Carbon Mapper QC Guide

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Carbon Mapper, Inc., is a non-profit with a mission to deliver and guide the adoption of digital public goods that facilitate timely action to mitigate human impacts to Earth's climate and ecosystems. Using airborne flights and satellites, Carbon Mapper persistently pinpoints, quantifies, and tracks strong methane (CH_4) and CO_2 emissions at facility scale. This Quality Control (QC) Guide is intended to demonstrate how to pinpoint and QC review methane and CO_2 plumes using Carbon Mapper's PlumePortal. The guide starts with a definition of terms, how to generally identify plumes, and attribute them to a source. This guide will also show which quality artifacts to be aware of. How to use PlumePortal is described in more detail towards the bottom of the guide.

Glossary

Candidate ID - unique identifier for each plume. Format is {platform}{YYYYMMDD}{HHMMSS}-{suffix}, where the first three characters represent the platform (e.g., GAO = Global Airborne Observatory, ang = AVIRIS-NG) and the next fourteen characters represent the date and time of acquisition. The suffix (e.g., "A") helps identify multiple plumes captured in the same image in the order they were detected.

Matched Filter (MF, MFA, MFMA, etc.) - The matched filter is a fast-running, statistical based retrieval algorithm that has been validated across multiple controlled release tests and independent aircraft mass-balance surveys. The matched filters generate the image products you see in PlumePortal labeled as ch4mf, ch4mfa, etc. Each matched filter has a different algorithm best suited for unique observing environments.

- Unimodal (Most validated with controlled release testing of airborne sensors): Classical column-wise matched filter as described initially.
  - ch4mf: methane (CH4), Matched Filter, Unimodal
  - ch4mfa: methane (CH4), Matched Filter, Unimodal, dynamic absorption spectrum
  - co2mfa: carbon dioxide (CO2), Matched Filter, Unimodal dynamic absorption spectrum
- Multimodal (potentially superior for suppressing systematic artifacts, e.g., flaring): Column-wise matched filter with a clustering of pixels based on radiance values.
  - ch4mfm: methane (CH4),clou Matched Filter, Multimodal
  - ch4mfma : methane (CH4), Matched Filter, Multimodal, dynamic absorption spectrum
  - co2mfma: carbon dioxide (CO2), Matched Filter, Multimodal, dynamic absorption spectrum

RGB - Refers to a natural color image created using bands in the visible spectrum (red, green, and blue bands). In PlumePortal, these are in our overlays as RGB.tif and RGB.kmz.

Concentration - The CH_4 or CO_2 mixing ratio relative to background levels in a given scene. A high concentration of methane will appear bright white in a greyscale matched filter image, while a low concentration will be darker and diffuse.

Diffuse - Spread over a large area. Diffuse plumes will appear to be speckled white on a mostly black background.

.tif - Tag Image File Format (TIFF) is a type of file format used for storing image data. We use GeoTIFFs as a georeferenced raster format for storing our matched filters.

.kmz - KMZ is a compressed version of a Keyhole Markup Language (KML) file format. It's a file format that is primarily used within Google Earth. Our legacy data pipeline created matched filters in KMZ format, so you may see it occasionally.

What is a plume?

The various matched filter image products in PlumePortal allow analysts to review maps of CH_4 or CO_2 concentrations over extended areas. CH_4 or CO_2 emissions from a point source appear as higher atmospheric concentrations (enhancements) of those gases in the vicinity of the source. Enhancements undergo dispersion in the atmosphere that varies with a number of factors including emission rate, source elevation, wind speed and direction, terrain, and turbulence. In most cases, the enhancements appear as a plume of gas extending from the emission source - similar to smoke from a fire. In other cases, for example in presence of calm or no wind, the plume can appear as a blob centered over the source.

Real (physical) plumes generally have the following characteristics.

- They do not strongly correlate with surface features like roofs, roads, or mineral outcroppings
- Exhibit more coherent signal than the background Tend to be non-uniform in shape
- With sufficient wind, will become elongated in shape (like a smoke plume)
- Becomes increasingly diffuse at greater distances downwind of the source
- Appear to originate from surface infrastructure, recognizable the RGB overlay

The matched filter output on the right includes a good example of a plume enhancement. Notice how it appears bright and exhibits a more coherent shape than the background pixels. The plume is most prominent towards its source in the lower right corner of the image and becomes more diffuse downwind toward the upper left corner. The RGB/satellite imagery on the left confirms that this is an oil and gas field and that the plume origin appears to be associated with a physical source on the ground (in this case a well pad).

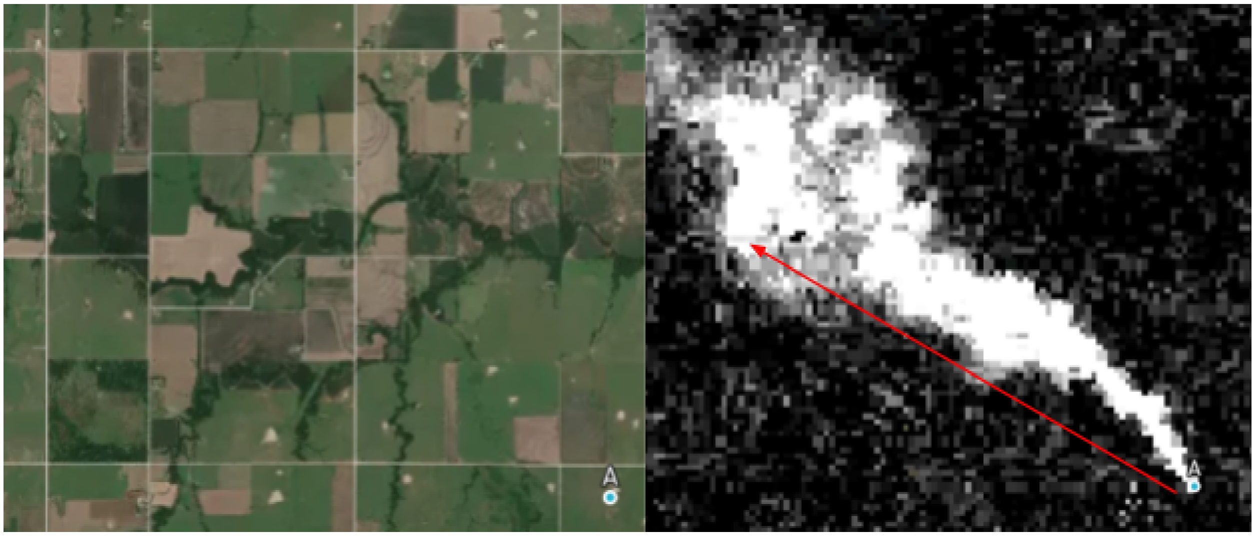


Figure 1: Left panel shows a true color image (RGB) and the right panel shows the same scene in the matched filter retrieval. There is a clear plume in the matched filter retrieval. The red arrow indicated the wind direction.

