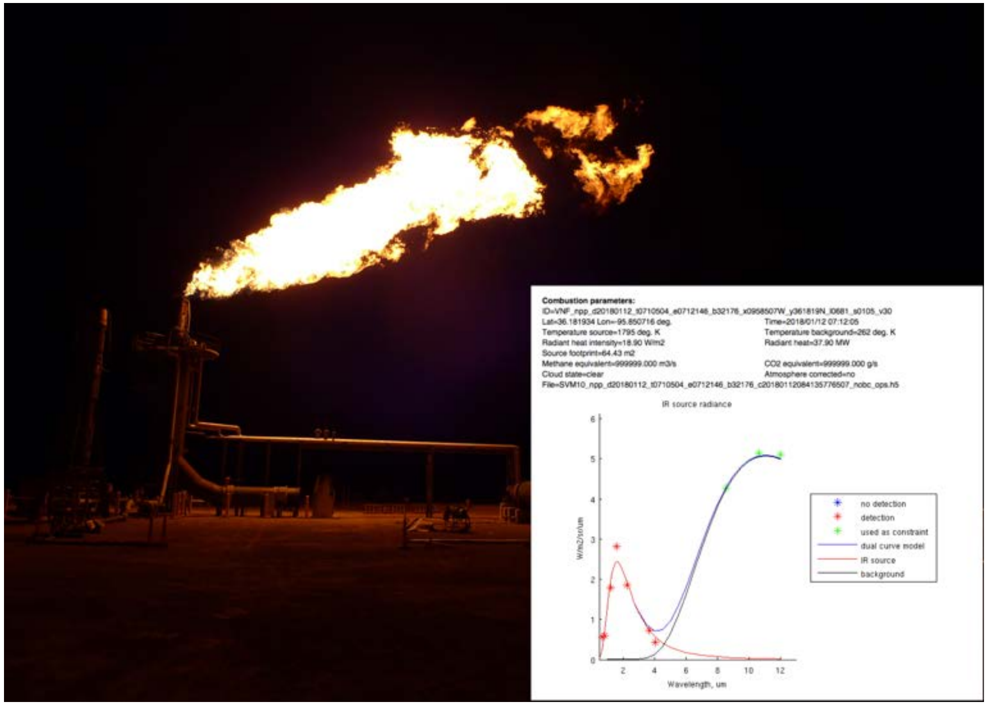

Ground-truth Validation of VIIRS Nightfire for Gas Flaring Estimates

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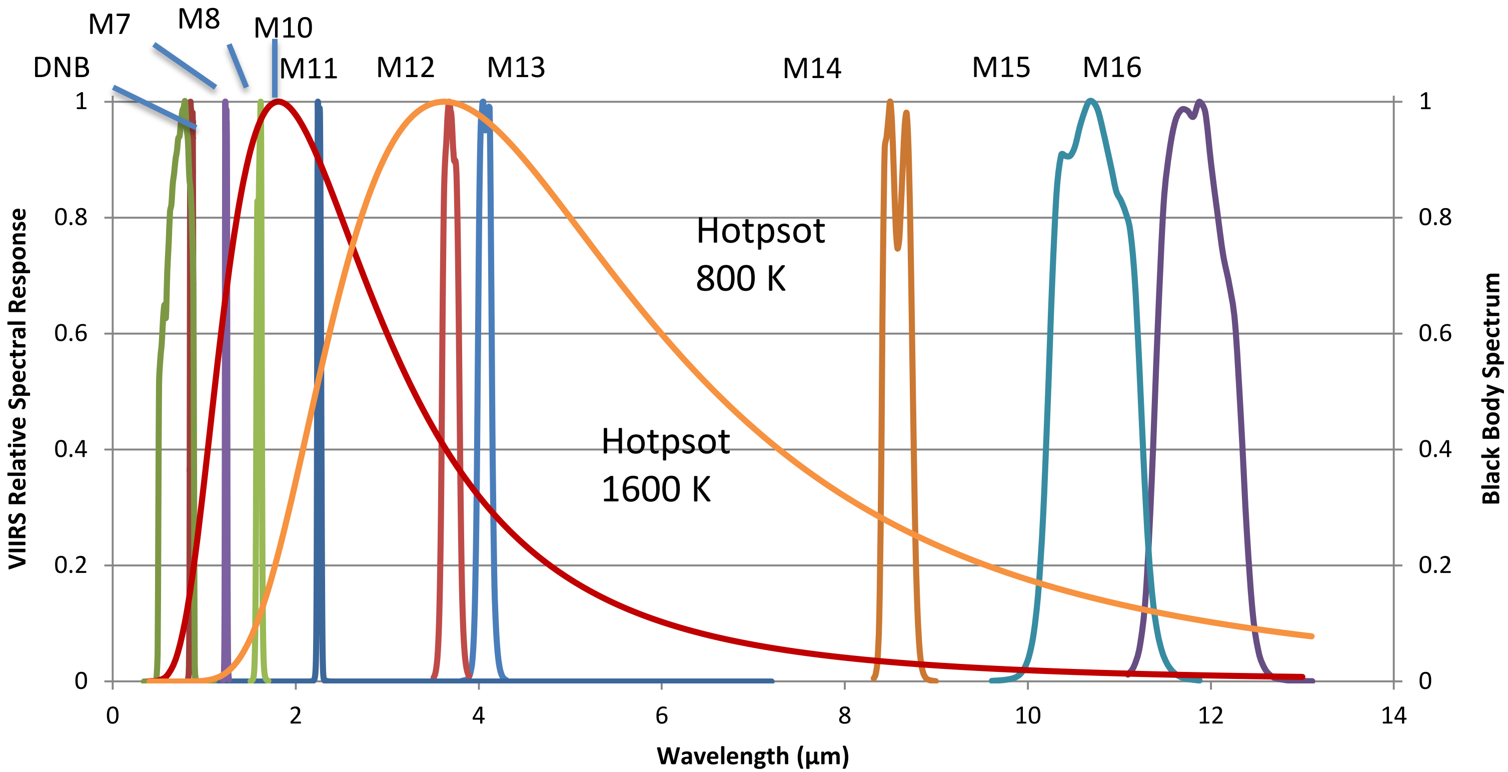
VIIRS Nightfire (VNF)

