The RST-FLARE algorithm for gas flaring characterization by satellite data: the case of Niger Delta region

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THE GAS FLARING

The burning of natural gas associated with oil extraction mainly acting as safety device to protect vessels/pipes from over-pressuring due to unplanned upsets

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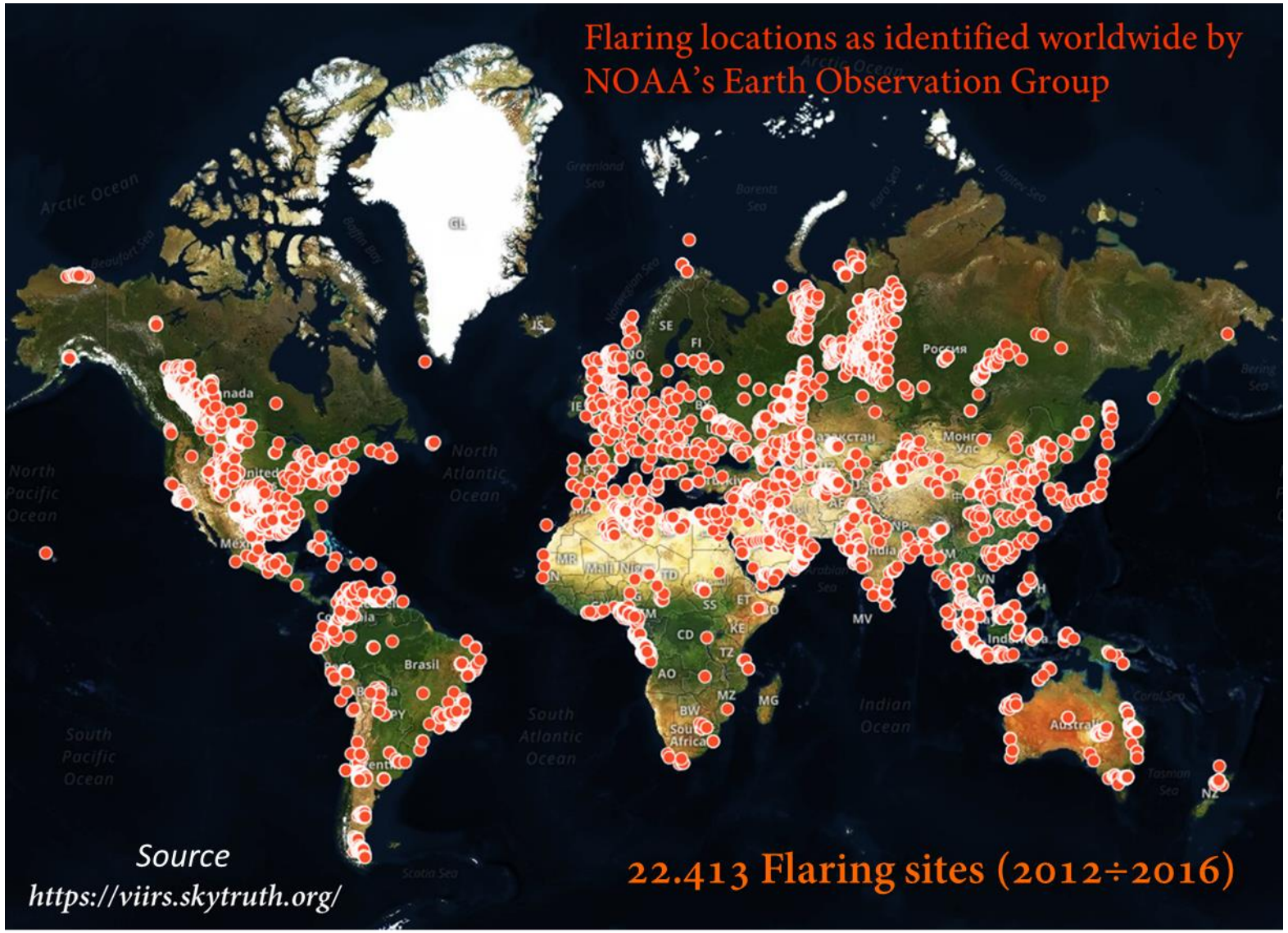
A Global Challenge



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A Global Challenge

Double Negative Effect

Waste of a valuable clean energy resource

waste of 3,000MW of electricity

Anthropogenic source of GHGs

~ 400 million tons of CO_2 into the atmosphere

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THE ROLE OF REMOTE SENSING IN GF MONITORING

The **main issue** involved in addressing environmental aspects of flaring consists in the **lack of systematic, complete and reliable data** on its magnitude and spatial distribution

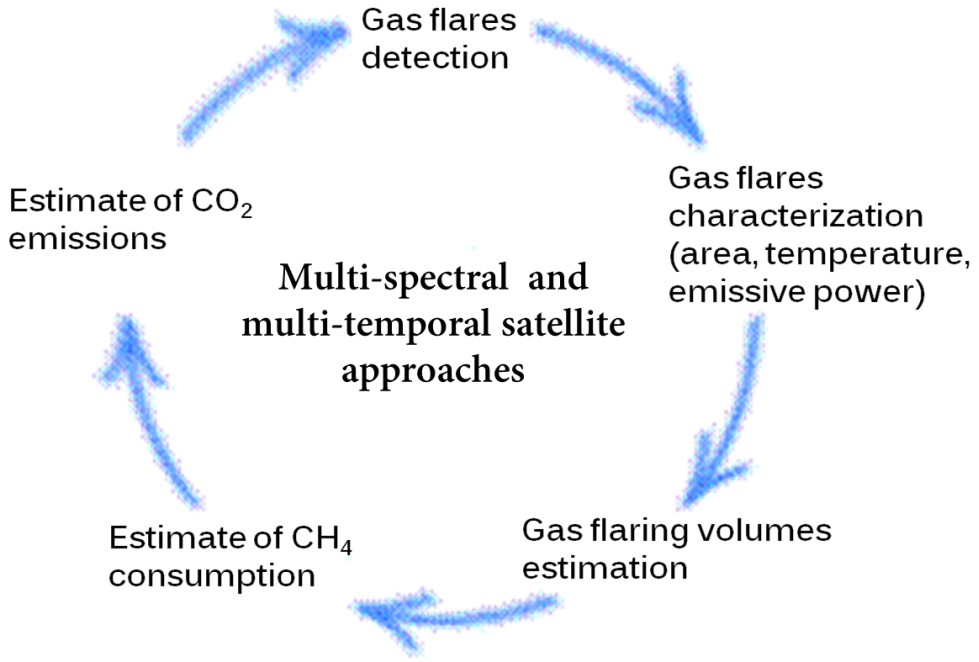
Limiting factors:

(i) a limited access to official information on flaring locations

(ii) the heterogeneity in spatial and temporal sampling strategies

(iii) data typically self-reported by the flare operators

EXPLOITATION OF SATELLITE DATA



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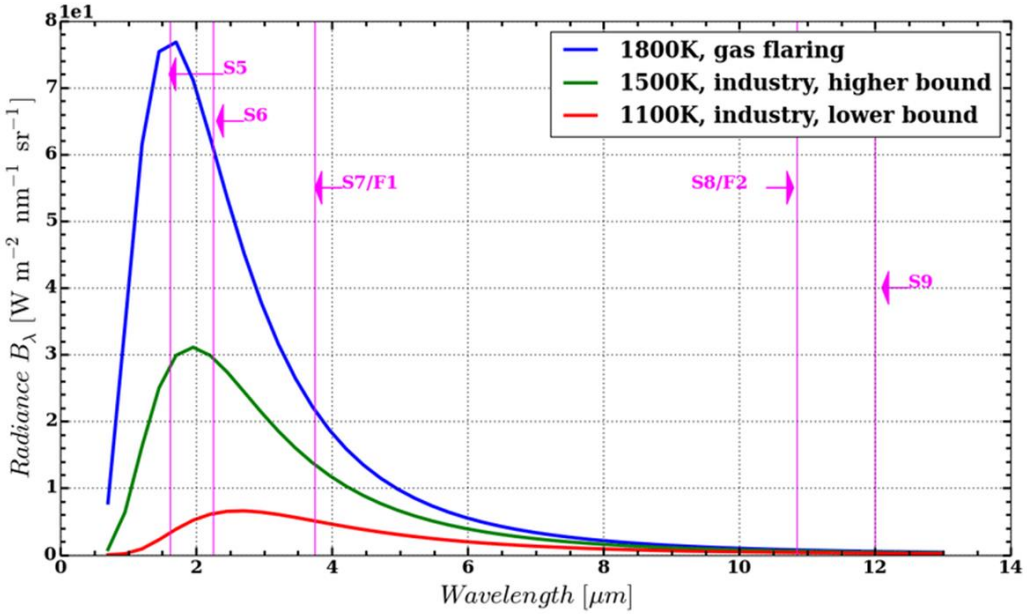
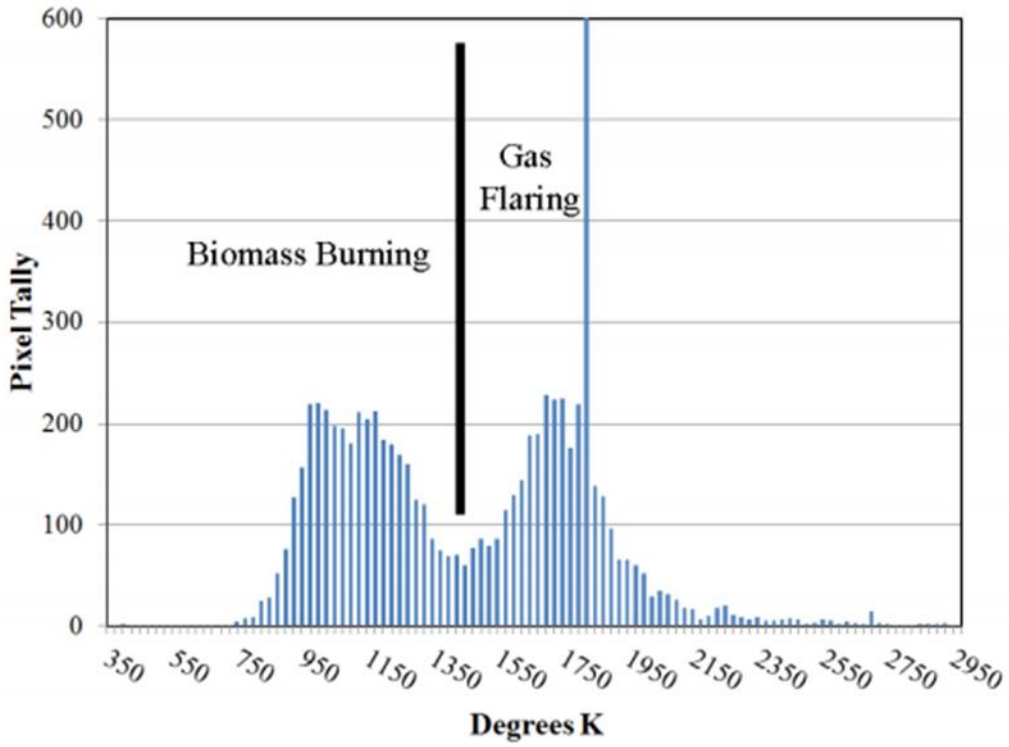
General gas flares characteristics

- **Permanent point-sources**
- **Sub-Pixel Sources**

  (fraction of $1x10^{-4}$ within a 1x1 km^2 pixel)

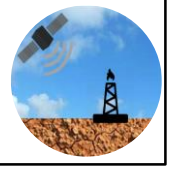


Planck curves for typical industrial processes and gas flaring temperatures, together with ***SLSTR*** *SWIR (S5 and S6), MIR (S7 and F1) and TIR (S8, S9 and F2) channels [****source: Caseiro et al. 2018****]*



Temperature histogram for 3 July 2013 VIIRS image [source: Elvidge et al. 2013]

- **Mostly continuously active**
- **High temperature**



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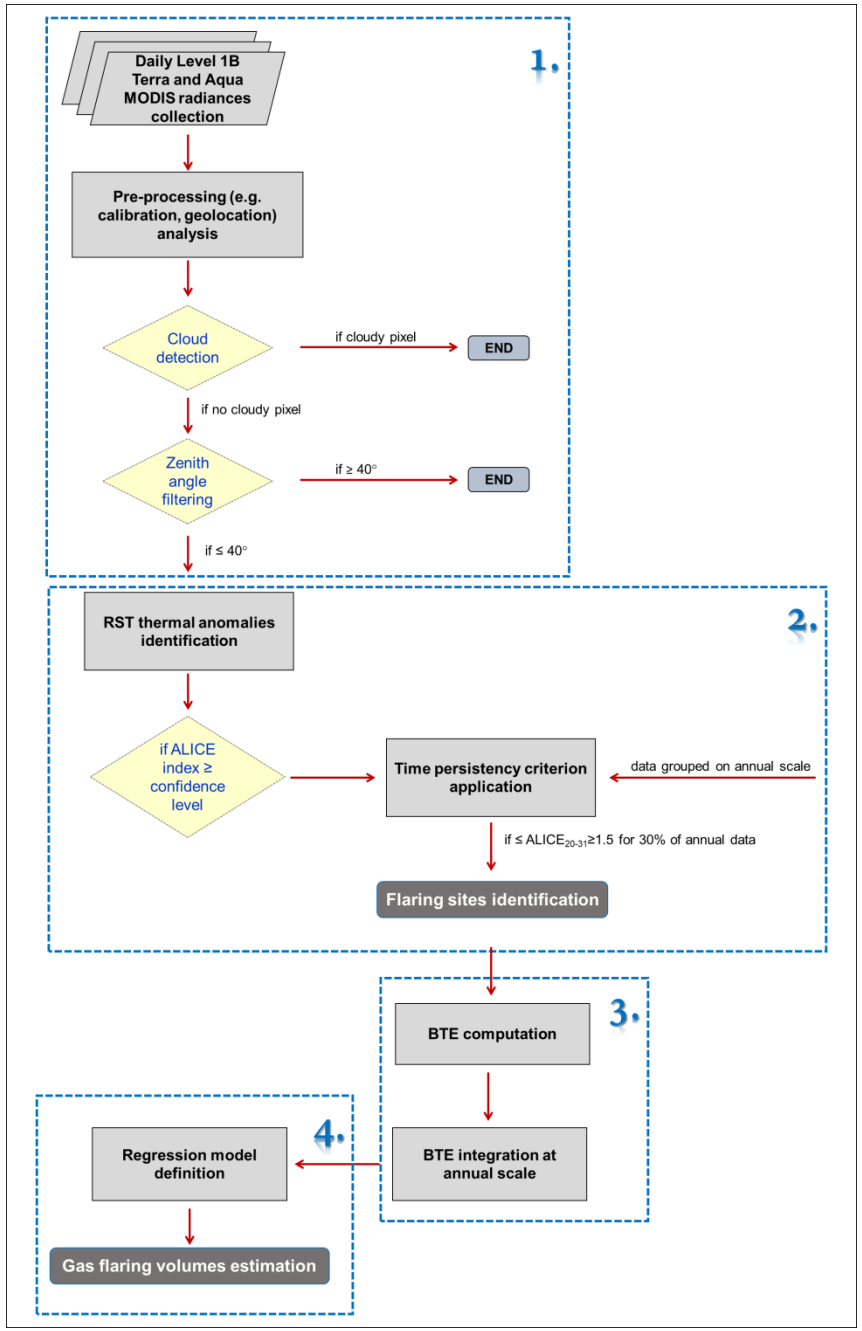
The RST-FLARE Algorithm

