Assessing the magnitude of multi-site flaring events attributed to supply chain disruptions in oil and gas production basins

Colette Schissel, Erin Tullos and David T. Allen*

Center for Energy and Environmental Systems Analyses, University of Texas at Austin, 3925 West Braker Lane, Austin, TX 78759, United States

*Corresponding author: David T. Allen; email: allen@che.utexas.edu; tel.: 512-475-7842

Abstract

Flaring in oil and gas production is used to combust flammable hydrocarbons that otherwise would be vented to the atmosphere. One potential cause of flaring is intermittent disruptions in gas supply chains between oil and gas production sites and gathering and boosting operations. Since gathering and boosting facilities serve multiple production facilities, these types of supply chain disruptions would be expected to cause simultaneous flaring at multiple upstream sites in the regions served by a gathering and boosting facility experiencing a disruption, unless production sites are able to use other gathering and boosting facilities or the production sites immediately shut-in production. To assess the potential magnitude of this type of event, the overall frequency of multiple flares being detected in a localized area (<5 km radius from another flare) was assessed using spatiotemporal patterns in satellite based daily flare detections using the VIIRS Nightfire (VNF) product. Multiple detections in a localized area are unlikely if flaring is caused by independent conditions at individual sites. In contrast, multi-site detections in a localized area may be indicative of potential supply chain disruptions. Hundreds of flares in the Eagle Ford production region in south central Texas that are detected infrequently (<18% observations) were evaluated. For these infrequently detected flares, which account for approximately half of flared gases in the region, 87% had 80-100% of their detections classified as multi-site events. This suggests that efforts to reduce flaring should consider impacts of supply chain disruptions.

Synopsis: Simultaneous satellite detections, in small regions, of multiple flares that are typically detected infrequently, suggest that localized supply chain disruptions cause significant flaring.

Key words: Flaring, emissions, natural gas production, oil production

Introduction

Flaring in oil and gas production is used to combust flammable hydrocarbons that otherwise would be vented to the atmosphere. Worldwide, approximately 148 billion cubic meters (bcm) of gases were flared from global oil and gas supply chains in 2023[1], approximately 3.7% of global gas production,[2] the highest reported flaring volume since 2019. Multiple regulatory and voluntary initiatives are aimed at reducing flaring in oil and gas production. For example, in Texas, oil and gas producers must apply for a Statewide Rule 32 flaring exception to be approved to flare during drilling, completion, and production of oil and gas and the number of these exemptions has been decreasing while oil and gas production has increased.[3] At the global level, partners in the World Bank's Global Gas Flaring Reduction Partnership (GGFRP),[4] that represent ~60% of global gas flaring, have pledged to eliminate routine flaring by 2030. In the GGFRP, routine flaring includes "flaring during normal oil production operations in the absence of sufficient facilities or amenable geology to re-inject the produced gas, utilize it on-site, or dispatch it to a market".[5] In the GGFRP, routine flaring is distinguished from safety flaring and non-routine flaring. Safety flaring is designed to "ensure safe operation of the facility" and includes flaring associated with emergency operations.[5] Nonroutine flaring is defined as all other types of flaring and may have similar causes as routine flaring, such as the inability of a downstream or customer facility to accept gas, but "is typically intermittent and of short duration" whether planned or unplanned. To distinguish among the various types of flaring, it is necessary to identify the factors driving the flaring. Previous analyses[6] have shown that a major cause of flaring can be the capacity, at a production basin level, to economically deliver gas to markets. In the United States, analyses of flared gas volumes, gas production and natural gas transmission pipeline capacities showed that flaring in the Permian Basin production region in Texas and New Mexico was reduced by approximately 70% as new natural gas transmission capacity was brought on-line.[5] Additional analyses have shown similar patterns in other U.S. production regions.[7]