RGB vs Basemap

Visible imagery can help us discern if enhancements are coming from surface features or true methane. Each scene you QC will have an RGB image constructed from the same image as the matched filters. The basemap in Plume Picker is provided by Mapbox. Google/Maxar has a resolution of <1m GSD (ground sampling distance), while airborne scenes will usually be between 3-8m GSD, and EMIT scenes have a resolution of 60m GSD. This means each pixel in an EMIT scene represents 60m. Since resolution varies a lot by spectrometer (AVIRIS, GAO, EMIT, Tanager, Skysat, etc.), it is often necessary to consult different imagery in determining if an enhancement is originating from a true methane signal, as well as to attribute plumes to specific sectors and infrastructure/equipment type.

What does a methane plume look like?

There are two different gas species, methane plumes and CO_2 plumes. Depending on the source of the plume and environmental conditions, they can take on different shapes. Note that CO_2 plumes detected by the class of sensors used by Carbon Mapper will only be prominent when combustion is taking place. You will notice this in stacks from coal and natural gas fired power plants, refineries, and petro-chemical plants. Cement plants are one exception, where strong CO_2 point source plumes can result from calcination due to a combination of limestone decomposition and fuel combustion. Area sources of CO_2 such as on road transportation, land use change and natural carbon fluxes are generally not detectable with our methods.

Methane plumes can vary in the way they look depending on where they're coming from. We can broadly sort methane plume detected by our technology into two groups:

- Livestock operations, landfill plumes, and surface coal mines tend to be more broad and diffuse (likely the combined result of multiple smaller plumes)
- Oil and gas, underground coal mine vents, and other industrial plumes tend to be more discrete and elongated from a single piece of equipment or source

Plumes from point sources detectable with this class of sensor generally come from either discrete pieces of equipment or extended facilities. A discrete piece of equipment, such as a leaky oil well, is a source that has methane coming from one location. Depending on wind speed, plumes from such sources usually take on a more gaussian shape. A gaussian shaped plume will be bright at its source, and more diffuse as the gas is dispersed downwind (like the letter V or like a cone). The plume below in the upper right from an oil and gas facility is a good example of a gaussian shape. An extended facility, such as a surface coal mine or a landfill, like in the lower right, is a facility that often has methane coming from multiple locations in close proximity, resulting in more complex plume structures.

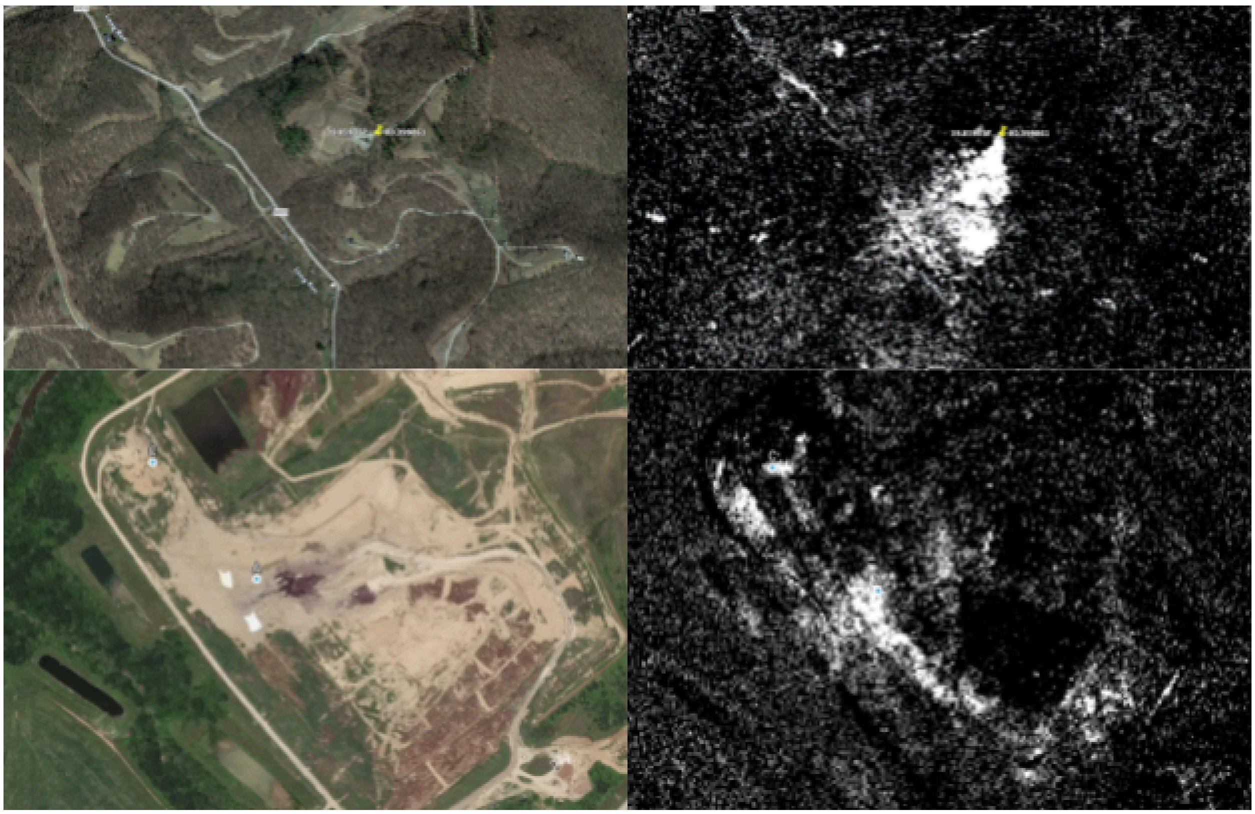


Figure 2: Left panel shows a true color image (RGB) and the right panel shows the same scene in the matched filter retrieval. The plume in the upper right panel has a clear origin and has dispersed downwind in a gaussian shape. The plume in the lower right panel has methane coming from multiple locations in close proximity, and has a more diffuse shape as a result.