1. Data Pre-Processing

2. Flaring Sites Detection

3. Source Emissive Power Computation

4. Gas Flared Volumes Estimation



Faruolo, M.; Lacava, T.; Pergola, N.; Tramutoli, V. On the Potential of the RST-FLARE Algorithm for Gas Flaring Characterization from Space. *Sensors 2018*, 18(8), 2466, https://doi.org/10.3390/s18082466.

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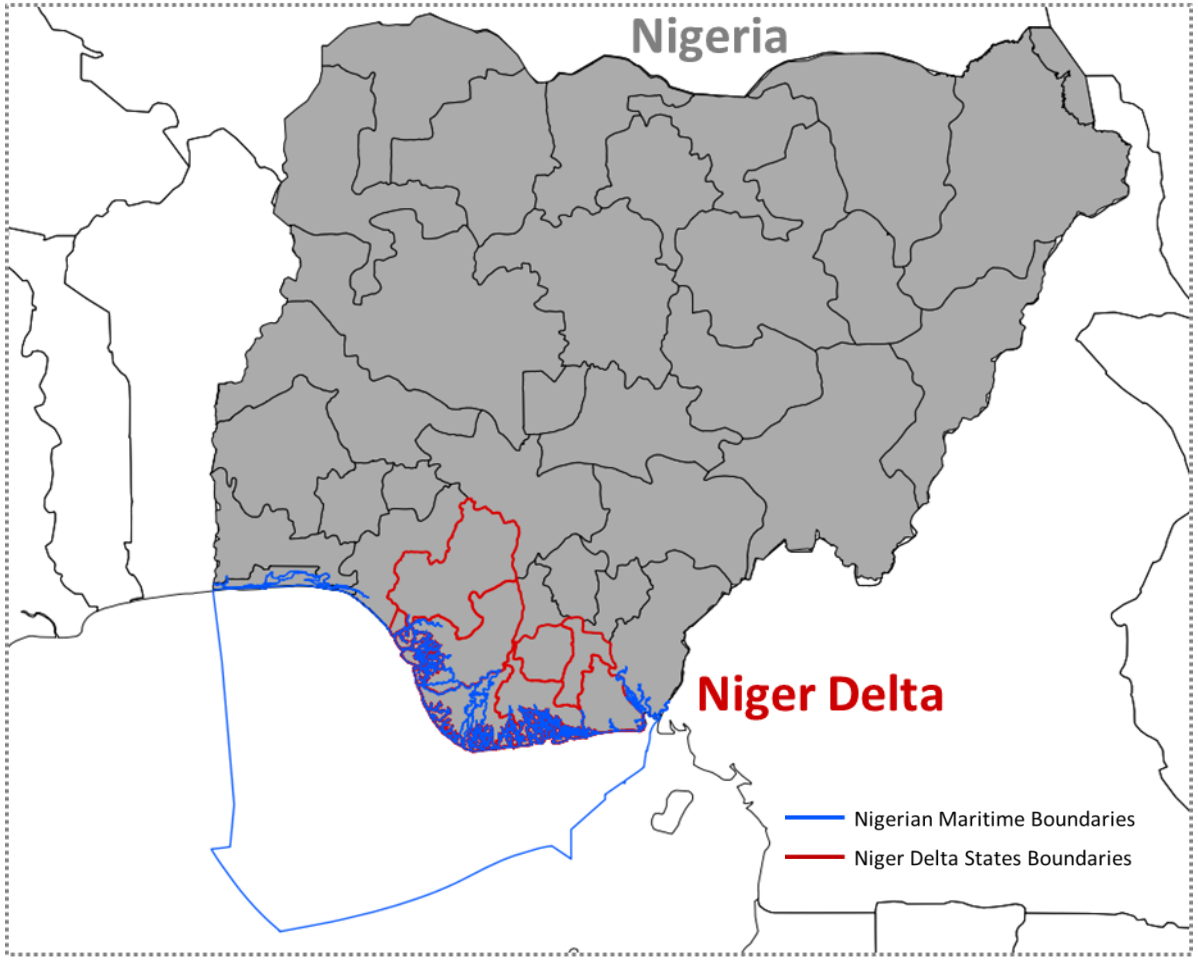
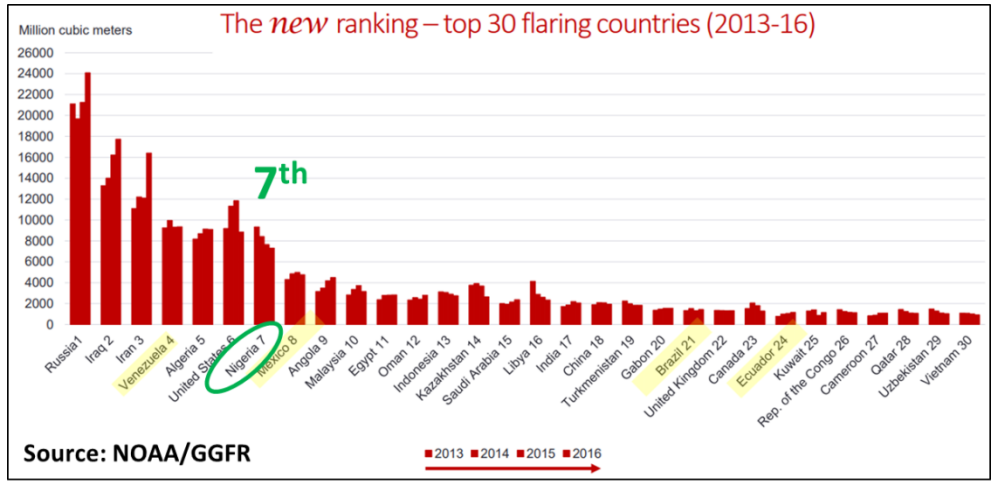
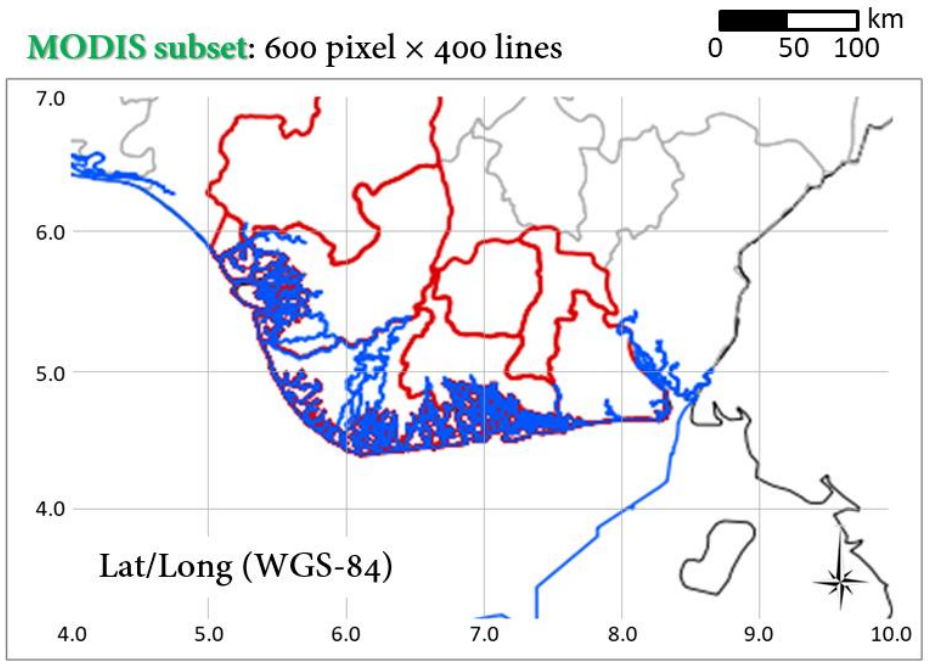
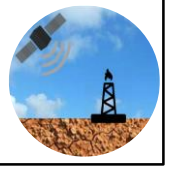
THE REGION OF INTEREST