A global fire product created from nighttime multispectral satellite data

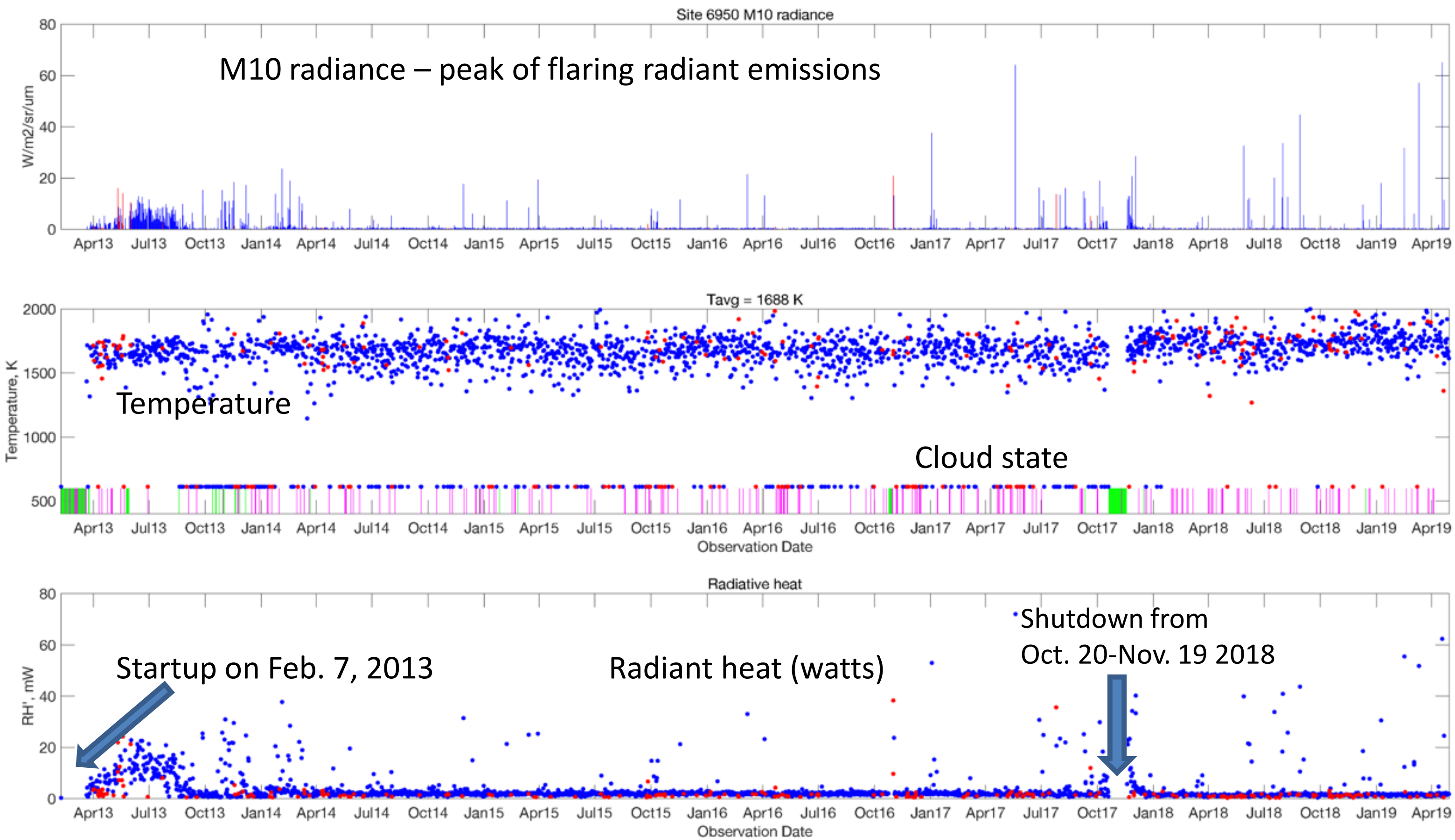


VIIRS M-band spatial resolution is 742m at nadir
Nighttime collection of channel M11 began in Dec 2017

Suomi NPP / VIIRS data is available from March 2012 – present
NOAA-20 (JPSS-1) / VIIRS data collected from June 2018

Flare in Algeria: VNF 2019-05-19
T = 1674 K, S = 8.4 m^2, RH = 3.7 mW

Radiance, Temperature, Heat versus satellite overpass time from March 2012 until May 2019
Single flare in Algeria



Temperature versus source area for VNF from January 2018
Overlayed are detection limit lines for VIIRS spectral bands

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Tulsa flare experiment tasks

- A major part of the project is to improve the accuracy of the flared gas volume estimates
- Collect and analyze VIIRS data of variable size flares with the same natural gas composition, no wind, no clouds
- The test flare data will be used to develop an improved calibration for calculating flared gas volumes from individual flaring sites
- Apply calibration to produce new estimates of annual flared gas volumes back 2012

Tulsa flare experiment plan

Stage 1, Jan.-Feb. 2018, 12 *single* flares

			Satellite zenith angle		
Flare size	Flow rate lb/hr	Flared volume BCM/yr	Nadir	Medium	Side
Small	750, later 1500	0.004, later 0.008	1	2	1
Medium	7500	0.04	1	2	1
Large	75000	0.4	1	2	1

