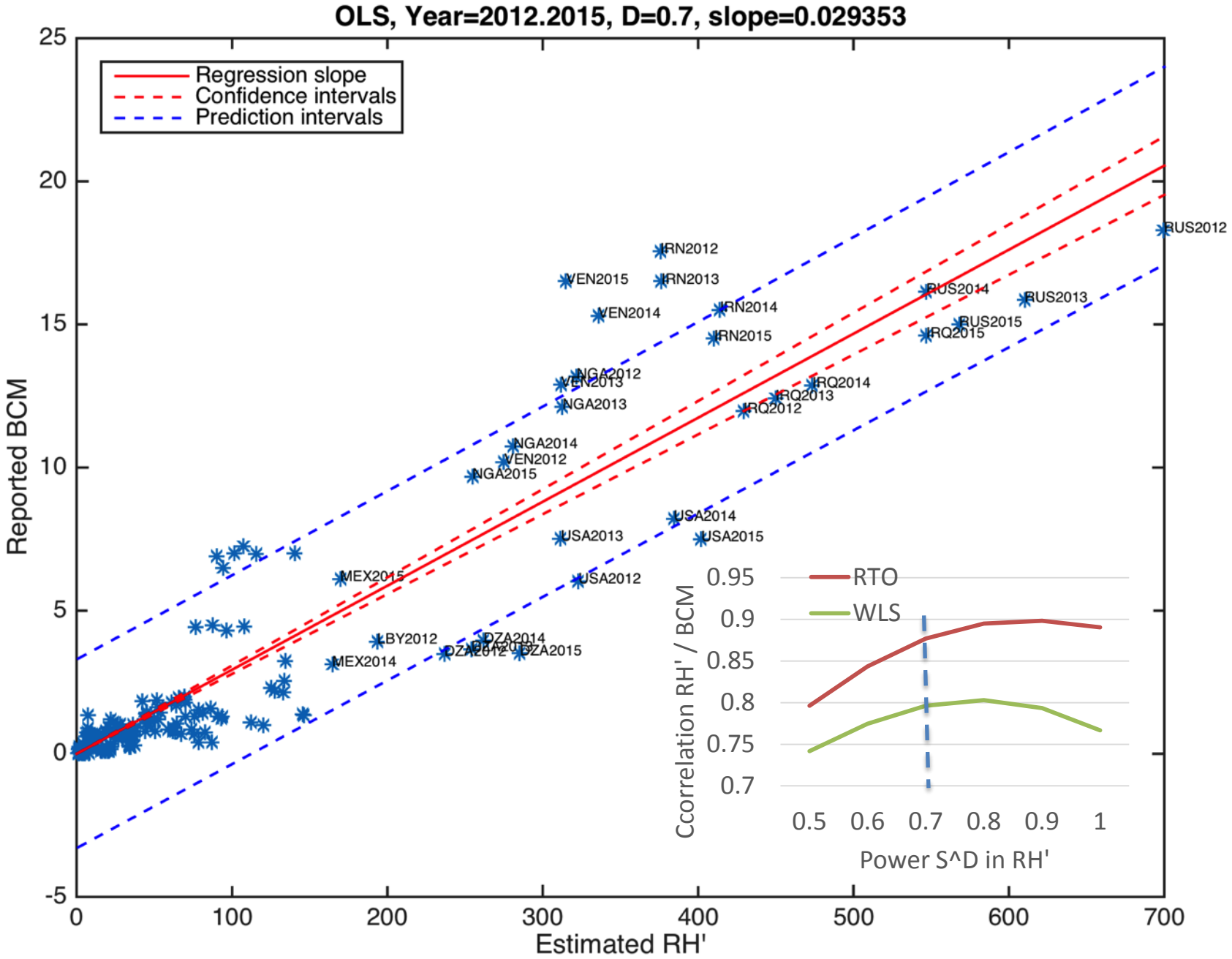
$$\text{Flared Volume} = \text{Slope} \times RH'.$$