THE NIGER DELTA REGION





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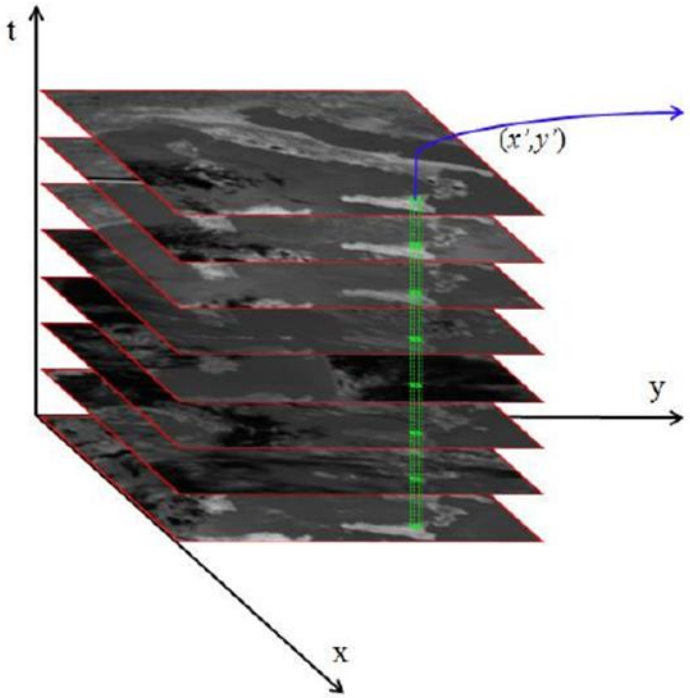
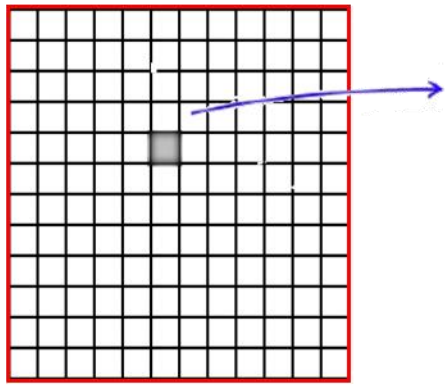
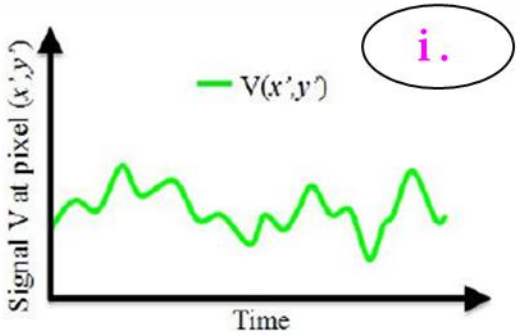
THE ROBUST SATELLITE TECHNIQUES

[Tramutoli 1998, 2005, 2007]

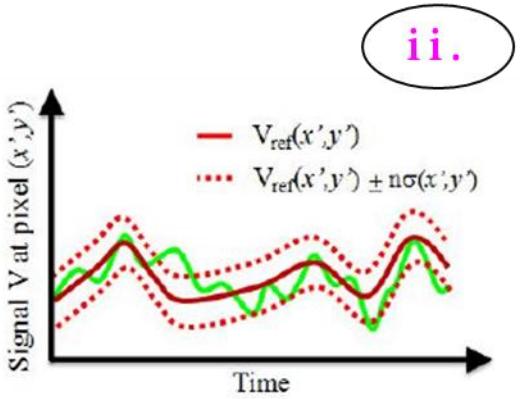
Change detection scheme based on the **analysis of multiyear series of satellite data acquired in homogenous spatiotemporal conditions** to reconstruct the normal behavior of the signal (i.e., same spectral channel, same geographic area, same month and hour of acquisition)







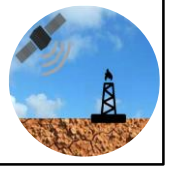
V: signal measured at time *t* for each pixel (*x*,*y*)



The signal behavior in "**normal**" **conditions** expressed in terms of

V_{REF} = **monthly temporal mean**

σ_V = **standard deviation**



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THE ROBUST SATELLITE TECHNIQUES

[Tramutoli 1998, 2005, 2007]

ALICE

Absolutely Local Index of Change of the Environment

iii.

$$\otimes_V(x,y,t) \equiv \frac{V(x,y,t) - \mu_V(x,y)}{\sigma_V(x,y)}$$

standardized variable characterized by a Gaussian behavior

A pixel is flagged as "anomalous" when the deviation from the value expected to measure in normal conditions (μ) is greater than its natural variability (σ)

$$\otimes_V(x,y,\tau) > c$$

c = confidence level

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THE ROBUST SATELLITE TECHNIQUES

[Tramutoli 1998, 2005, 2007]

For gas flares:

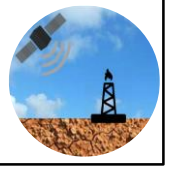
$$\otimes_{20-31}(x,y,t) = \frac{BT_{20-31}(x,y,t) - \mu_{20-31}(x,y)}{\sigma_{20-31}(x,y)} \geq 1.5$$

MIR: ch20 (3.66–3.84μm), TIR: ch31 (10.78–11.28μm)

implemented at the pixel level

assumed as representative of thermal anomalies related to gas flaring

Faruolo, M.; Coviello, I.; Filizzola, C.; Lacava, T.; Pergola, N.; Tramutoli, V. A satellite-based analysis of the Val d'Agri Oil Center (southern Italy) gas flaring emissions. *Nat. Hazards Earth Syst. Sci., 2014*, 14, 2783-2793, DOI:10.5194/nhess-14-2783-2014, (http://www.nat-hazards-earth-syst-sci.net/14/2783/2014/nhess-14-2783-2014.pdf). ISSN: 1561-8633.