While limited natural gas transmission capacity can lead to flaring, another potential cause of flaring is insufficient reliability in gathering systems that collect gas from multiple wells and deliver the produced gas to processing facilities. Disruptions in these systems can occur and cause flaring even if there is sufficient transmission capacity at a basin level. Flaring driven by this type of reliability constraint would likely occur, not at the gathering and boosting location, but at the production sites served by the gathering and boosting facility. Flaring due to gathering and boosting facility disruptions can also be intermittent. Partial or complete shutdown of a gathering and boosting station would be expected to cause flaring at multiple upstream sites in the regions served by the gathering and boosting facility if the production sites are not able to use other gathering and boosting facilities and if the production sites do not immediately shut-in production at the well site. Flaring caused by gathering and boosting disruptions would be expected to be most frequent in locations where individual well sites are served by a single gathering and boosting facility and in wet gas and associated gas production regions, where the value of the flared gas as a lost product can be a small part of the revenue produced by the oil and gas products.

This work will estimate the potential impact of gathering and boosting facility disruptions on flared gas volumes by examining spatiotemporal trends of satellite detection and quantification of flared gas volumes across individual flare sites. The analyses presented in this work will assume that flaring caused by a production site process upset would not impact the flaring at other nearby production sites. In contrast, if the flaring is caused by a disruption at a gathering and boosting site that serves multiple nearby production sites, then flaring at nearby sites should be temporally and spatially correlated. Further, it is expected that in dry gas production regions, operators will choose to immediately shut-in production if take-away from production sites is constricted. In contrast, wet gas and associated gas production regions would be expected to be more likely to flare gas if the value of the flared gas as a lost product is a small part of the revenue produced by the oil and gas products.

Analyses will be conducted for the Eagle Ford production region in south central Texas. The Eagle Ford was chosen for analysis because it has regions of dry gas, wet gas and oil production. Flared gas volumes will be estimated based on daily measurements available through the VIIRS satellite product.

Methods

Study regions

The Eagle Ford oil and gas production region in south central Texas is one of the largest oil and gas production regions in the United States. In 2024, oil production from the Eagle Ford Shale was approximately 1 million barrels per day (8% of U.S. production) and gas production averaged 5. billion standard cubic feet per day (>20% of U.S. production).[8] The ~20,000 oil and gas wells in the region have gas to oil ratios that range from less than 2,000 standard cubic feet of gas per barrel of oil to more than 50,000. These oil production and gas production regions are mapped in Figure 1a. Flare locations based on analyses of VIIRS data are mapped in Figure 1b and are located throughout the production region, but with greater density in the regions producing hydrocarbon liquids.

(a) (b)