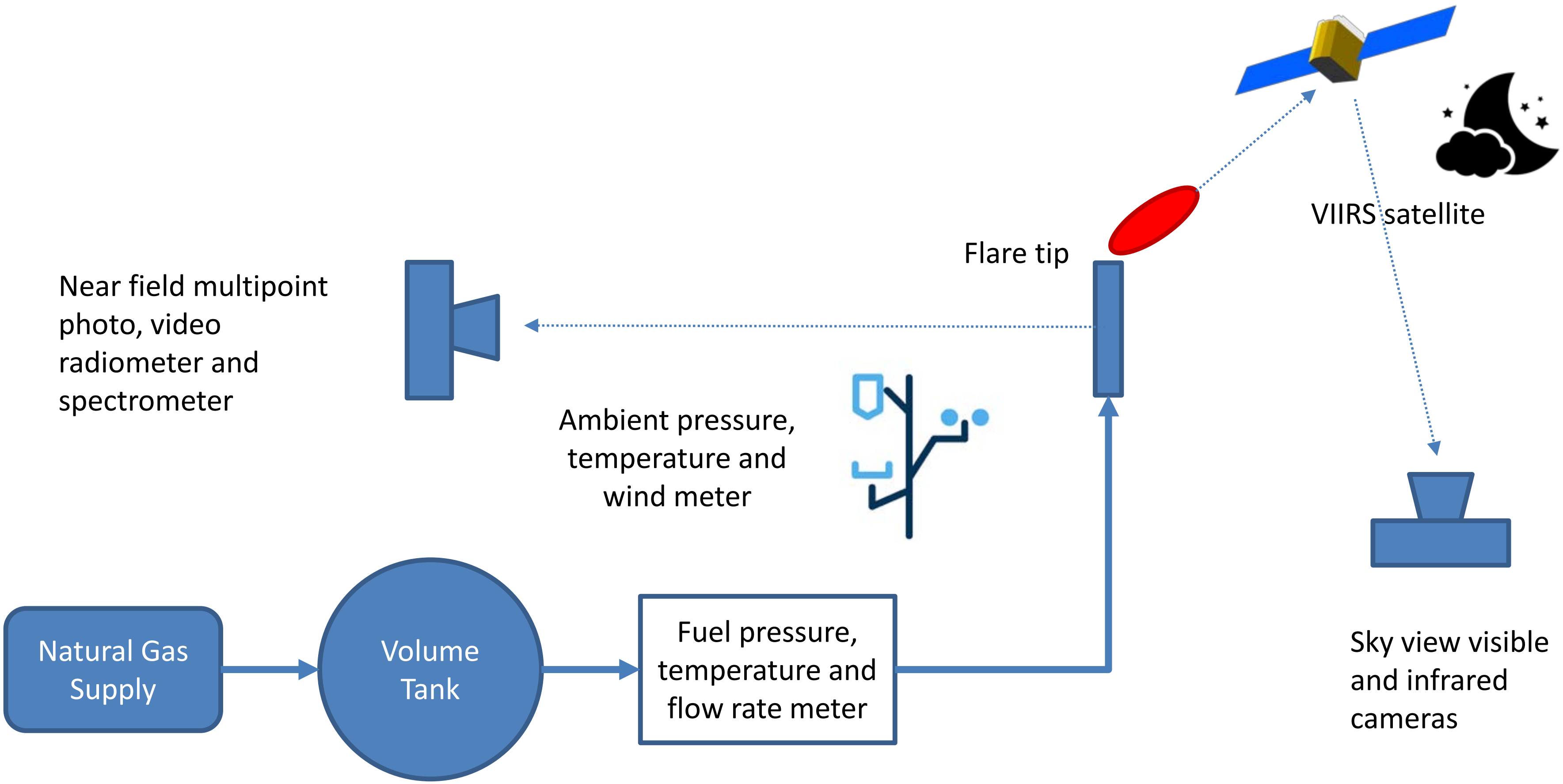
Stage 2, Oct. 2018, 12 *double* flares

			Satellite zenith angle		
Flare size	Flow rate lb/hr	Flared volume BCM/yr	Nadir	Medium	Side
Small + Small	1500 + 1500	0.016	1	2	1
Small + Medium	1500 + 7500	0.05	1	2	1
Medium + Medium	7500 + 7500	0.08	1	2	1

Stage 3, Aug. 2019 or later, Larger single flares

TBD

Tulsa flare experiment setup



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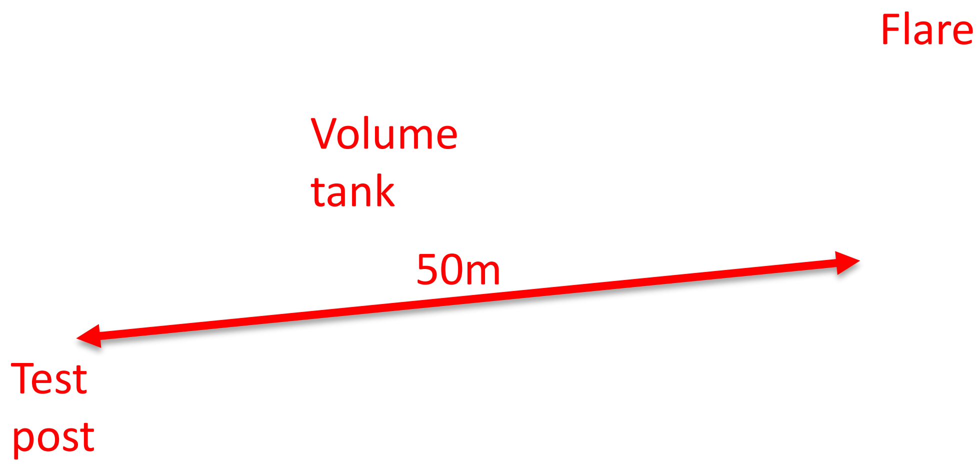
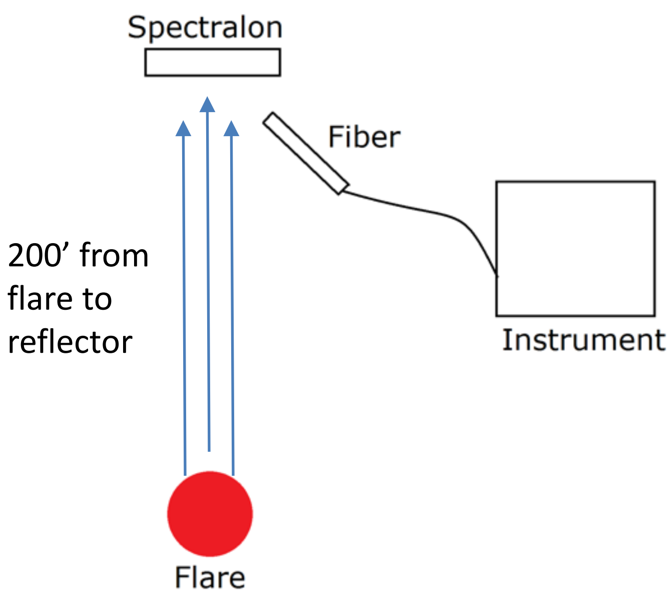
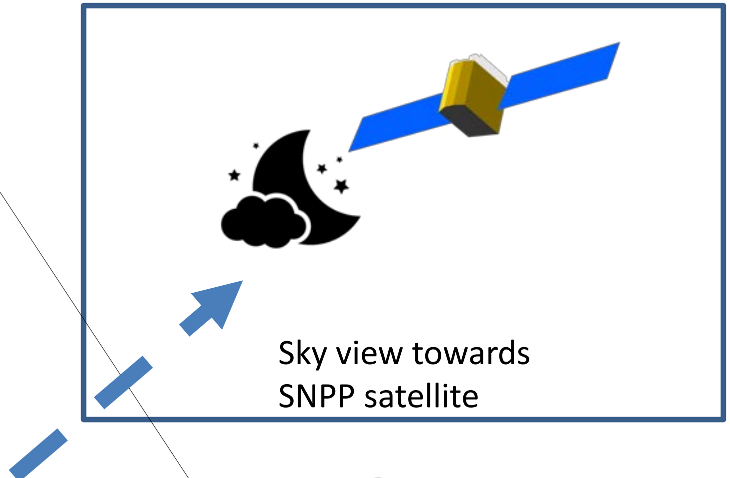