Under low wind conditions, plumes from oil/gas and coal mine vents can sometimes take other shapes too. Below you can see a large oil/gas methane plume that is pooling, making it look like a blob.

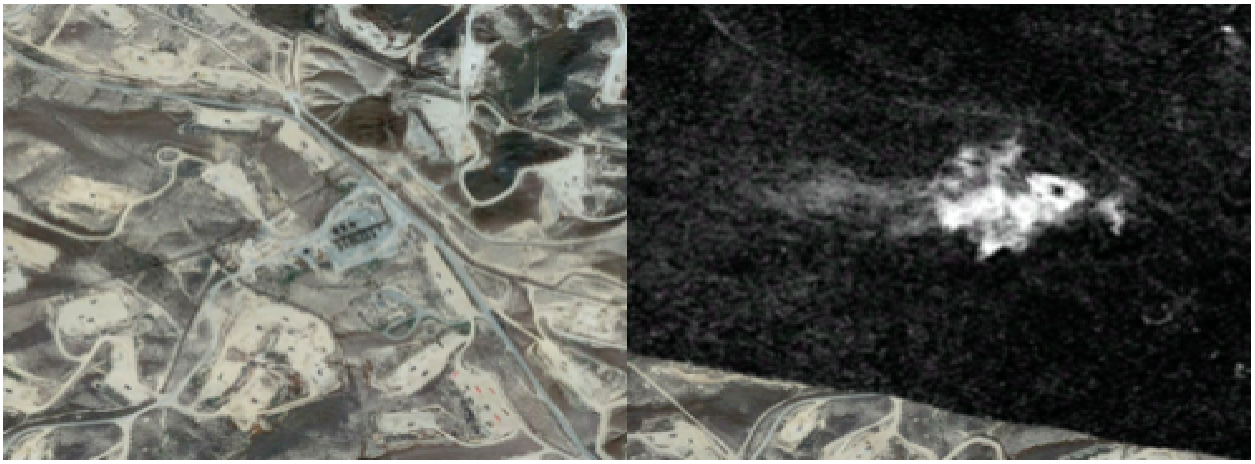


Figure 3: Left panel shows an RGB image and the right panel shows a plume from an oil/gas facility.

Oil/Gas

The oil and gas industry has distinct sectors which can appear as diverse infrastructure. Carbon Mapper includes upstream production, midstream transport and processing, and refining and distribution all within the Oil/Gas umbrella.

Upstream Sector

The upstream, or production, sector is typically easiest to identify from aerial imagery. Commonly, production sites, or well pads, appear as discrete pads connected by access roads as shown in the images below. Some oil/gas plumes will come from well pads. Well pads are flat, generally rectangular structures which can contain various kinds of equipment like small compressor engines, pump jacks, separators, well heads, storage tanks, flares and the like. Plumes can originate from planned operations such as tank unloading, maintenance activities, deliberate or accidental venting or from faulty infrastructure on the pad. Plumes in this sector tend to be discrete and semi- gaussian shaped plumes with sources that are fairly easy to attribute in airborne imagery. Below is an example of an upstream oil/gas plume. It’s small but see how it’s concentrated near the source and becomes more diffuse as the gas is dispersed downwind.

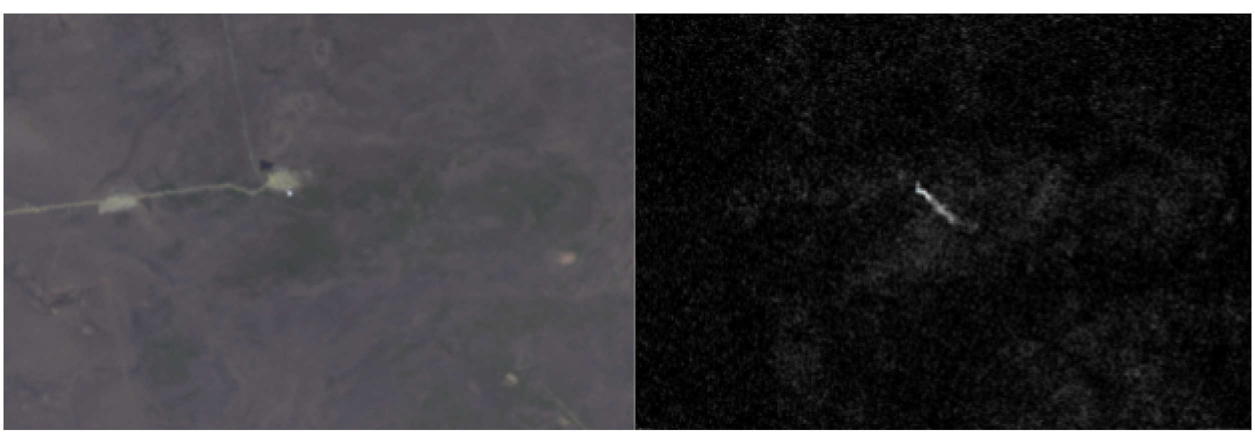


Figure 4: Left panel shows a true color image (RGB) and the right panel shows the same scene in the matched filter retrieval.

The Midstream Sector

The midstream sector of oil and gas includes pipelines, compressor stations, and gas processing plants. Pipelines may be above ground or buried. In an area with significant upstream oil and gas pads where a plume appears to be coming from bare ground can be a sign of a leak originating from a buried pipeline in the midstream sector. If large, clear plumes appear outside of production areas, analysts should look for signs of buried pipelines in aerial basemaps.
The midstream sector also includes compressor stations. Small compressor stations can look like well pads with extra infrastructure including large engines. Larger compressor stations can look like small gas plants. Gas processing plants are also part of the midstream sector, and are typically found in regions with heavy production. Gas plants can be medium to large sites that appear very similar to refineries (in the downstream sector, see below). Care should be taken to check facilities names on basemaps when attributing this kind of industrial facility to the oil and gas sector.