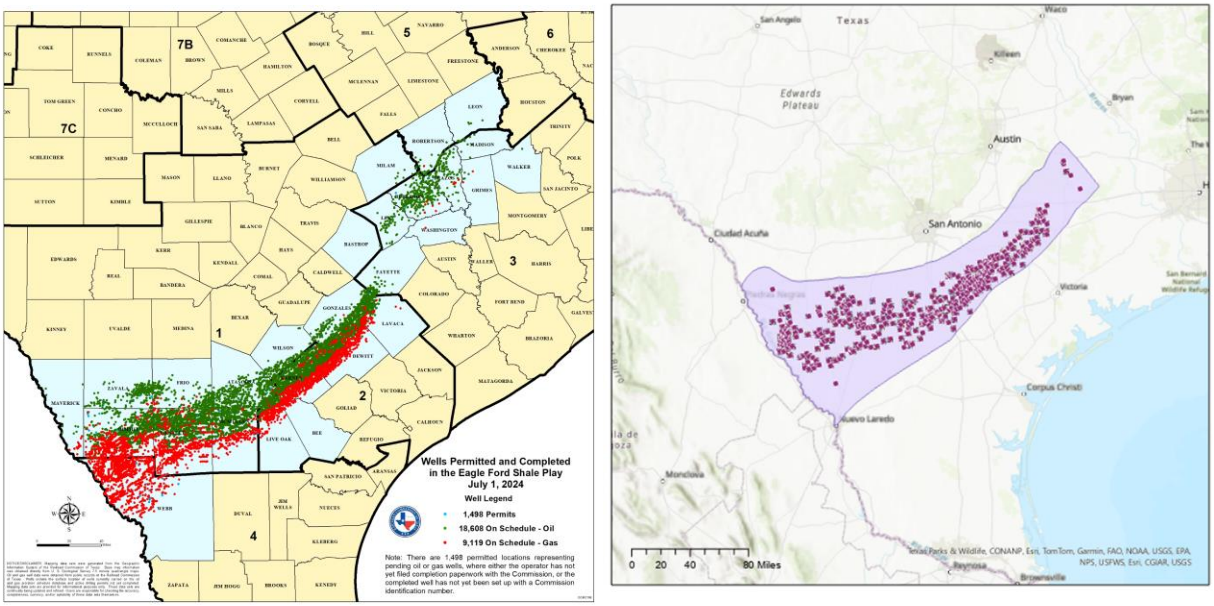


Figure 1 (a) Oil and gas well locations in the Eagle Ford;[8] (b) Flare detection clusters in the Eagle Ford

VIIRS Data

The Visible Infrared Imaging Radiometer Suite (VIIRS) is a satellite-based instrument aboard the Suomi National Polar-orbiting Partnership (Suomi NPP) satellites. VIIRS collects observation data across visible and infrared wavelengths, which are then processed in near-real time by the VIIRS Nightfire (VNF) algorithm, which identifies hot sources at the Earth's surface and calculates hot source characteristics such as source temperature and estimated source size using Planck curve fitting[9]. The VNF algorithm detects all high radiance sources, including gas flaring, biomass burning, and industrial heat sources. Gas flaring activity must therefore be isolated within the VIIRS dataset.

The Earth Observation Group at the Colorado School of Mines publishes an annual flaring dataset, where all individual detections that have been determined to be from flaring activities are aggregated and summarized[10]. This dataset provides information on the location, detection frequency, and estimated gas flared volume of each flare, which was used to determine overall detection frequency and flared gas volume distributions. The same-day detection analysis presented in this work, however, requires individual daily detection information in order to assess the extent to which there is spatial and temporal correlations across the flare time series data. This work makes use of the Nightfire v3.0 data repository, which contains all VIIRS data processed by the VNF algorithm[11]. The data from this daily detection dataset must be further processed to isolate detections from flaring activity.

<u>Candidate flare detections</u>

Flaring detections can be discerned from other events using temperature and location[12]. Flaring events are typically above 1400K, which is higher than most biomass burning events. To identify candidate flare detections, the daily dataset from January 1, 2023 to December 31, 2023 was filtered for detections above 1200K to not exclude any lower temperature flares, as has been done in previous analyses[12,13]. Candidate flare detections were kept in the analysis if they were within one kilometer of a known flare location, defined by proximity to a flare identified in the annual dataset.

Clustering flare detections and referencing VNF annual dataset

A defined-distance (DBSCAN) algorithm was used to identify clusters of individual candidate flare detections. Each cluster must have a minimum of 3 detections within a 1km radius, which aligns with the logic used to develop the VNF annual dataset[12]. Each detection within the cluster was given a cluster ID. This cluster ID was then mapped to flare IDs in the VNF annual dataset by identifying the closest annual flare location for a cluster within a 1km radius of the cluster centroid. Flare clusters that could not be tied to a known flare location were excluded from the rest of the analysis. If duplicate detections were identified, defined as detections on the same day, typically within one minute of each other, at the same flare, only one detection was kept.

Results and Discussion

Flaring frequencies

For the 452 flare clusters in the Eagle Ford production region that had VIIRS detections in 2023, the median detection frequency was 6%. The distribution of detection frequencies is shown in Figure 2. Also shown in Figure 2 is the distribution of flared gas volumes reported by VIIRS. About half of the flared volumes (54%) are accounted for by 92 (20%) of most frequently detected (>18% detection frequency) flares. These flare detections are unlikely to be due to periodic disruptions of gathering system operation, as frequent detections may be indicative that flaring activity is a routine part of operation.