Near field ASD FieldSpec radiometer
0.4 – 2.5 um VIS / SWIR spectral range



Sky view visible and infrared cameras

Infrared-enabled
astrophotography
DSLR camera



Stars with the astrophotography camera

No clouds with thermovisor

FLIR
Thermovisor

9 DOF IMU –
Inertial
Measurement Unit

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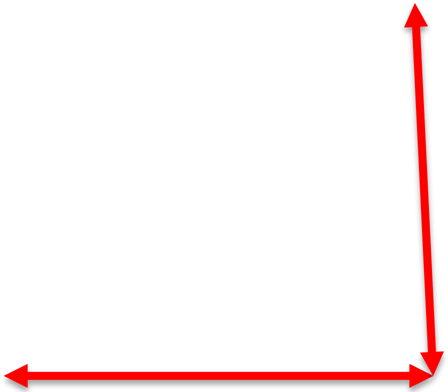

Large flare 2018-01-12 07:12 UTC

VNF: T = 1795 K, S = 64 m^2, RH = 38 mW

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Flowrate 77766.9 lb/hour ~ 0.43 BCM/year
Satellite zenith angle 66.76 deg (side view)

Flare 2018-01-12   T(ASD) = 1695 K

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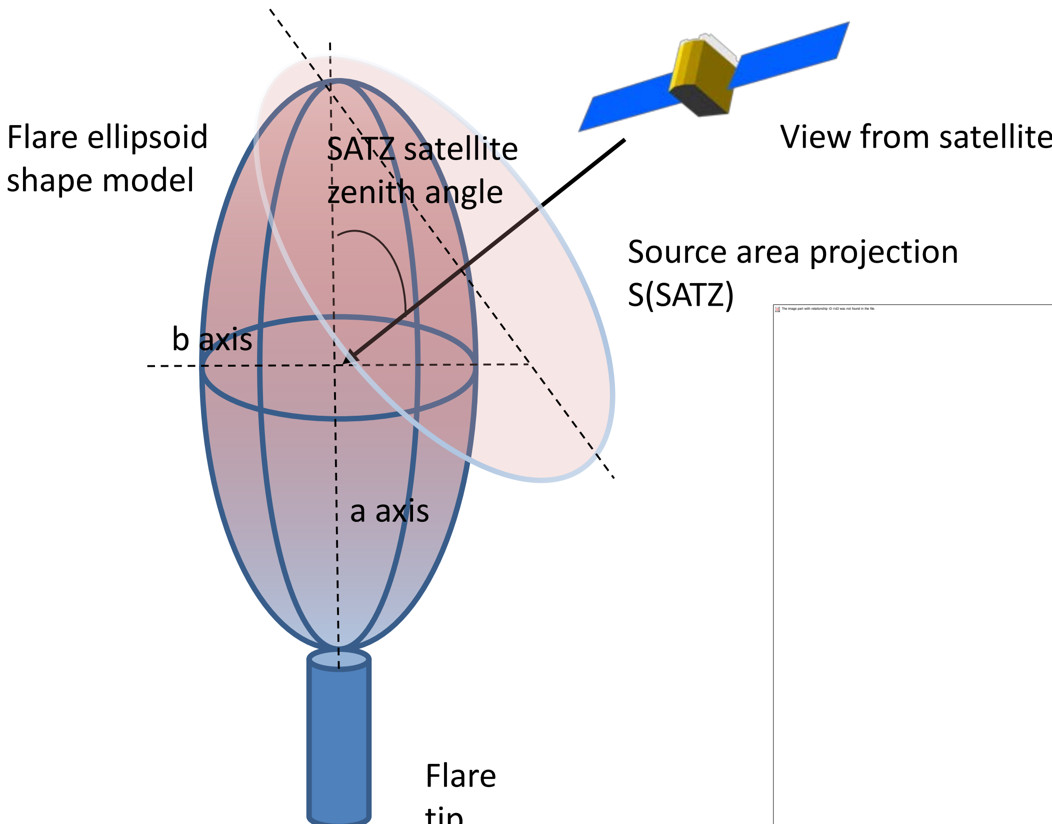
Flare 3D shape from satellite

- Assuming the shape does not change much with flow rate, we “normalize” the radiative heat (from VIIRS) by flow rate (measured at site)
- To derive the shape, we model flare as 3D ellipsoid
- Ellipsoid axes ratio should explain statistical scatter of RH/Flow and the satellite zenith angle

