World Bank's Global Gas Flaring Reduction Partnership:

Gas Flaring Estimates

Methodology for determining the gas flare volumes from satellite data

Overview

The World Bank's Global Gas Flaring Reduction Partnership (GGFR), in partnership with the U.S. National Oceanic and Atmospheric Administration (NOAA) and the Payne Institute for Public Policy at the Colorado School of Mines, has developed global gas flaring estimates based upon observations from satellites launched in 2012 and 2017. The advanced sensors of this satellite detect the heat emitted by gas flares as infrared emissions at global upstream oil and gas facilities. The Colorado School of Mines and GGFR quantify these infrared emissions and calibrate them using country-level data collected by a third-party data supplier, Cedigaz, to produce robust estimates of global gas flaring volumes.

Interpretation methodology

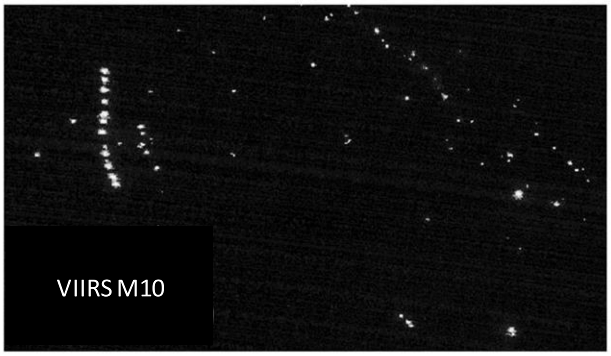
Detecting gas flares

The satellite data for estimating flare gas volumes is collected by NOAA's satellite-mounted Visual and Infrared Radiometer Suite of detectors (VIIRS). VIIRS has a multispectral set of, infrared detectors which:

- at nighttime respond only to heat emissions and hence are not affected by sunlight, moonlight or other light sources
- respond to wavelengths where emissions from flares are at a maximum
- overflies every flare several times per night
- have excellent spatial resolution

The images below, covering an area over Kuwait, Iraq and Iran, show the differences in resolution between the current VIIRS satellites and those used before 2012.

- The image on the left shows both flares and lights from towns and cities. This image is taken from NOAA's DMSP satellites, used prior to 2012.
- The image on the right shows the excellent resolution of the VIIRS detectors and their ability to respond exclusively to heat from the flares and not to the surrounding visible light.



The ability of VIIRS to detect discriminate hot sources, such as gas flares, enables flares to be detected automatically with minimal manual intervention. Emissions from non-flare hot sources (e.g. biomass burning) can be removed from the data by selecting only emissions with temperatures above 1100 C; other hot sources burn at lower temperatures. Indeed, flares burn hotter than any other terrestrial hot sources, including volcanos.

Since the first year of year of operation in 2012, VIIRS has automatically detected ~10,000 flares annually around the globe.

Estimating gas flare volumes from the VIIRS satellite data

Flare volumes are estimated using the heat generated by the gas burning in the flare. The amount of heat generated is close to proportional to the volume of gas being burned. The heat (in the form of infrared emissions received from a flare by the satellite) generates a signal with a unique temperature and magnitude which, when combined, are used to estimate the radiant heat being emitted by the flare (in Watts).

The infrared emissions received by the VIIRS detectors from a flare are affected by a number of factors as they travel from the flare, through the atmosphere, to the satellite detectors. While the effect of the atmosphere is essentially constant over the entire globe, conversion of the radiant heat into flare volume requires use of on-site measurements of flare volume to "calibrate" the radiant heat in terms of flare volume. Satellite data is calibrated with on-site measurements collected annually by Cedigaz, an organization that provides consultancy services to the oil and gas industry.

The above process results in estimates of the flare volume for each of the ~10,000 flares detected annually by the satellite. As the geographical position of each flare is detected by the satellite, the flare volumes can be precisely allocated to the country in which the flaring takes place, and the World Bank publishes these annual estimates of the gas flaring for each country on its website www.worldbank.org/ggfr.

A more detailed description of the methodology by which the radiant heat is estimated from the satellite data and then converted into estimates of gas flaring volumes is provided in the following Appendix.