Here are some examples of what oil/gas production facilities can look like.

Figure 5: Examples of oil/gas facilities in both the basemap and the RGB. The right hand panels are RGB images, the rest are basemap images.

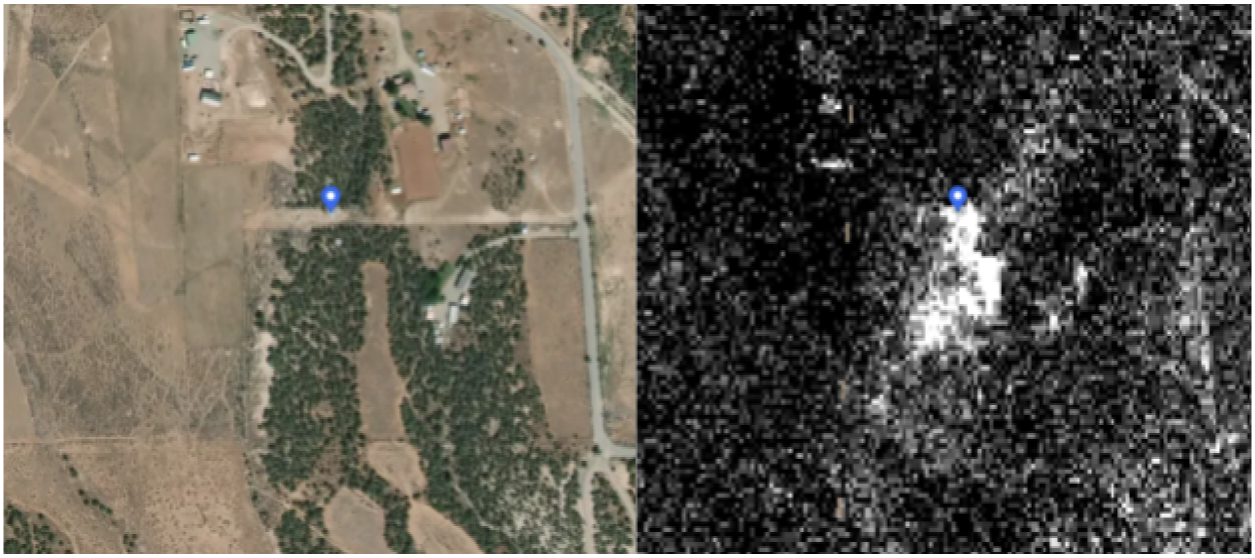


Figure 6: Left panel shows an RGB image and the right panel shows the same scene in the matched filter retrieval. The plume is coming from a buried pipeline.

The Downstream Sector

The downstream sector includes refineries and gas distribution pipelines. Carbon Mapper does not try to attribute pipeline leaks to the oil and gas sector, so if pipeline leaks are clear, they can safely be attributed to the oil and gas sector generally. Refineries are large industrial plants which can also be attributed to the oil and gas sector. Care must be taken to distinguish refineries from power plants and petrochemical facilities, which are generally considered “other” and not considered to be part of the oil and gas sector. If in doubt, please flag any uncertain facilities for additional QC.

Figure 7: Basemap images of oil refineries

Coal Mines

There are two types of coal mines. The first is underground mines, which are characterized by underground tunnels used to access buried coal and bring it to the surface. Open pit mines are similar to quarries, where coal that is near the surface is excavated. Both types and associated infrastructure can be attributed to the Coal sector. Both types can be located near piles of coal and waste that are being processed or loaded into rail cars or trucks. Coal piles are generally black in color, as are coal deposits seen in open pit mines. This black color has a low albedo, which can make plumes over coal difficult to detect.

Underground Coal Mines

Underground coal mines can extend for hundreds of meters vertically underground and kilometers horizontally. Often, geolocation for the mine shows the management office location or the center of the coal mine rather than the location of the mine itself. Underground coal mines in basemaps are central locations rather than locations of the vent shaft, which can be km away. There can be many vent shafts radiating out from a central location. Underground coal mines are often required to operate large ventilation systems in order to maintain safe working conditions. Ventilation systems dilute methane released into the mine workings as coal is extracted and remove the gas from the mine, sometimes using fans to increase circulation. Ventilation shafts can be located kilometers from the mine entrance.

Below are a few examples of Coal mine vent shafts from a high resolution RGB image. Coal mine ventilation shafts are point source emissions, similar to oil/gas plumes, however they emanate from distinct infrastructure that can be identified in high resolution RGB images. They can also have structures on them used to control and/or capture gas from the ventilation shaft.   This example of a plume from an underground coal mine vent is taking on a gaussian shape.

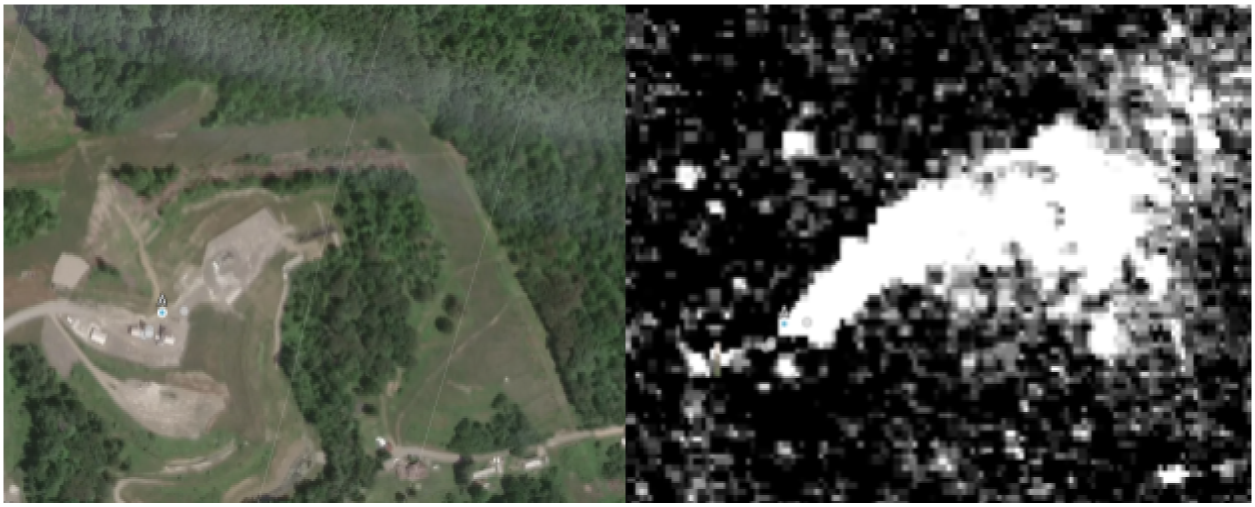


FIgure 8: Basemap image in the left panel and gaussian plume in the right panel coming from a coal vent. Underground mines often have very strong and discreet plumes, however the vent can sometimes be hard to spot in base map images