Ellipsoid model for flare 3D shape



Single flare axes ratio from VNF= 3:1

Near-field flare shapes from ground video camera

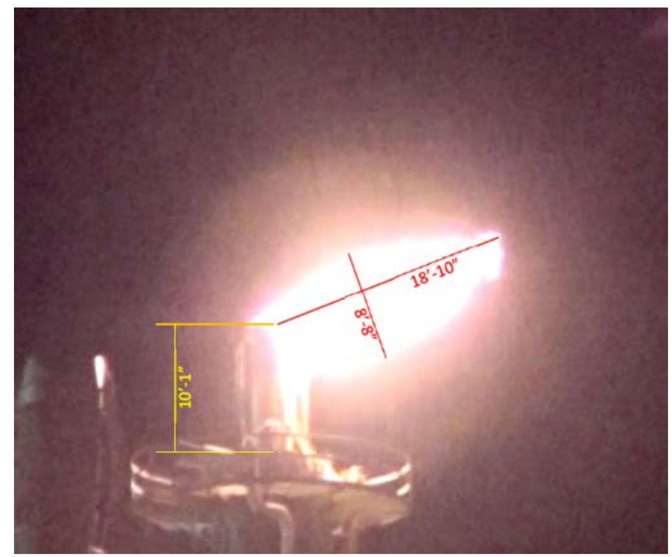
Large, 75K flow rate

Shape 96’ : 30’
Ratio 3.2

Medium, 7.5K flow rate

Shape 27’ : 10’
Ratio 2.7

Small, 0.75K flow rate



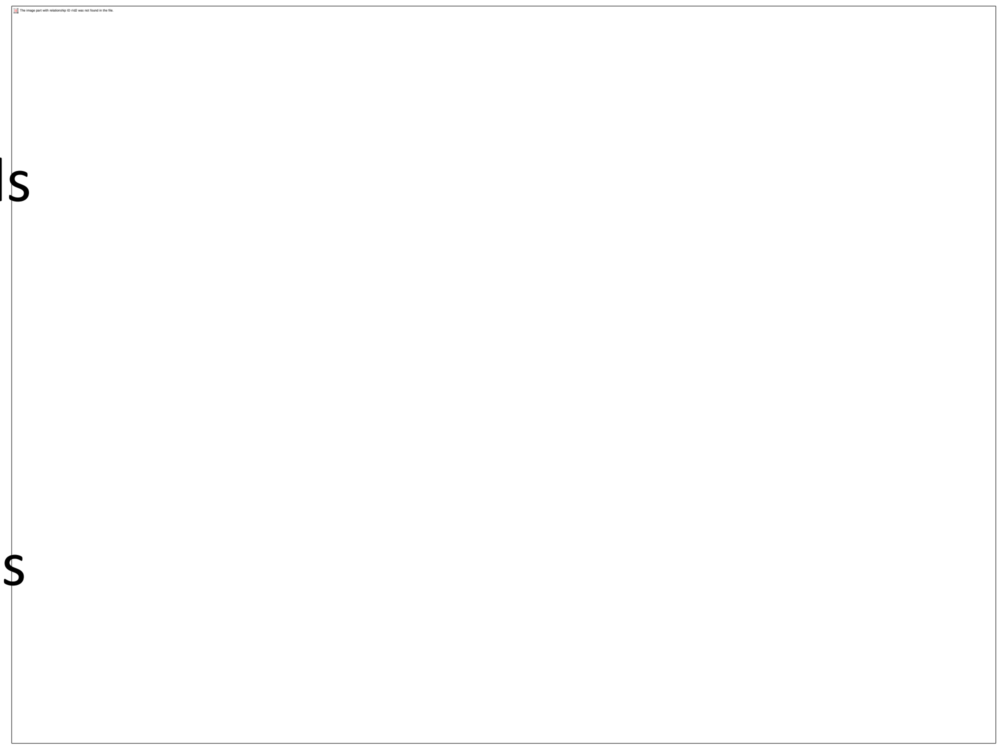
Shape 18’ : 8’
Ratio 2.25

Multiple pixel detections for subpixel size source ?

For 2/3 of the test flares VNF detects multiple pixels

“Old” strategy: use pixel with maximum heat RH

”New” strategy: sum pixels with RH > 0.75 max(RH)



Flowrate vs Radiant Heat correlation

max(RH)
with 3D correction
$R2 = 0.96$

Sum [RH > 0.75 max(RH)]
without 3D correction
$R2 = 0.99$

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CEDIGAZ 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'

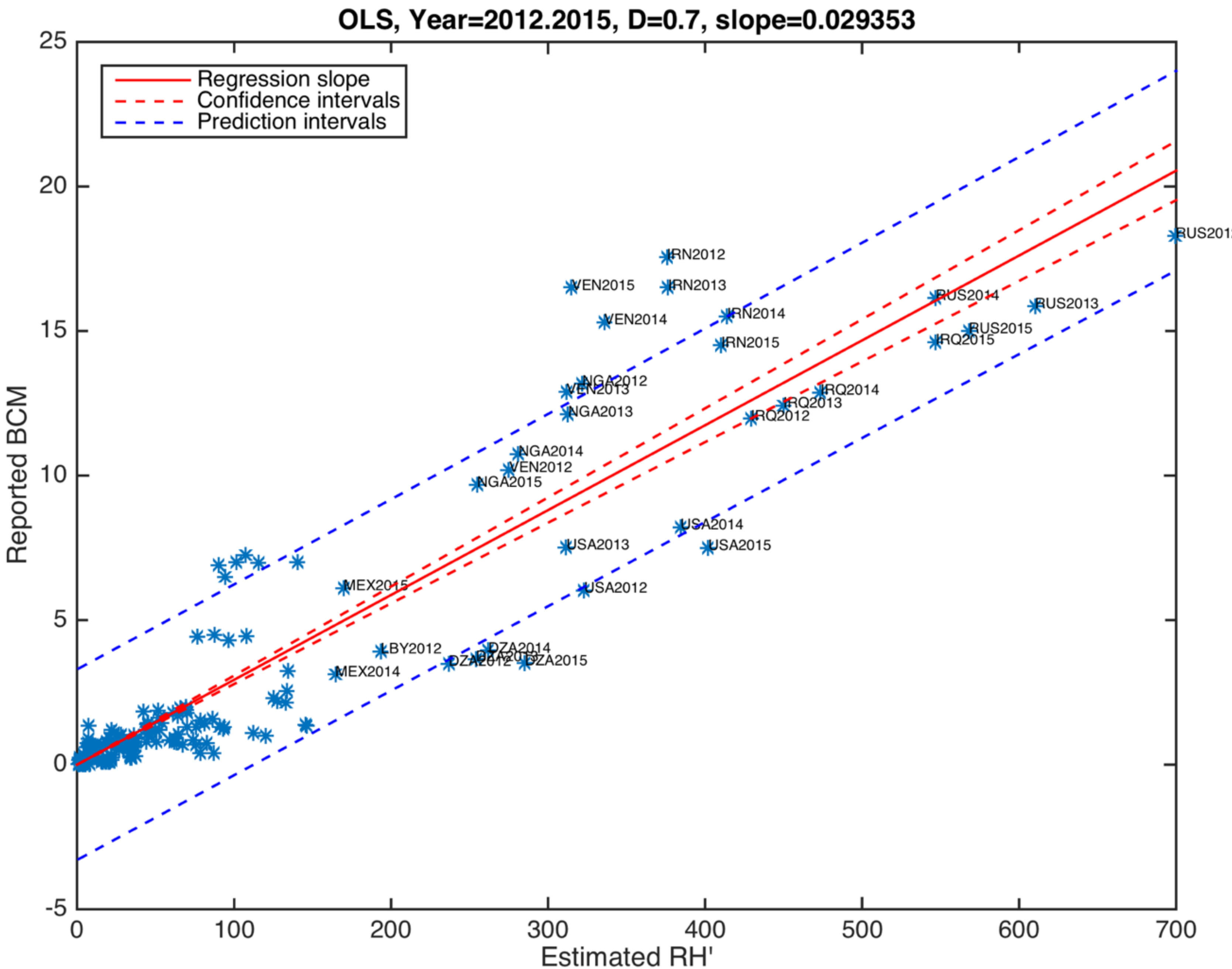
$$\text{Flared Volume} = \text{Slope} \times \text{RH}'.$$