References

Elvidge, C.D.; Zhizhin, M.; Hsu, F.-C.; Baugh, K.E. VIIRS Nightfire: Satellite Pyrometry at Night. Remote Sens. 2013, 5, 4423-4449. https://doi.org/10.3390/rs5094423

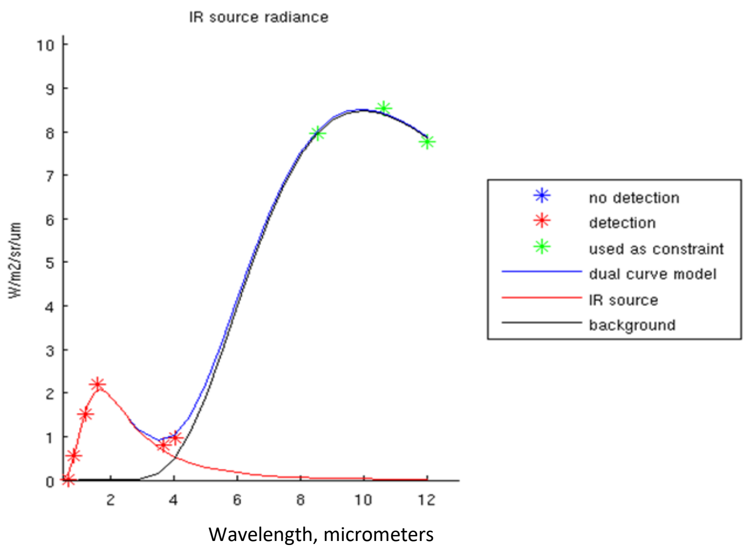
Elvidge, C.D.; Zhizhin, M.; Baugh, K.; Hsu, F.-C.; Ghosh, T. Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data. Energies 2016, 9, 14. https://doi.org/10.3390/en9010014

Appendix

Interpretation methodology to derive gas flare volumes from the VIIRS satellite data

Estimating flare radiant heat from the VIIRS satellite data

Responding to emissions at different wavelengths, the multiple VIIRS detectors enable Planck curves to be fitted to the detector responses. A Planck curve is a unique spectrum of emissions from a source of a given temperature; hotter sources emit at shorter wavelengths. Flares have maximum emissions at the shorter wavelengths detected by VIIRS. By fitting two Planck curves to the VIIRS detector responses (the red and green stars), one for a hot source (the flare) and one for a cooler source (the background), the emission spectrum from the flare can be defined.



The "hot" Planck curve from the gas flare (the red curve in the example above) uniquely defines the flare's temperature, in this case 1740 deg K; the black curve defines the very much lower temperature of the background. Using Stefan's Law, which relates the infrared flux per unit area (watts/m^2) to the flare temperature, this temperature can be used to estimate the infrared flux per unit area being received from the flare. To estimate the total infrared emissions (watts) from the flare also requires an estimate of its effective emitting flare area. This area (m^2) is proportional to the height of the observed flare Planck curve; the ratio of this height to the height of the Planck curve for a theoretical flare whose size completely fills the (known) detector area provides the estimate of the flare's emitting area.

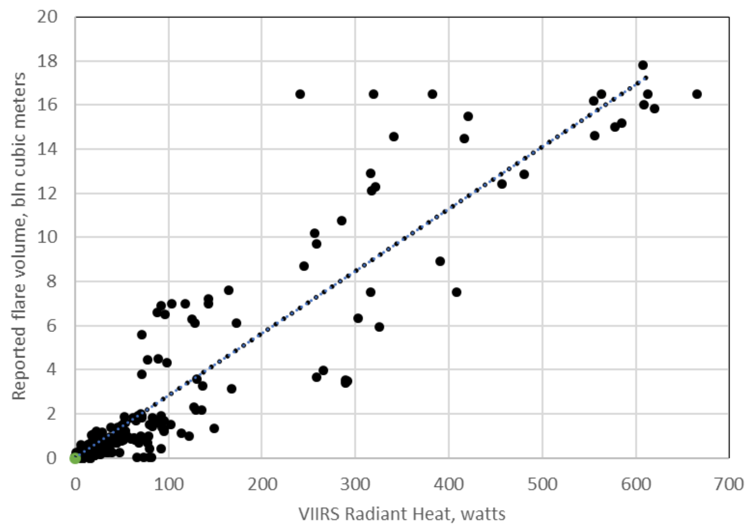
The total infrared emission (the radiant heat in watts) received at the VIIRS detectors from the flare is then estimated as the product of the infrared flux per unit area (watts/m^2) and the flare emitting area (m^2). These estimations of the radiant heat are made automatically for each of the ~10,000 flares detected annually by VIIRS.

Estimating flare volumes from satellite radiant heat estimates

The infrared emissions received by the VIIRS detectors from a flare have been affected by a number of factors as they travel from the flare, through the atmosphere, to the satellite detectors. While at the wavelengths of interest the effect of the atmosphere is small and effectively constant over the entire globe, the combination of factors affecting the received emissions is too complex for theoretical correction. The infrared estimates must therefore be calibrated using reported data.