Figure 9: Basemap images of underground mines. A clear vent shaft can be seen in the upper left image

Surface/Open Pit Coal Mines

The other form that coal mine emission can take are more diffuse plumes from open surface mines. These can appear similar to surface mineral mines or even landfills. Generally, black coal can be seen in surface coal mines, while other mineral surface mines are lighter in color. Coal mines also often have coal piles nearby and can have coal processing structures. Like landfills, surface features like pits at a coal mine may change over time, so the basemap may not accurately show the coal mine surface or boundary. Care must be taken by analysts to attribute surface mines to the correct sector. Base maps can be very helpful in sector attribution, but if a sector can not be definitively determined, these mines should be flagged for additional QC.

Surface coal mines can have methane plumes at certain locations, while other, seemingly similar mines have none. Gas from surface coal mines, if present, can be diffuse, similar to what might be seen at a landfill.

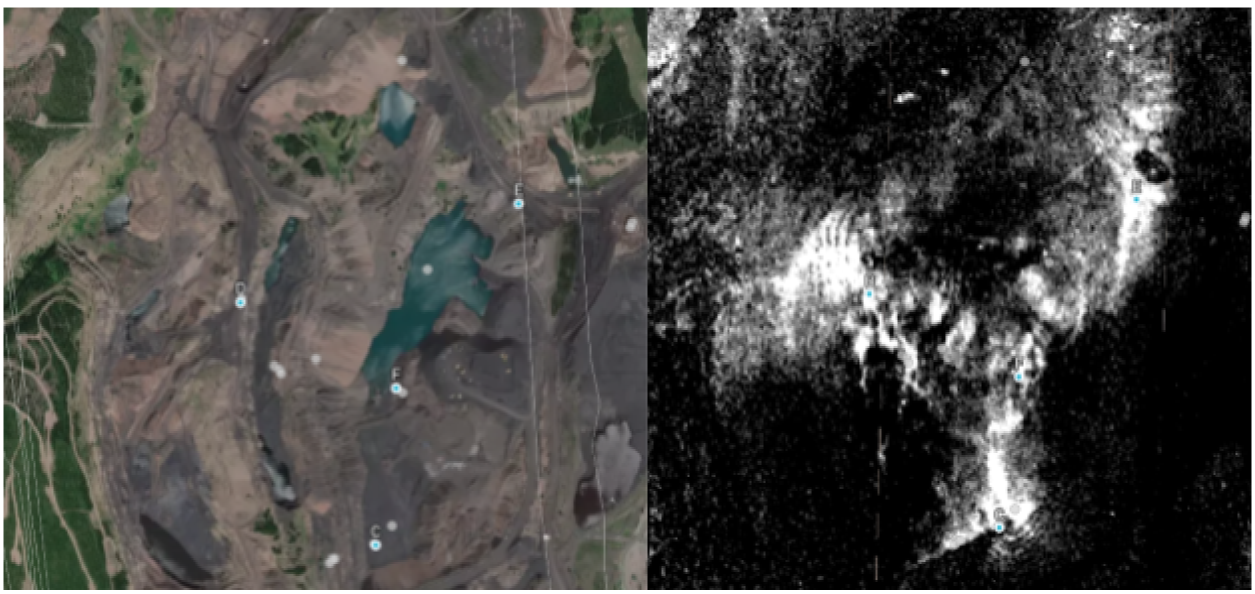


Figure 10: A plume from a surface mine in the right hand panel. When surface mines produce methane, it's often a complex pattern driven by multiple smaller plumes - similar to what we see at landfills.

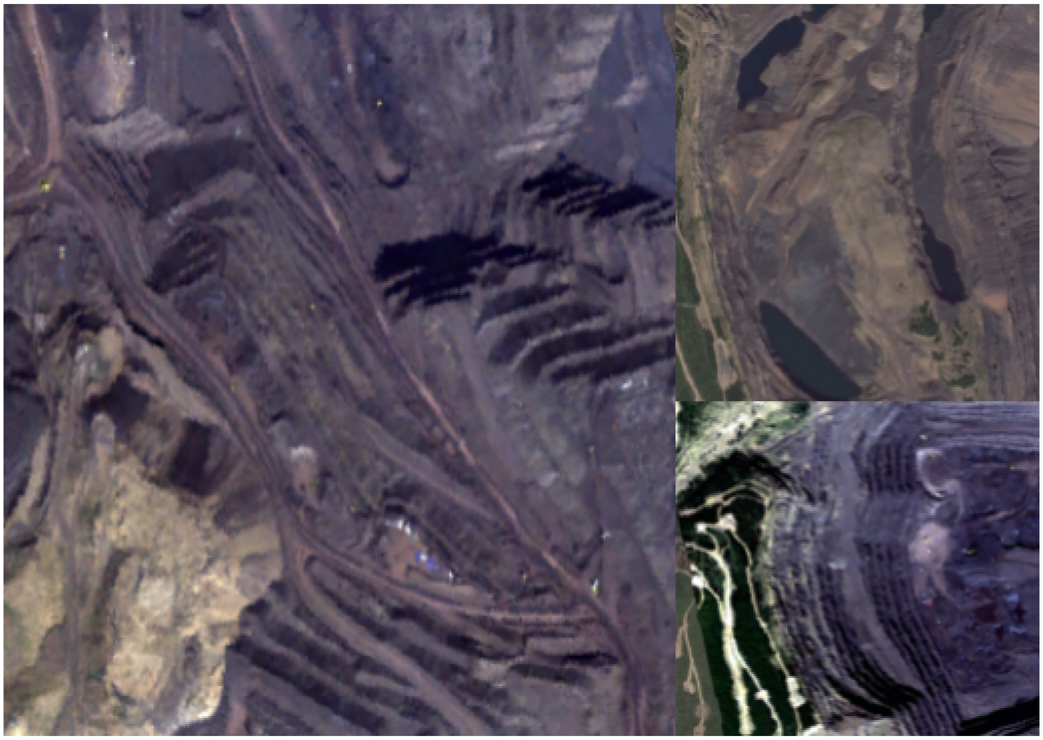


Figure 11: Basemap images of surface mines

Agriculture

Concentrated Animal Feeding Operation (CAFO)