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
RUS2012
IRN2012
VEN2015
IRN2013
RUS2014
RUS2013
VEN2014
IRN2014
RUS2015
IRN2015
IRQ2015
NGA2012
VEN2013
IRQ2014
IRQ2013
NGA2013
IRQ2012
NGA2014
VEN2012
NGA2015
USA2014
USA2013
USA2015
MEX2015
USA2012
LBY2012
DZA2014
DZA2012
DZA2015
MEX2014

From instant Flowrate – to BCM / year

Ideal gas law:

$$PV = \frac{flowrate}{molar\ mass} RT$$

Using ambient P and T in Tulsa:

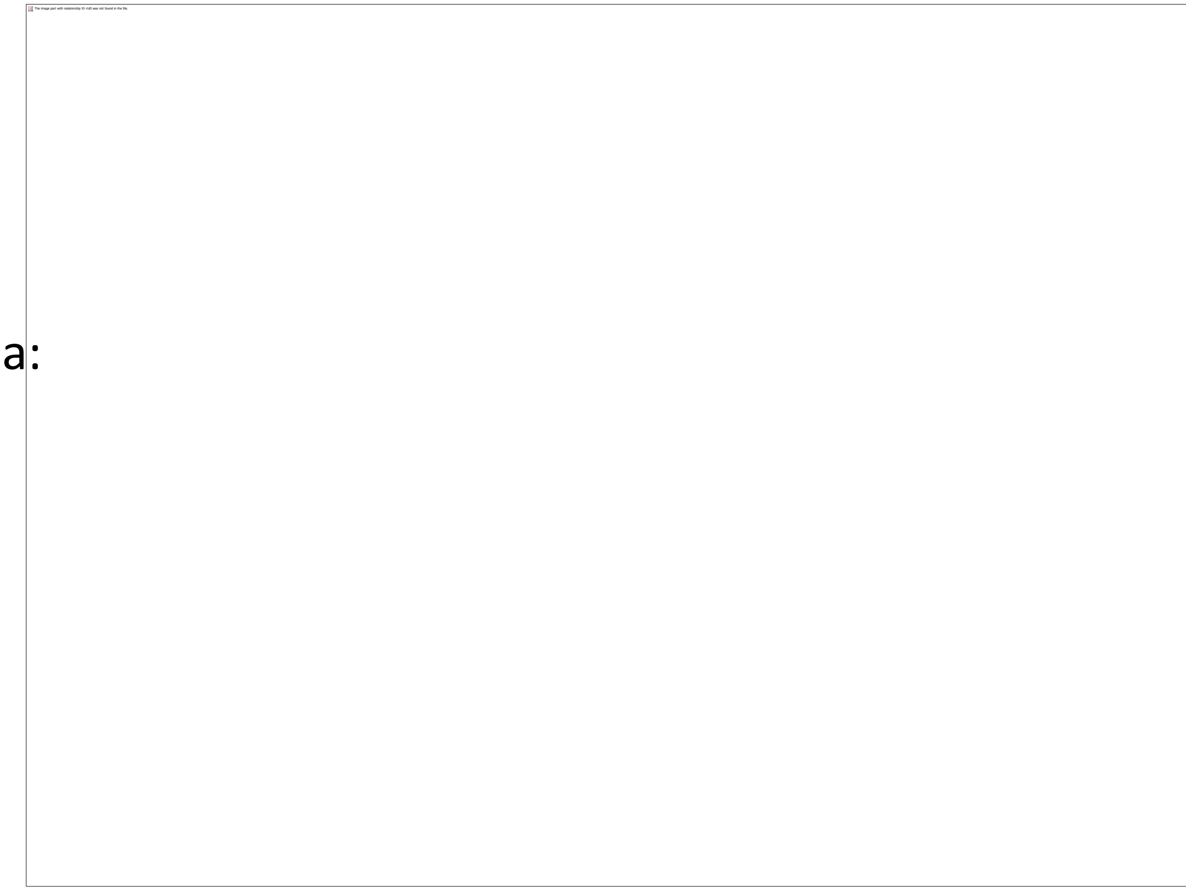
BCM_{Tulsa} = 0.032539 RH'