There are limited reported flare volume measurements made on-site available in the public domain. However, Cedigaz, an organization that provides consultancy services to the oil and gas industry, uniquely collects flare volume data from the majority of countries and has made this data available for calibration of the satellite data. It should be noted that the data collected by Cedigaz comes from a variety sources of variable reliability, ranging from “official” data reported by governments to “guesstimates” made by “informed” individuals. Cedigaz therefore does not guarantee the accuracy of the data it provides.

To make the current calibration, the total VIIRS estimates of infrared emissions from flares in each country has been correlated with the country-level data collected by Cedigaz for 2013-2017, assuming a linear relationship between VIIRS emission estimates and flare volume.



Correlation between Cedigaz reported flare volumes and VIIRS radiant heat estimates

The correlation coefficient of the correlation is 0.85, and from the least-squares regression:

Satellite flare volume estimate = 0.0281 x VIIRS radiant heat

Using the regression relationship obtained between VIIRS emission estimates and reported flare volume data, an estimate of flare volumes can be made for each of the ~10,000 flares for any time period. In this way, both global gas flaring estimates and estimates for individual countries have been made annually for each year from 2012 to 2018.

In 2018, tests at John Zinc’s flare testing facility in Oklahoma were commenced to validate and/or modify this calibration. At these tests, simultaneous on-site measurements and satellite estimates of flare volumes are being made so that a direct relationship between the two can be established. The gas volumes flared in these tests have been up to the equivalent of 2 bcm/year, so the range of data being acquired in the tests covers the full range of flare volumes encountered at flaring sites around the world. The correlation between this initial comparison of satellite data and the measured flare volumes differs only slightly from that between the satellite and the Cedigaz data.

In 2020 these tests will be continued to confirm the linearity of the relationship between radiant heat and flare volume, and to investigate any impact, for example of. variations in gas composition, on this relationship.

Relationships used to estimate flare volumes from VIIRS data

1. The flare **Temperature** is calculated using Wein's Displacement Law:

$$T = b/\Lambda_{max}$$

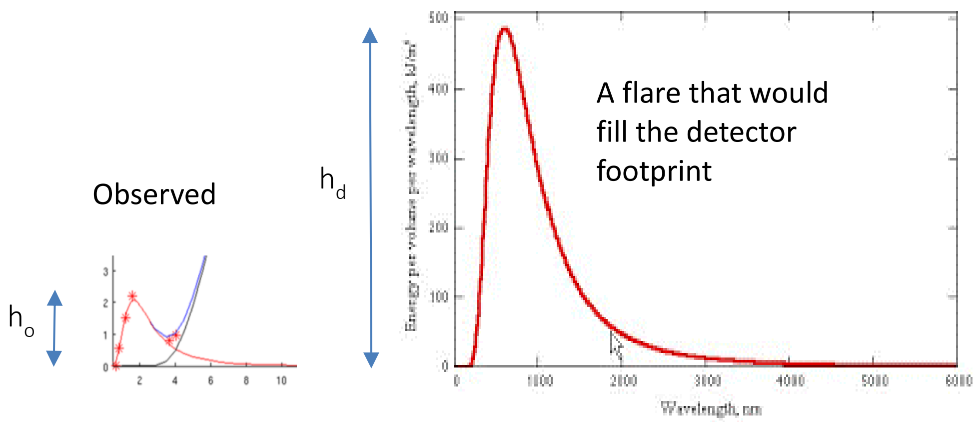
   where T is the temperature (deg K), Λ_{max} is the wavelength at the flare Planck curve's peak, and b is Wien's displacement constant.

2. The flare **Radiant Heat per Unit Area** is calculated from the temperature estimate using the Stephan-Boltzmann equation:

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

   where J is the Radiant Heat per Unit Area (watts/m2), ϵ is the flare emissivity (assumed constant) and σ is the Stefan-Boltzmann constant.

3. The flare **Surface Area** (m^2) is estimated from the ratio of the height (h) of the observed flare Planck curve and the height of the curve that would result from a flare that fills the entire area of detector footprint, times the area of the detector footprint:



$$\textit{Flare surface area} = h_o / h_d \times \textit{detector footprint area}$$

4. Total **Radiant Heat** (watts) is then:

$$RH = J \times \text{flare surface area}$$

5. The flare volumes are then estimated from the Radiant Heat using the calibration obtained from the correlation between the radiant heat and reported flare volumes obtained from Cedigaz:

$$\text{Satellite flare volume estimate} = 0.0281 \times RH$$