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1. Data Pre-Processing

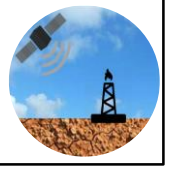
Collected Satellite Data

- Nighttime Daily Level 1B MODIS data (2000÷2016)
- NOAA CLASS web site archive
- BTs: ch20 (3.66–3.84μm); ch31 (10.78–11.28μm); ch32 (11.77–12.27μm), at 1km spatial resolution

Used Satellite Data

- **No cloudy Pixels**
  (OCA approach on MODIS ch32)
- satellite zenith angle (SatZA) < 40°
  (to reduce the impact of resampling and path radiance effects)
- solar zenith angle (SolZA) < 101°
  (to assure nighttime conditions)

* All data were collected at monthly scale to implement the RST-FLARE algorithm



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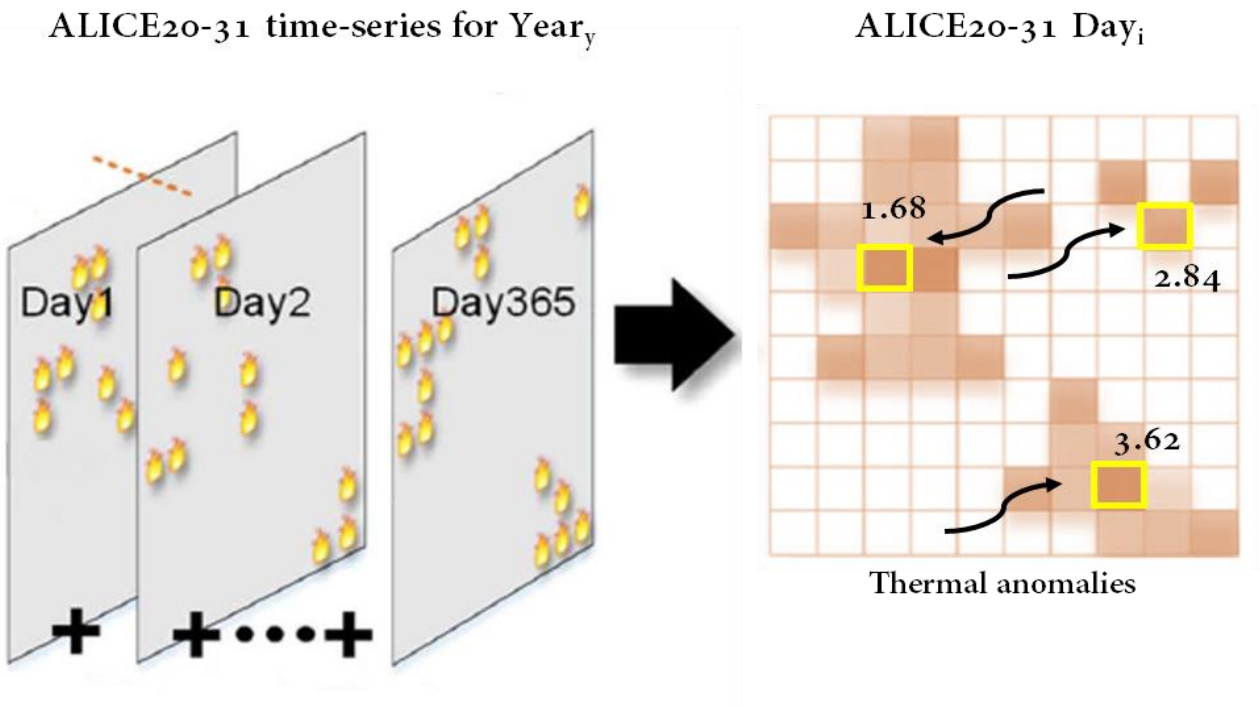
2. Flaring Sites Detection

I STEP: thermal anomalies detection



In each useful image (i.e., for all clear pixels with SatZA<40° & SolZA<101°), a pixel is flagged as thermal anomaly if $ALICE_{20-31} \geq 1.5$

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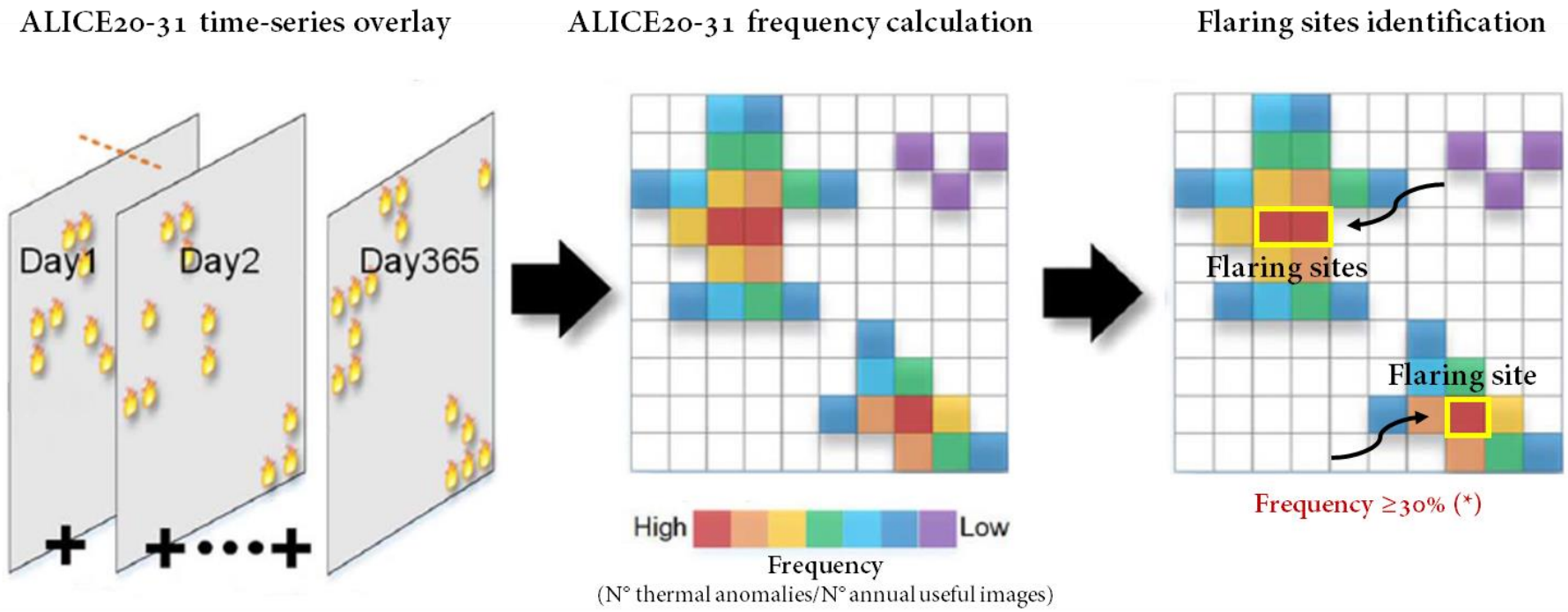
2. Flaring Sites Detection

II.a STEP

A **time persistency criterion** applied to the $ALICE_{20-31} \geq 1.5$ for each year (**Annual Aggregation**)



Within each year, a pixel is classified as flaring site when thermal anomalies (**ALICE20–31≥1.5**) are detected over **at least in 30% of images** belonging to the annual dataset (i.e., all clear pixels with SatZA<40° & SolZA<101°)

(*) Threshold derived by a series of tests based on the comparison between potential persistent source maps and a reference map (i.e., Google Earth)