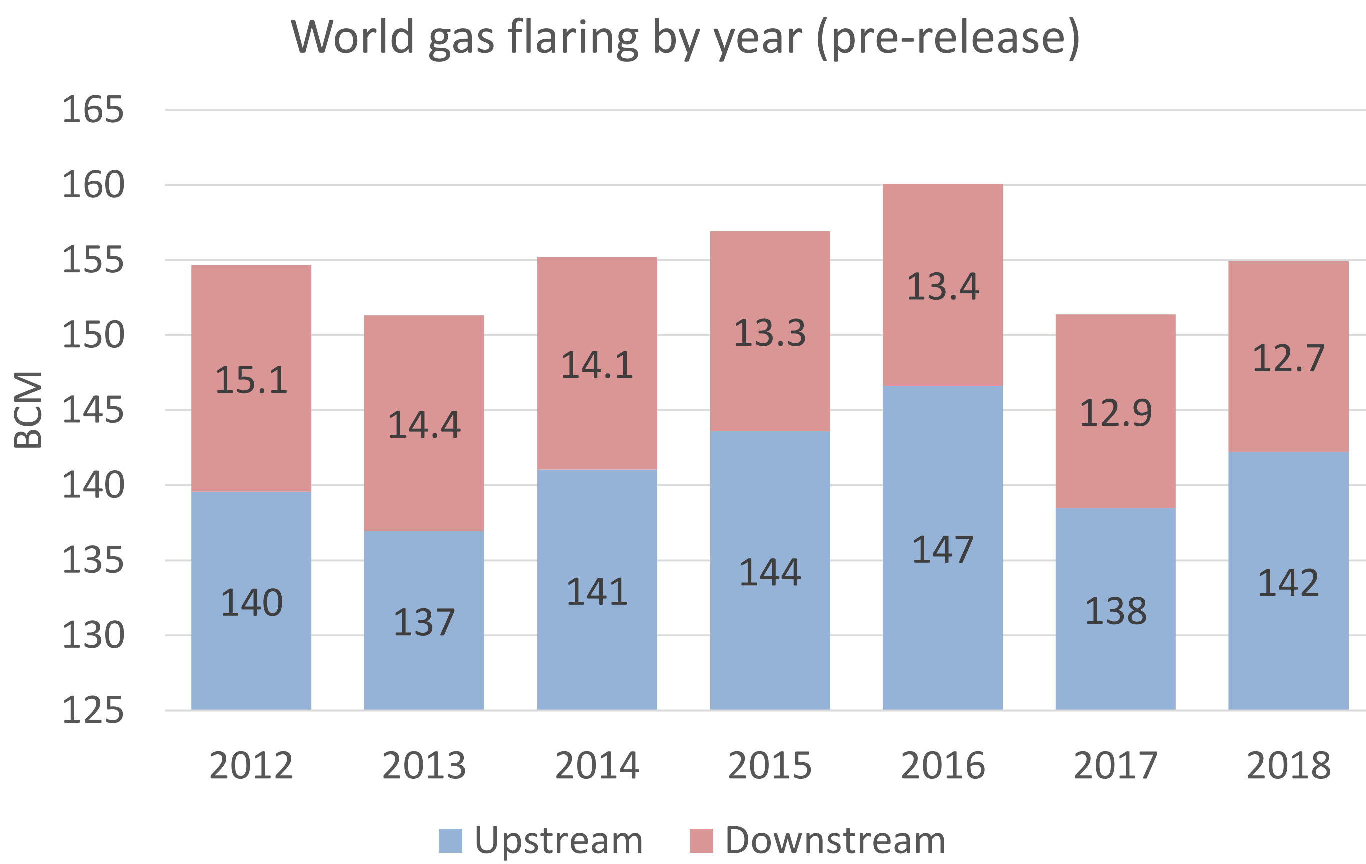
Compare to CEDICAZ scaling:

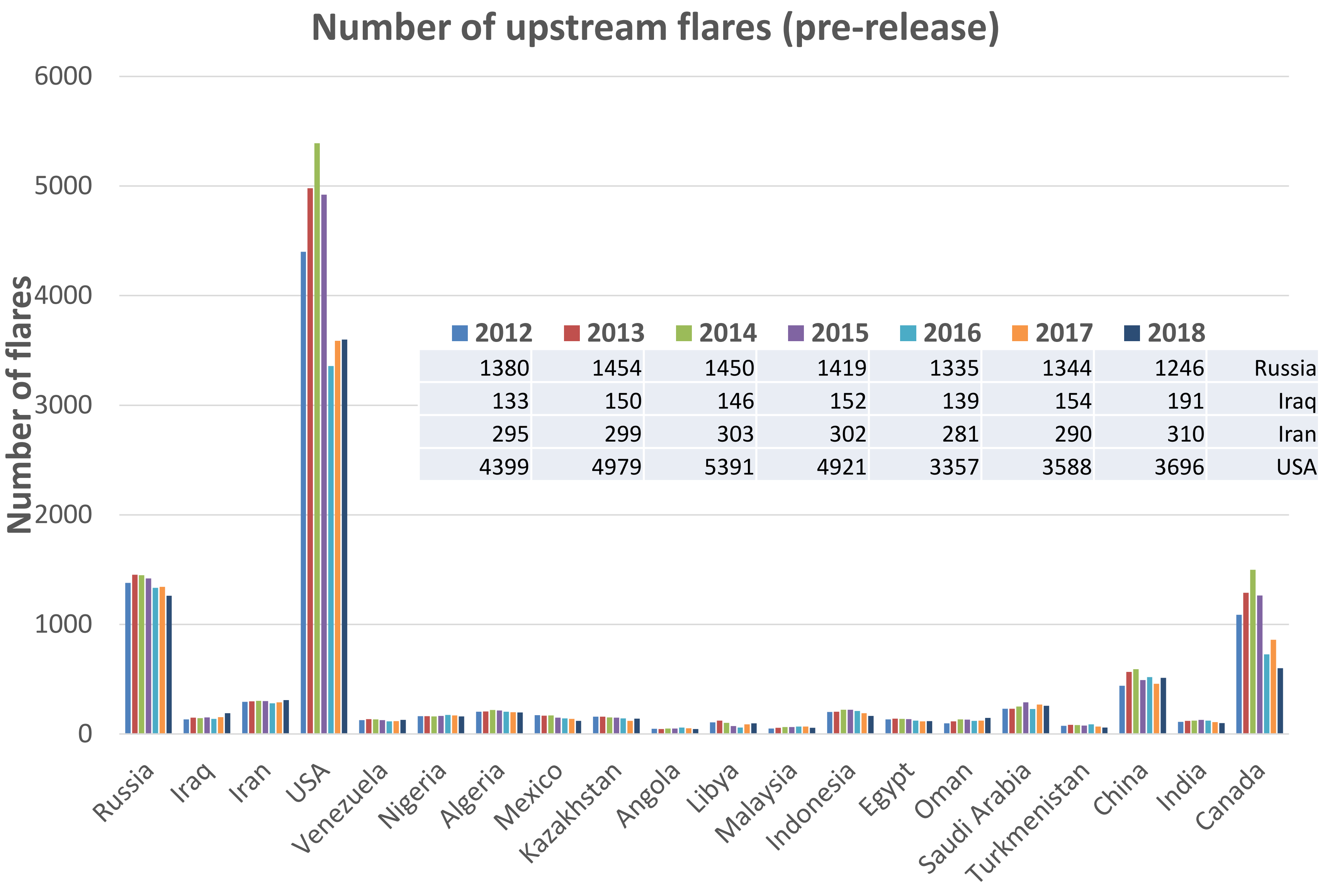
$BCM_{CEDIGAZ}$ = 0.029353 RH'