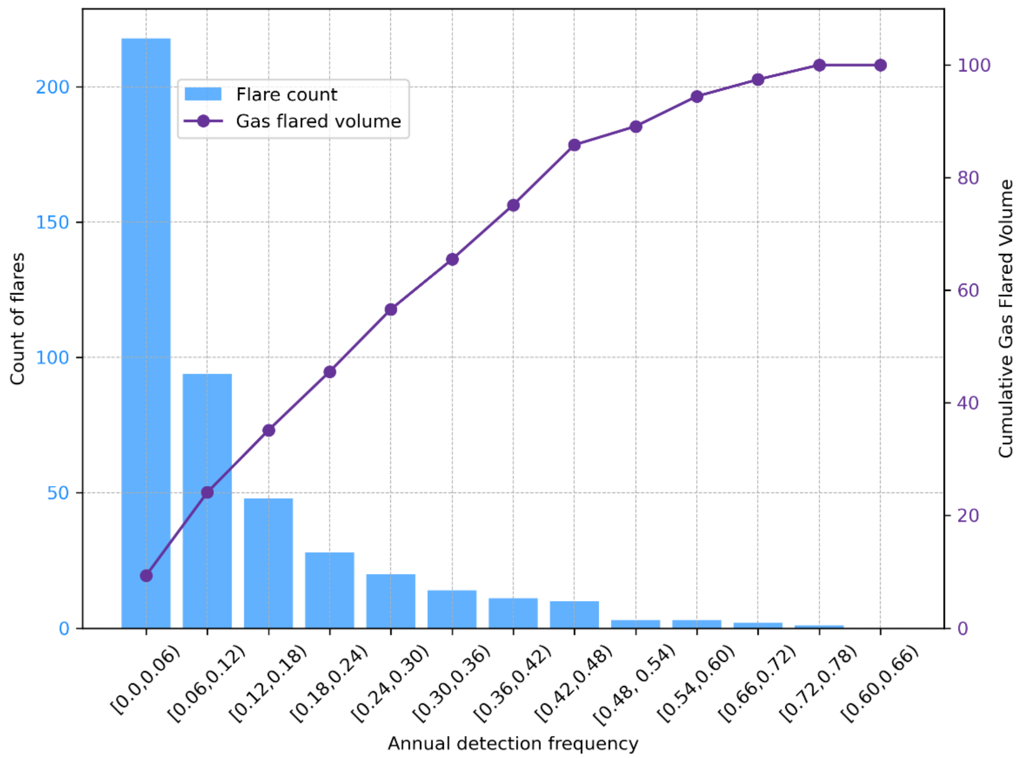


Figure 2. Distribution of detection frequencies for flares in the Eagle Ford Shale (blue) and the cumulative percentage of flared gas volume in each detection frequency bin (purple).

Estimating magnitudes of multi-site flaring events

One reason gas flaring occurs is due to disruptions of the supply chain. If it is assumed that nearby wells or upstream facilities are serviced by the gathering, boosting, and transmission operations, then the extent of same-day flaring among nearby well sites can provide information on the extent to which flaring is driven by supply chain disruptions and transmission capacity issues. Table 1 compares the relative rate of same-day flaring between nearby flares and the average same-day flaring rate across the entire Eagle Ford Shale (Table 1).