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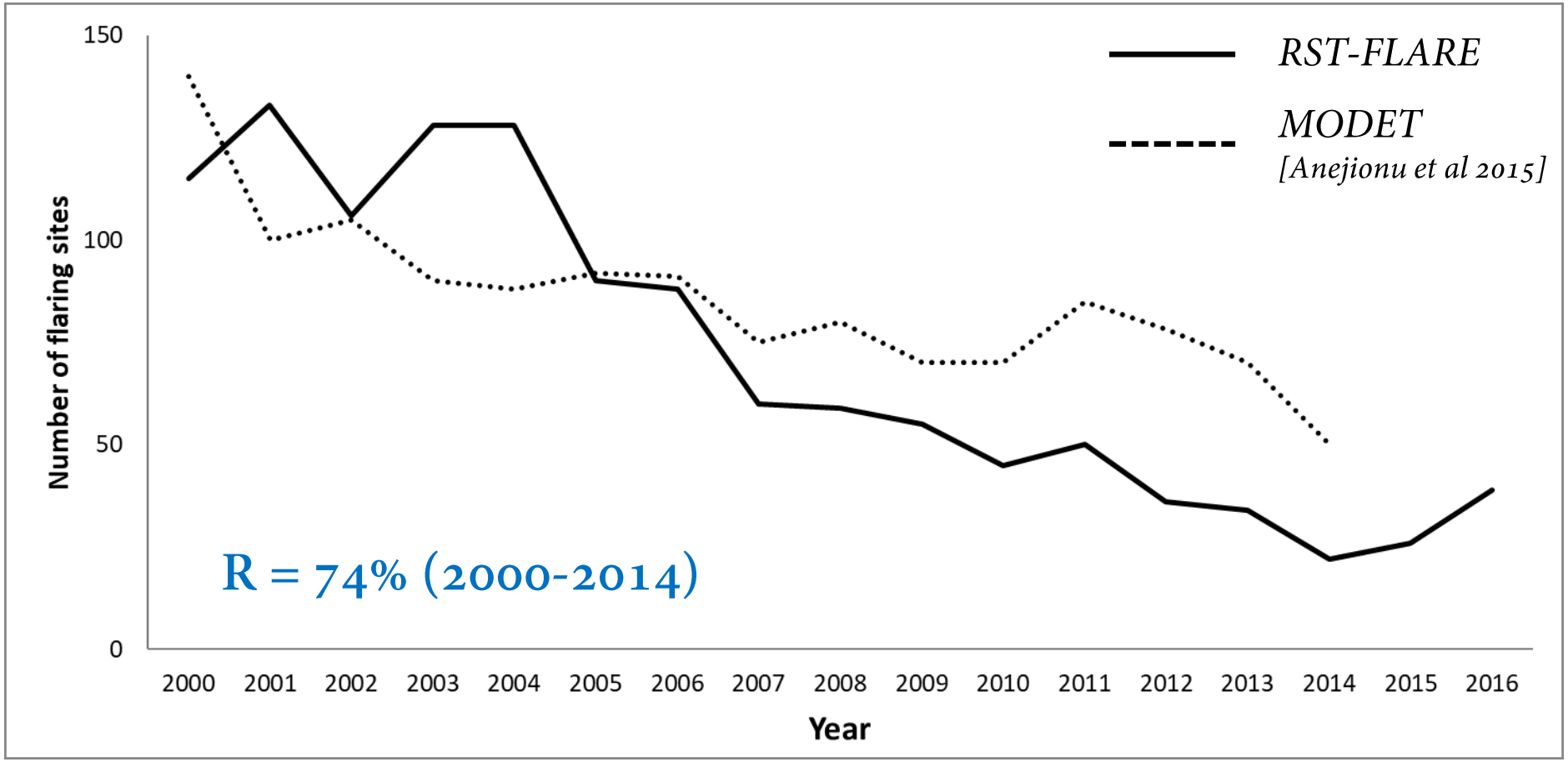
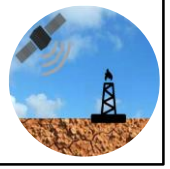
2. FLARING SITES DETECTION

ANNUAL ESTIMATES:
Flaring sites active «*for sure*» in that year

RESULT



Annual number of flaring sites detected in the Niger Delta region



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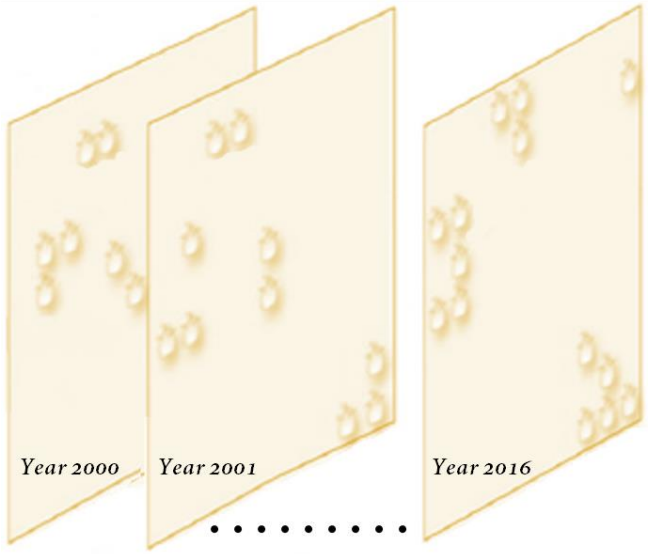
2. Flaring Sites Detection

II.b STEP

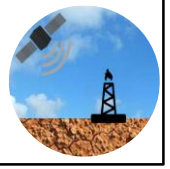
A **time persistency criterion** applied to the $ALICE_{20-31} \geq 1.5$ in all investigated years (**Multi-temporal Aggregation**)

Annual flaring sites maps



«or» condition applied to the 17 annual maps

To take into account the activity variation of each site (due to decommissiong/reactivation periods, increasing in oil production, etc.), a multi-temporal map is defined assuming as **flaring sites** all those pixels that, **at least in one year within the 17 investigated**, have been detected as **anomalous**