Scaling difference:

BCM_{Tulsa} / $BCM_{CEDIGAZ}$ = 1.1

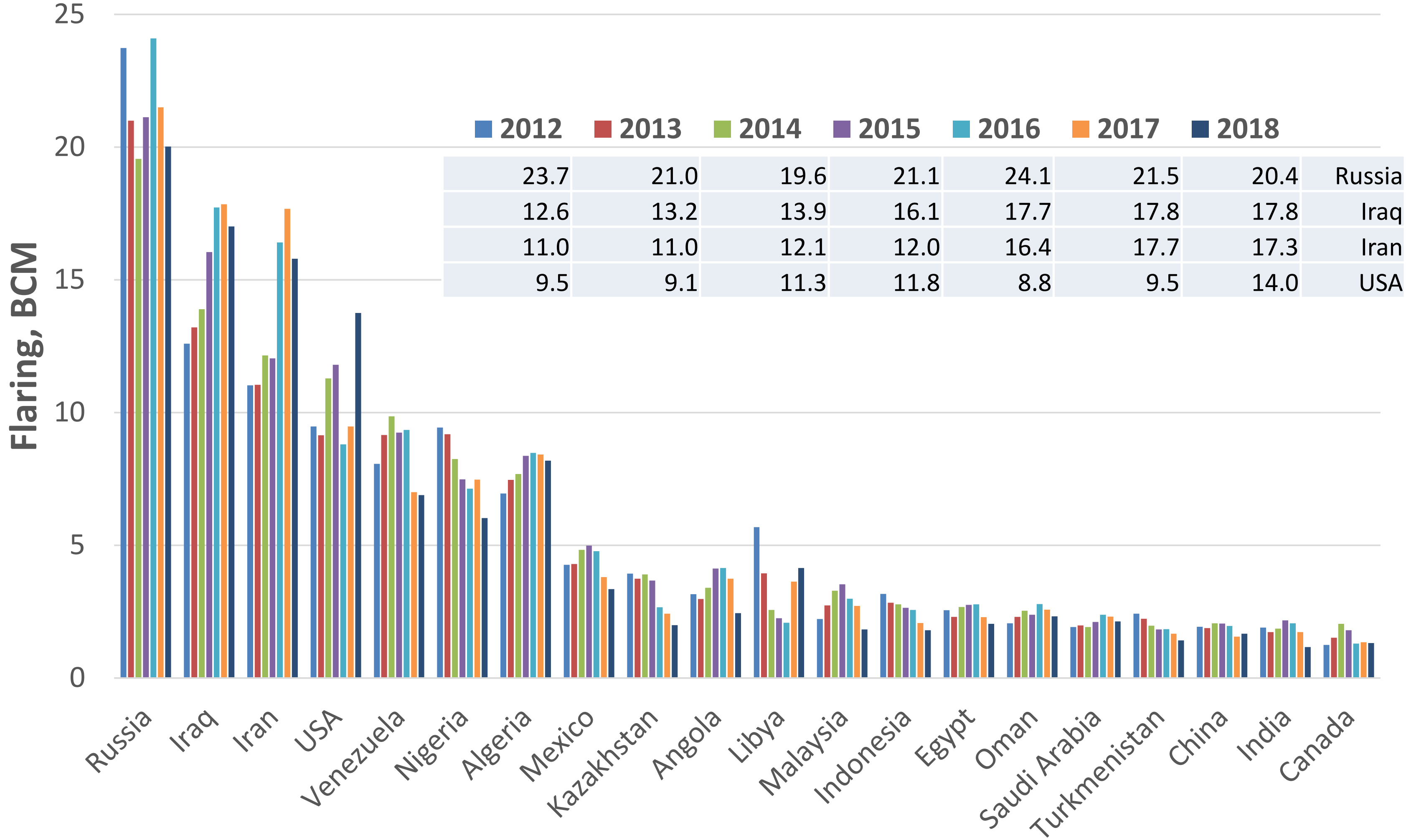



World gas flaring by year (pre-release)
BCM
165
160
155
150
145
140
135
130
125
2012
2013
2014
2015
2016
2017
2018
140
137
141
144
147
138
142
15.1
14.4
14.1
13.3
13.4
12.9
12.7
Upstream
Downstream



2012	2013	2014	2015	2016	2017	2018	
1380	1454	1450	1419	1335	1344	1246	Russia
133	150	146	152	139	154	191	Iraq
295	299	303	302	281	290	310	Iran
4399	4979	5391	4921	3357	3588	3696	USA

Upstream Flaring in billions of cubic meters (pre-release)



2012	2013	2014	2015	2016	2017	2018	
23.7	21.0	19.6	21.1	24.1	21.5	20.4	Russia
12.6	13.2	13.9	16.1	17.7	17.8	17.8	Iraq
11.0	11.0	12.1	12.0	16.4	17.7	17.3	Iran
9.5	9.1	11.3	11.8	8.8	9.5	14.0	USA

Conclusions

- *VNF sensitivity* is sufficient to detect 0.005 BCM flares
- *"Black body" flare spectrum* for SWIR VIIRS bands was confirmed by the ground truth radiometer
- *3D flare shape* can be detected from orbit with multiple angle detections
- Both Max(RH) and Sum [RH > 0.75 max(RH)] are strongly *correlated with flow rate*
- CEDIGAZ country-level RH to *BCM scaling is confirmed* with the test flares within 10% error