The 95 % confidence interval for the RTO slope are

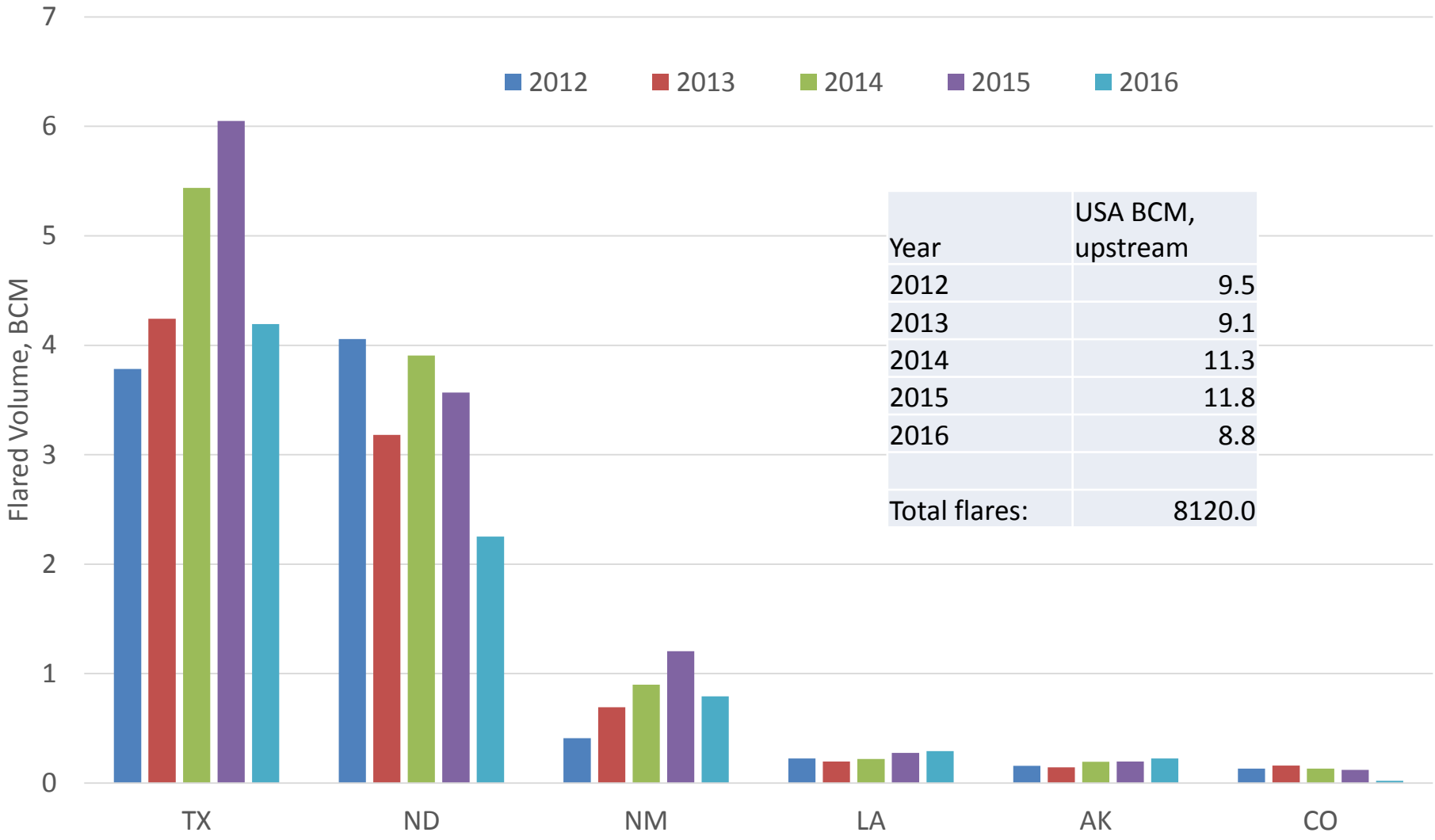
$$\text{Slope} = 0.0294 \pm 0.0017$$

For RTO the prediction interval varies in a narrow range 3 - 3.5 BCM for the full range of the observed RH’ from 0 to 700.