Large factory livestock operations are often referred to as Concentrated Animal Feeding Operations (CAFOs), where thousands of animals are housed in “feedlots” with varying approaches to managing manure and other waste. Generally speaking, methane point source emissions detectable with this class of sensors tend to occur at very large cattle or swine CAFOs that employ wet manure management techniques (e.g., manure covered by water in “lagoons”) rather than dry-scrape methods. The CAFO below has a plume that is concentrated at its source (a manure lagoon) but becomes more diffuse downwind.

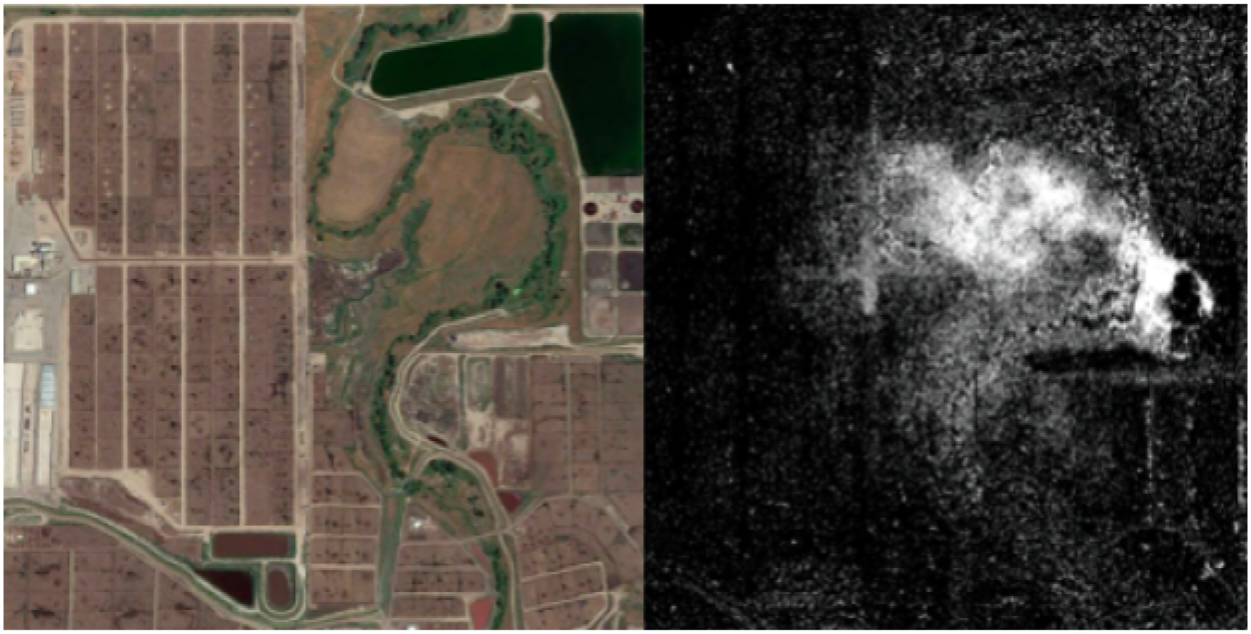


Figure 12: A plume from a CAFO in the right hand panel, and a basemap image on the left.

Here are some examples of cattle CAFO's - dairies in central California. They are often surrounded by fields planted with forage crops. The long metal roofs are feedlot sheds housing cattle. Some CAFOs that use wet manure management that can include uncovered settling ponds or manure lagoons that are often the main source of methane our technology detects. Examples of these settling ponds are seen in figure 9. Some CAFOs have a system to capture methane produced from the manure lagoons, these are known as digesters and can look like large plastic "bags" covering lagoons to capture methane and divert it for combustion or storage. Examples of digesters are seen in figure 12. Digesters are not supposed to leak methane but occasionally they do and this results in larger discrete plumes.

Figure 12: Basemap images of CAFO’s

Waste

Landfills and waste dumps

Solid waste disposal varies dramatically around the world but generally consists of Municipal Solid Waste (MSW) Landfills and Unmanaged Dumps. Landfills often have specific characteristics like an active filling area where trash is deposited, a covered portion of the landfill where an intermediate cover is used like grass or synthetic materials, and gas capture infrastructure. Unmanaged Dumps will not have these features and will instead have trash deposited across the surface of the dump.

Figure 13: Landfill surface feature examples. For the two landfills, (a) marks the active filling area on the landfill, (b) marks the intermediate cover (here are examples of grass and synthetic materials being used for cover), and (c) marks gas capture and electricity generating infrastructure.