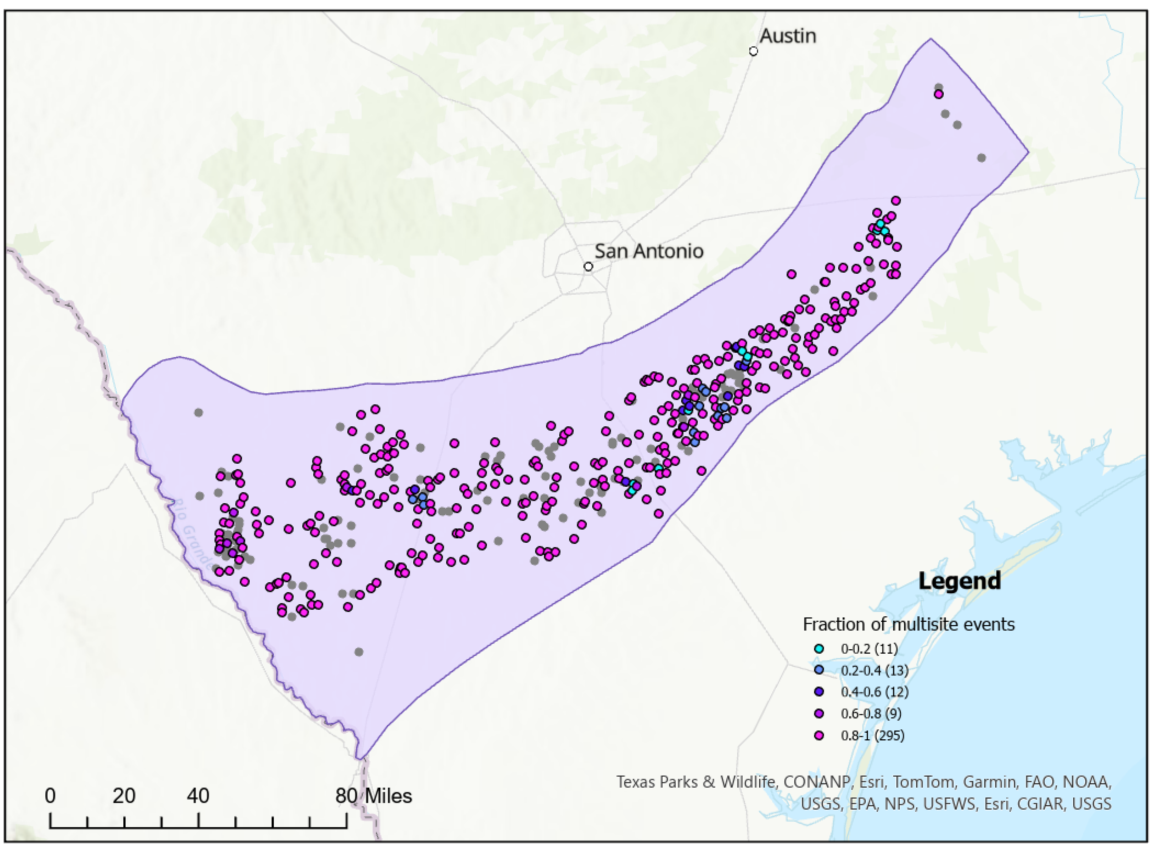
Table 1: Comparison of same-day detection behavior within the entire Eagle Ford Shale and detections constrained to within a 5km radius

	Entire EFS	**Within a 5km radius**
Average number of flares emitting at the same time	41.8	1.6
Number of flares in the region	452	3.6 (average)
Average number of flares emitting at the same time/number of flares in the region	**9%**	**44%**

Based on the analysis presented in Table 1, there is a clear difference between the average rate of same-day observation (9%), and the rate of same-day observation at nearby flares only (44%).

The prevalence of nearby same-day flaring events, or multi-site flaring events can be quantified by determining the fraction of detections that are multi-site flaring events for a given flare. Flaring activity that was likely due to routine operation, defined as flaring sites that had an annual detection frequency of greater than 0.18 (Figure 2), was excluded. A multi-site flaring event was defined as flare detection that has at least double the basin-wide average rate of same-day detections across its nearby flares. Specifically, a flaring detection for a given flare is classified as a multi-site flaring event if at least 18% (double the Eagle Ford average) of its nearby flares (within 5km) were also observed on that day. The results from this analysis are shown in Figure 4.

Figure 4: Flare detections in the Eagle Ford Shale, color coded by the fraction of events in 2023 that were classified as multi-site events. The gray detections are flares with annual detection frequencies greater than 0.18, which were excluded from the multi-site event analysis.



The overwhelming majority of flares that had annual detection frequencies less than 0.18 also had a high fraction of their detections that were classified as multi-site events. As seen in Figure 4, of flares that were included in the multi-site analysis (detection frequencies less than 0.18), 87% of flares had 80-100% of their detections classified as multi-site events. In general, flares with infrequent events are often observed on the same days as nearby flares, which could be indicative of flaring activity that is driven by supply chain or transmission capacity issues.

Similar analyses for additional production basins will be examined in future work.

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