CEDIGAZ, http://www.cedigaz.org/

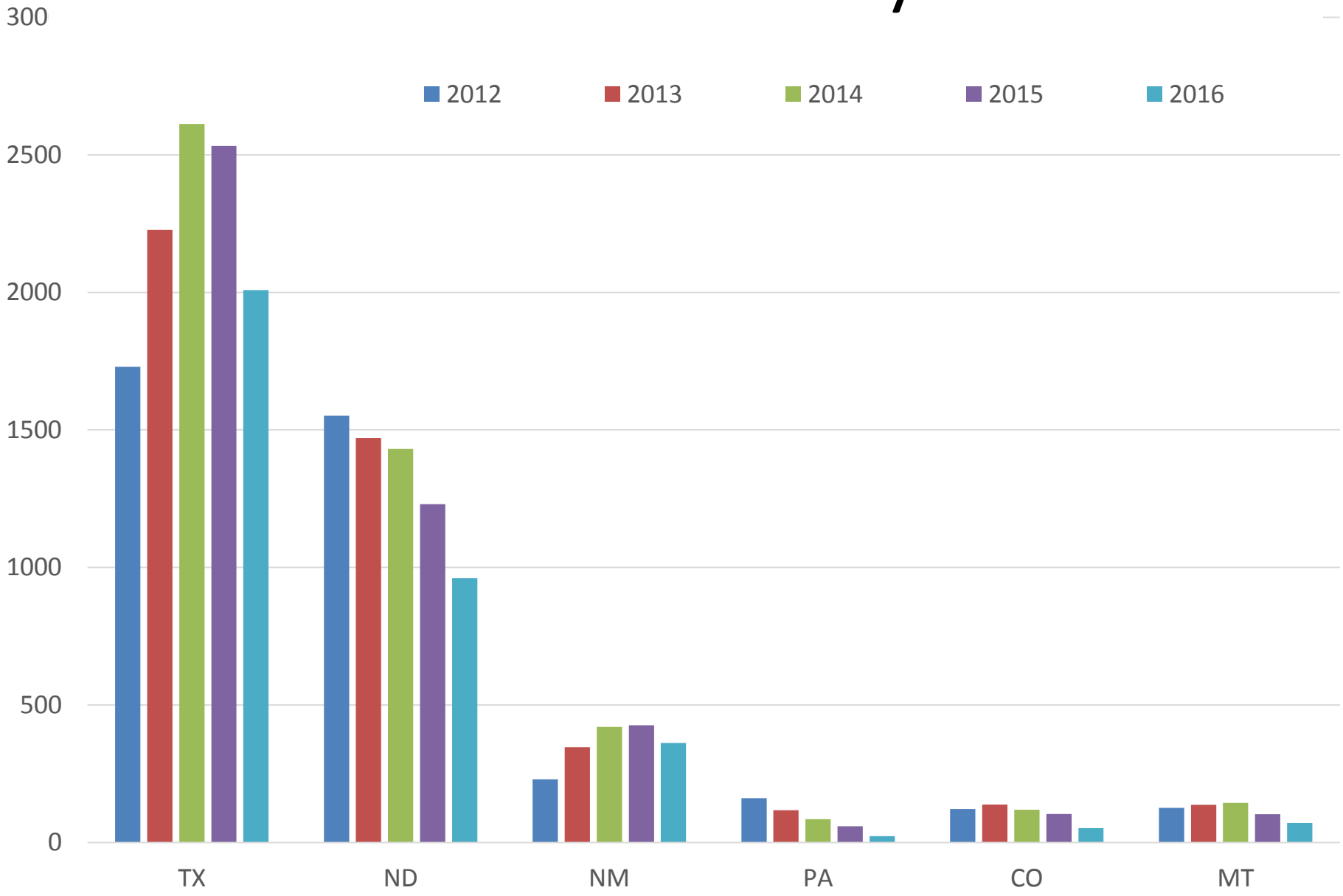

OLS, Year=2012.2015, D=0.7, slope=0.029353
Regression slope
Confidence intervals
Prediction intervals
Reported BCM
Estimated RH'
25
20
15
10
5
0
-5
0
100
200
300
400
500
600
700
IRN2012
VEN2015
IRN2013
VEN2014
IRN2014
IRN2015
NGA2012
VEN2013
NGA2013
NGA2014
VEN2012
NGA2015
MEX2015
LBY2012
MEX2014
DZA2014
DZA2012
DZA2015
USA2013
USA2012
USA2014
USA2015
IRQ2012
IRQ2013
IRQ2014
IRQ2015
RUS2014
RUS2015
RUS2013
RUS2012
Ccorrelation RH' / BCM
0.95
0.9
0.85
0.8
0.75
0.7
RTO
WLS
0.5
0.6
0.7
0.8
0.9
1
Power S^D in RH'