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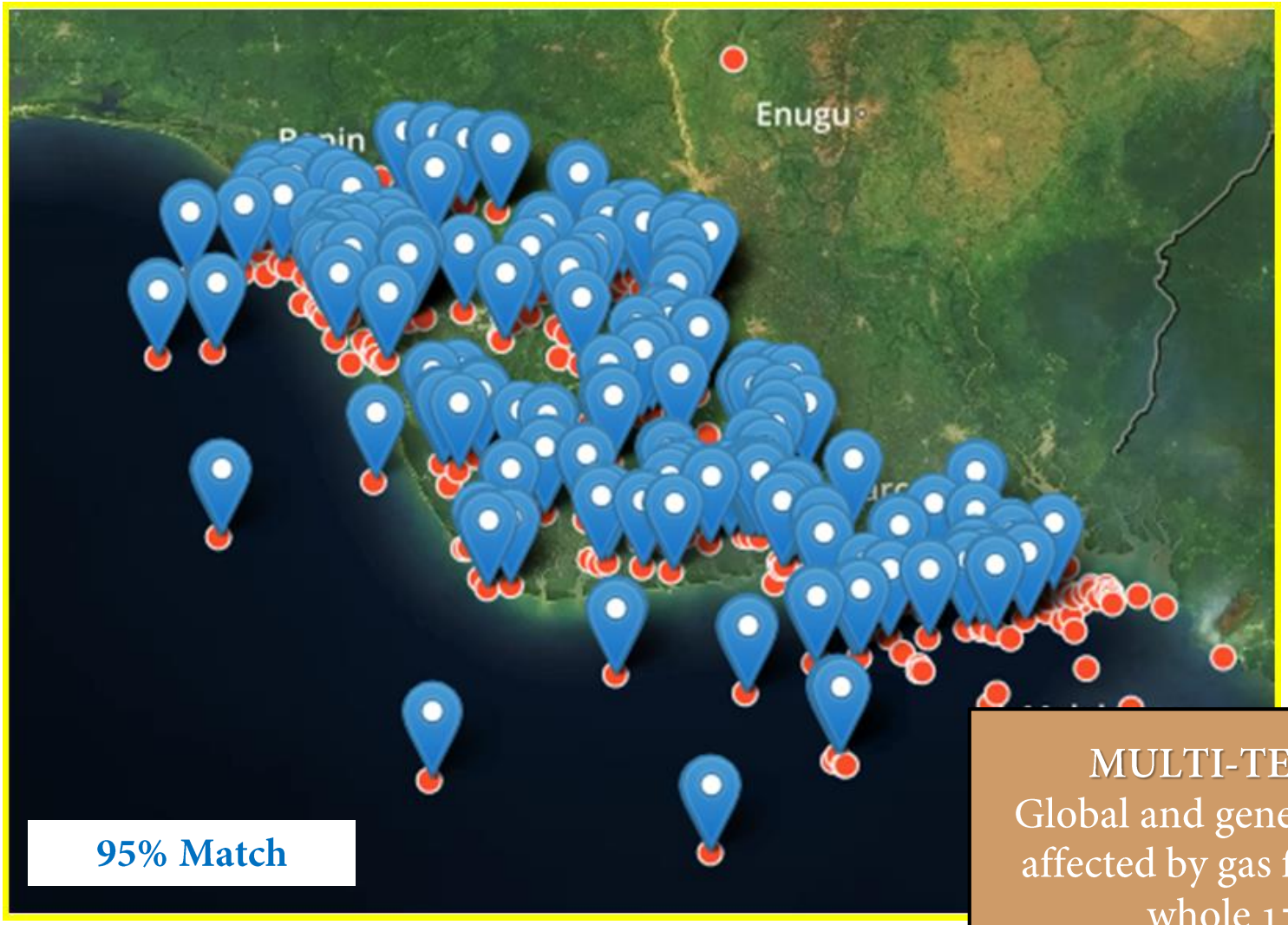
2. Flaring Sites Detection

Result



Background: SkyTruth layout (https://viirs.skytruth.org/apps/heatmap/flar

VNF

[Elvidge et al 2013]

RST-FLARE

MULTI-TEMPORAL MAP
Global and general overview of areas affected by gas flaring activity in the whole 17-year period

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3. Source Emissive Power Computation

Brightness Temperature Excess (BTE)

$$BTE_y = \sum_{j=1}^{M} \left(BT20_j - < BT20_{j,bg} > \right) \cdot \alpha_{j,y} \, [K]$$

computed for each flaring site only when a thermal anomaly is identified by the $ALICE_{20\text{-}31}$

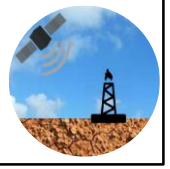
y refers to each of the investigated years in the 2000–2016 period

j refers to each of the M identified flaring site (only in presence of detected thermal anomaly)

BT20j is the brightness temperature (K) measured in the MODIS band 20 for the target j

<BT20j,bg>, referred to the background, is equal to the spatial mean of the temporal mean $\mu_{20}(x,y)$ in a 5x5 box around the site

α is a coefficient which weights the variability, between years, in sampling and cloud cover



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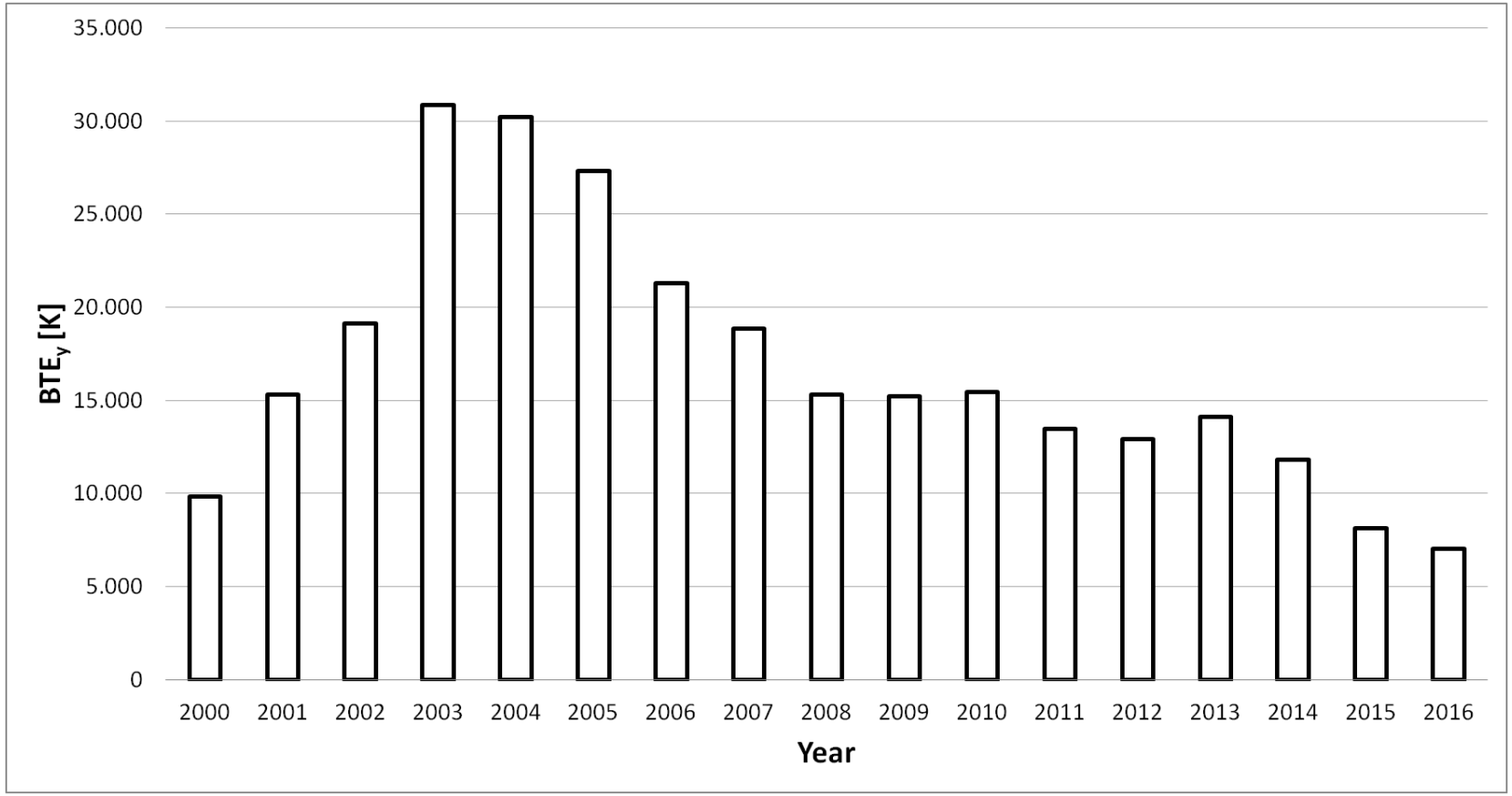
3. Source Emissive Power Computation

Result



Flaring sites BTE temporal trend

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4. Gas Flared Volumes Estimation