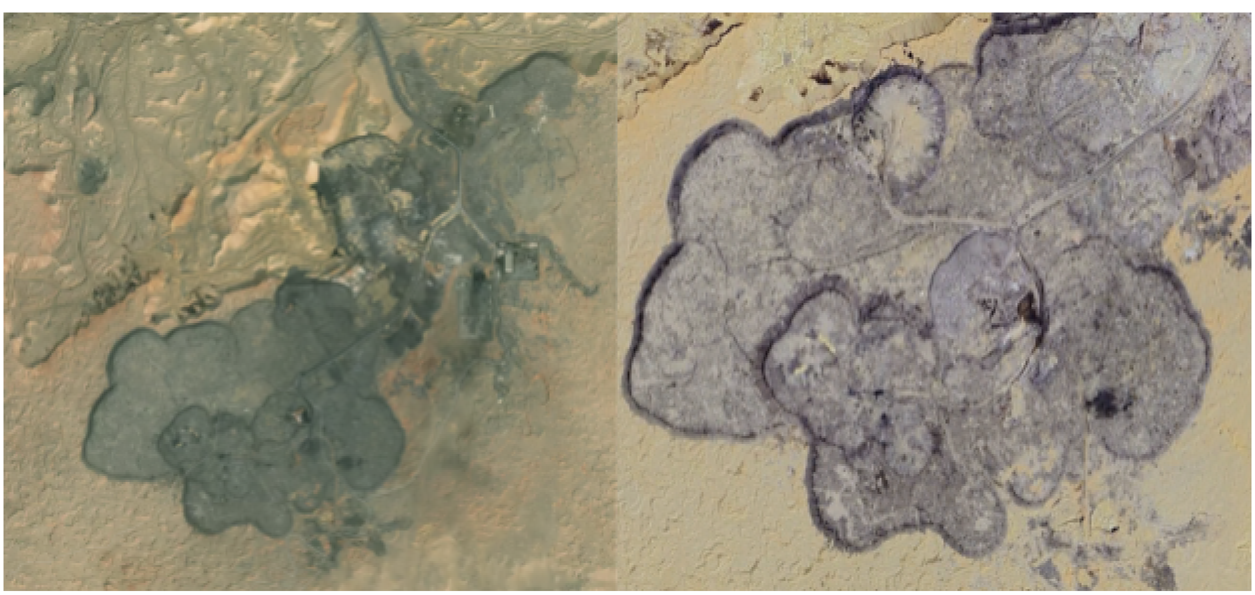


Figure 14: Example of unmanaged dump. Trash is deposited across the surface of the dump, with no active filling area or cover present.

Landfills and dumps vary in their degree of methane generation, but all have the potential to generate strong point source plumes. Potential sources of methane at a landfill include leakage from cracks in the intermediate cover, methane plumes from the active filling area where trash is present, and leakage or venting from gas capture infrastructure. Because of these multiple potential sources, landfills can generate methane from multiple point sources across the landfill surface or it may appear that emissions are coming from a large extended area of the landfill rather than a discrete point, as shown in the example below. Because trash is constantly being deposited, the surface features on a landfill may change over time, so the basemap may not accurately show the landfill surface or boundary. It is best to compare the RGB with the Basemap to determine if the Basemap is out of date for the landfill.

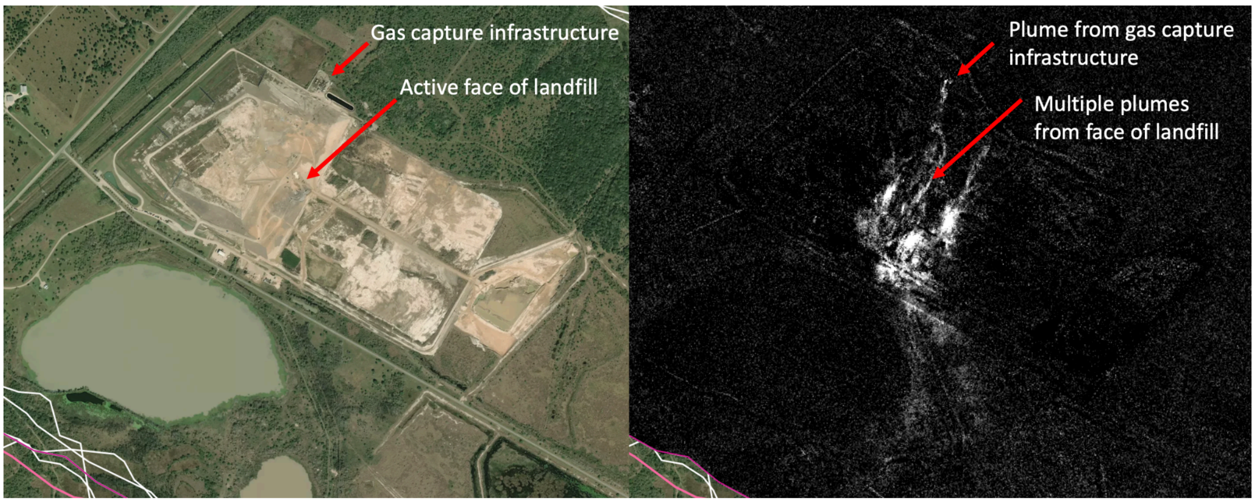


Figure 15: Example of multiple plumes at a single landfill. One plume originates from the gas capture infrastructure at the landfill, and multiple plumes originate from the active face of the landfill where trash is being deposited.

The landfill below has a small plume in the lower right circled in red. Landfill plumes can be more diffuse than oil/gas and coal mine vent plumes. Because of this, it may appear that there is no clear source of the landfill plume (Figure 15a), and it is best to mark the plume origin at the highest enhancement. If there are multiple overpasses available, a comparison between overpasses may help identify the source of a plume (Figure 15b).

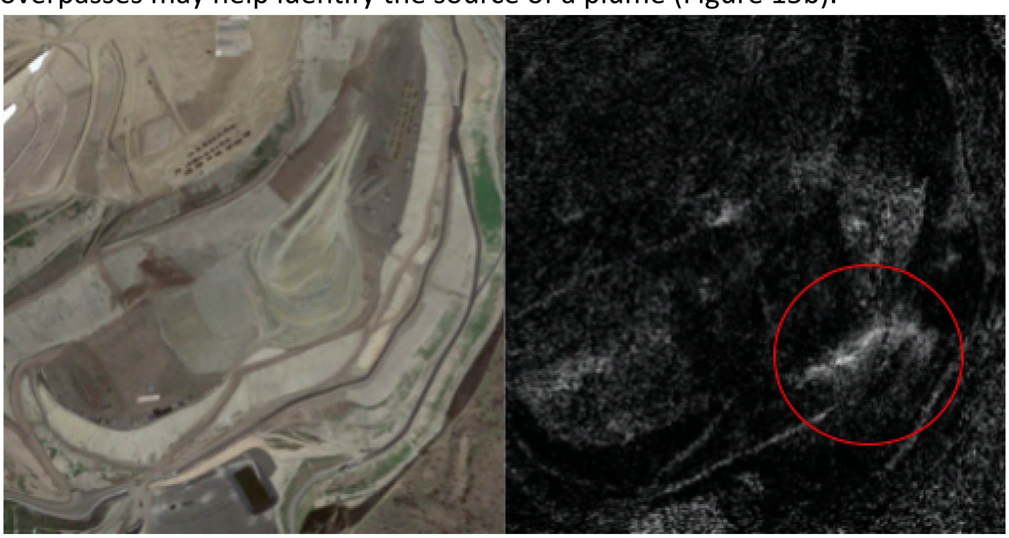


Figure 16a: Basemap image in the left hand panel and matched filter image in the right hand panel of a landfill. A plume is circled in red in the matched filter image