Flared Volume by State

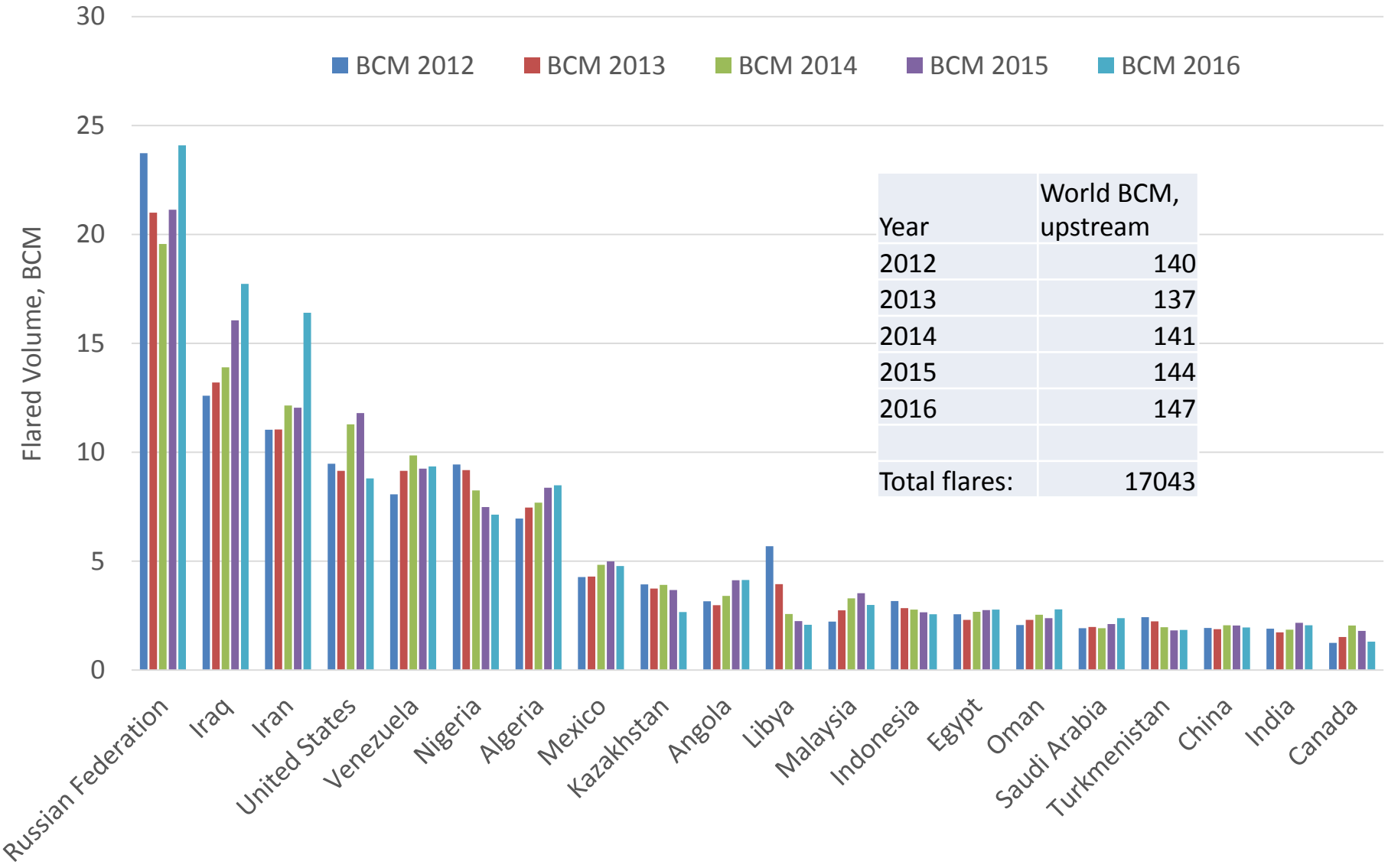


Year	USA BCM, upstream
2012	9.5
2013	9.1
2014	11.3
2015	11.8
2016	8.8
Total flares:	8120.0