Linear Regression Model :

$$\text{Gas flared}_y = \gamma * BTE_y + \beta$$

Gas flared (assessed for the year y): the response variable in the model (Y)

BTE: the predictor variable (X)

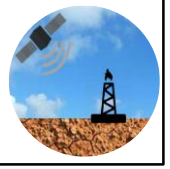
γ and β: the regression coefficient and the Y-intercept (site-specific coefficients derived and valid for the Niger Delta)

OPEC: Organization of the Petroleum Exporting Countries

http://www.opec.org/opec_web/static_files_project/media/downloads/publications/ASB2016.pdf

EIA: Energy Information Administration

https://www.eia.gov/beta/international/analysis_includes/countries_long/Nigeria/nigeria.pdf



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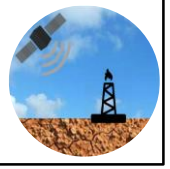
4. Gas Flared Volumes Estimation

Result

Source	Temporal Range	Regression Model Equation	R^2	*p*-Value	Year of Estimation	Gas Flared Volume [BCM]
OPEC	2000–2013	Gas flared [BCM] = 0.0005*BTE + 9.401	65%	<0.01	2014	14.3
					2015	12.4
					2016	11.9
EIA	2005–2013	Gas flared [BCM] = 0.0008*BTE + 3.902	67%	<0.01	2014	13.4
					2015	10.4
					2016	9.5



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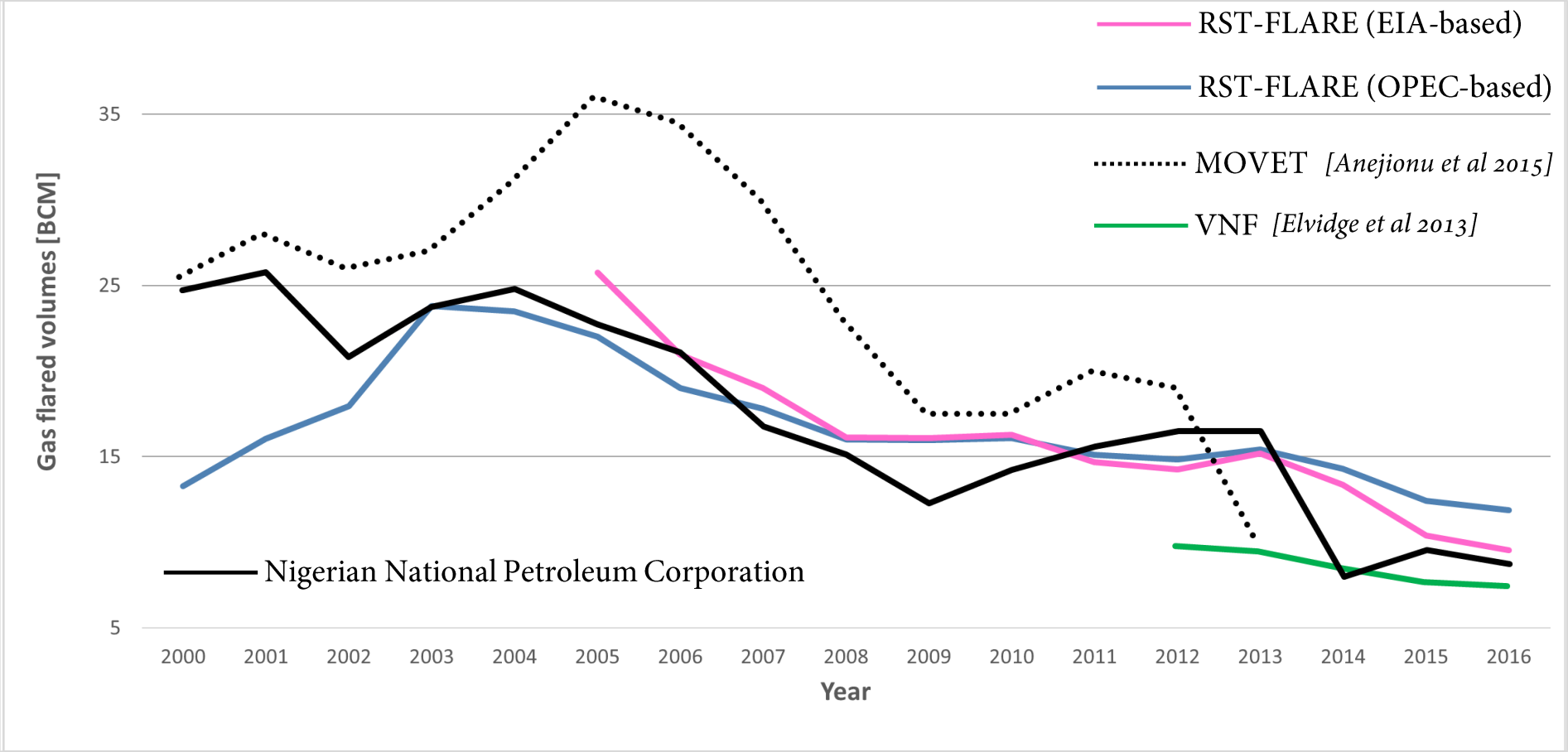
4. Gas Flared Volumes Estimation

Result



Annual values of gas flared volumes computed by RST-FLARE

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4. Gas Flared Volumes Estimation

Result

RST-FLARE performances:

when compared to other two satellite products:

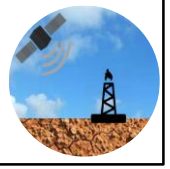
RST-FLARE (OPEC-based) vs MOVET: R=62% (2000-2013)

RST-FLARE (EIA-based) vs MOVET: R=86% (2005-2013)

RST-FLARE vs VNF: R=95% (2012-2016)

when compared to official data:

when referred to NNPC	Max Bias	Min Bias	Mean Bias
RST-FLARE OPEC-based	78.4%	0.3%	19.7%
RST-FLARE EIA-based	67.0%	0.8%	15.9%
MOVET	78.9%	3.2%	34.1%
VNF	42.5%	6.2%	24.9%



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4. Gas Flared Volumes Estimation

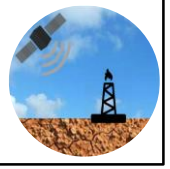
Result

in the long period:

	NNPC	RST-FLARE (OPEC_based)	MOVET
2000-2013	270.7 BCM	246.7 BCM (-9%)	344.8 BCM (+27%)

	NNPC	RST-FLARE (EIA_based)	MOVET
2005-2013	154.9 BCM	158.2 BCM (+2%)	197.5 BCM (+34%)

	NNPC	RST-FLARE (OPEC-based) (EIA-based)	VNF
2012-2016	59.3 BCM	62.7 BCM (+6%) 68.8 BCM (+16%)	42.9 BCM (-28%)



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Conclusion & Work In Progress

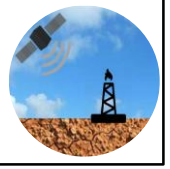
RST-FLARE configuration, based on **nighttime** MIR&TIR MODIS data, demonstrated to be a **reliable semi-automatic tool** for

i) identifying gas flares

ii) estimating gas flared volumes

iii) analyzing possible spatiotemporal dynamics of flaring activity

Works in progress are currently focused on the calibration of a new version of RST-FLARE aimed at exploiting the great potential of NIR and SWIR bands (acquired by new generation satellite sensors, like Suomi-NPP-J1/VIIRS and Sentinel-3/SLSTR) to further improve its performances in detecting flares and measuring their radiant power



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Thank you for the attention

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