Number of Flares by State

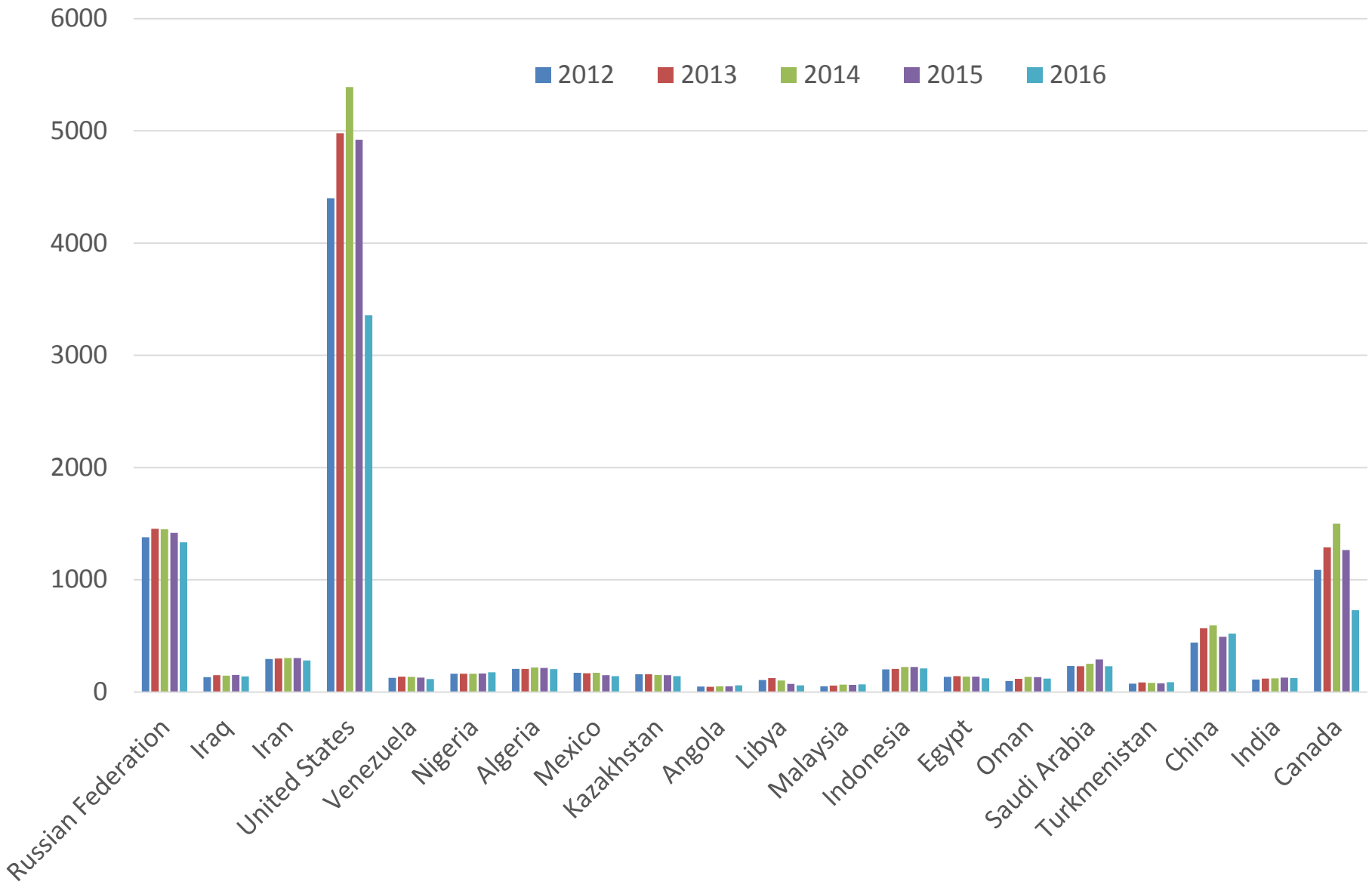


Flared Volume for Top 20 Countries, Upstream



Year	World BCM, upstream
2012	140
2013	137
2014	141
2015	144
2016	147
Total flares:	17043

Number of Flares for Top 20 Countries, Upstream



Q & A

- Where to find the Nightfire data ?

  https://www.ngdc.noaa.gov/eog/viirs/download_viirs_fire.html
  https://www.ngdc.noaa.gov/eog/viirs/download_global_flare.html

- Where is it published ?

1. Elvidge, C.D.; Ziskin, D.; Baugh, K.E.; Tuttle, B.T.; Ghosh, T.; Pack, D.W.; Erwin, E.H.; Zhizhin, M. A Fifteen Year Record of Global Natural Gas Flaring Derived from Satellite Data. Energies 2009, 2, 595-622 (Best paper award in 2013) DOI: 10.3390/en2030595 http://www.mdpi.com/1996-1073/2/3/595

2. Elvidge, C.D.; Zhizhin, M.; Hsu, F.-C.; Baugh, K.E. VIIRS Nightfire: Satellite Pyrometry at Night. Remote Sensing 2013, 5, 4423-4449. DOI: 10.3390/rs5094423 http://www.mdpi.com/2072-4292/5/9/4423

3. Elvidge, C.D., Zhizhin, M., Baugh, K.E., Hsu, F.-C. and Gosh, T. Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data. 2016, 9(1), 14; DOI:10.3390/en9010014 http://www.mdpi.com/1996-1073/9/1/14