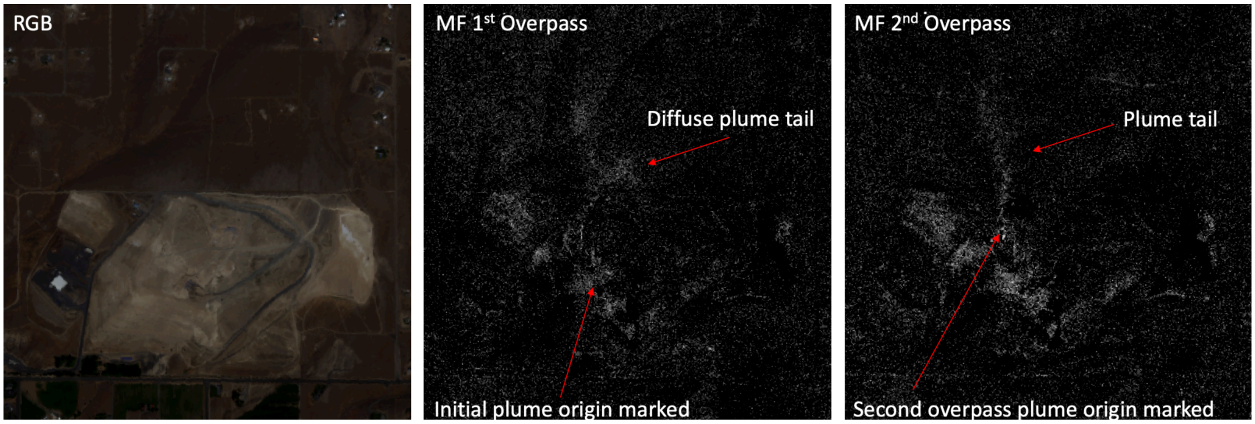


Figure 16b: Another example of a diffuse plume at a landfill (GAO20230720t192543p0000 and GAO20230720t211143p0000). Matched filters are shown for two different overpasses on the same day. This example shows where a second overpass can be used to verify a source location. For the 1st overpass, a “Bad” plume is marked over the center of the landfill because it is unclear if the enhancements are background or methane and the origin of the diffuse plume is unclear. For the 2nd overpass, there is a clear plume and it is marked questionable due to the difficulty in identifying its source. A comparison of the two overpasses shows us two things: (1) The enhancement over the center of the landfill and marked as plume origin in the 1st overpass is likely an artifact given similarities between 1st and 2nd overpass and (2) The source of the diffuse tail in the 1st overpass is likely to the north and possibly coming from the same source as the plume in the 2nd overpass.

Here are more examples of what landfills look like on the *RGB.tif.* They usually look like broad raised areas that are different (often lighter) in color in comparison to their surroundings. Due to the build up of waste, landfills often have step-like features on the surface allowing trucks to access raised areas. Some might have settling ponds around or in them like the corner right. You may see trucks or other infrastructure on them, and you may see white speckled patterns on part of the landfill surface where trash is being actively dumped.

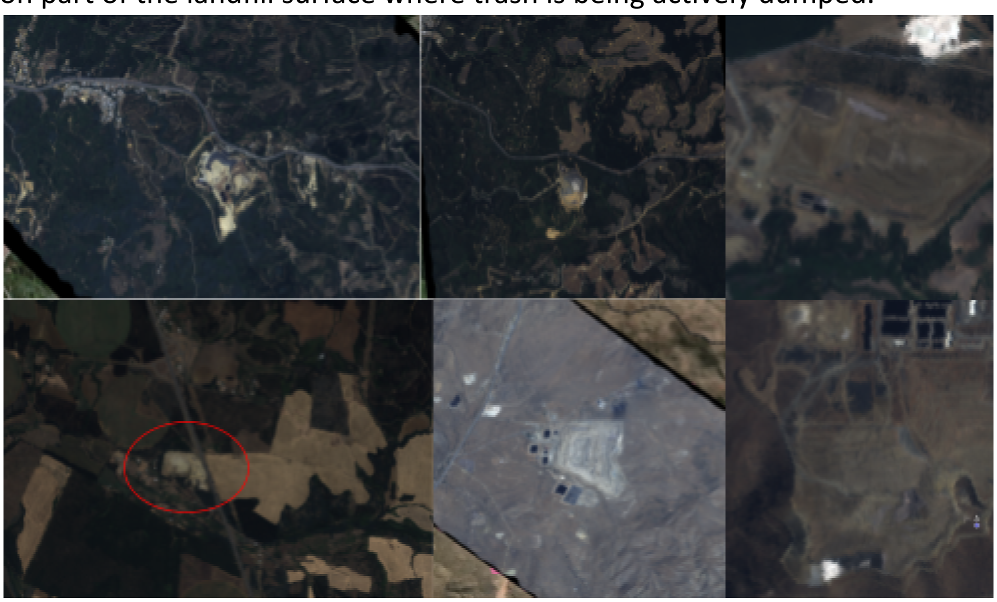


Figure 17: Examples of landfills in the RGB filter

Keep in mind, it is also possible that there will be multiple parts to a landfill close together. This often happens when landfills get large and expand to a second or third site around the original landfill. The original facility may be the only site that is identified in the Basemap and GIS.

Quarries vs Landfills

Note that landfills can easily be confused with quarries and non-coal surface mines. Below are examples of (a) a landfill and (b) a quarry. Distinct characteristics of the landfill are that it has visible trash where they are actively filling the landfill, and cover over the part of its surface where there is no active filling of trash (Figure (a) has grass cover on the south side). Distinct characteristics of the quarry are its very homogenous light colored surface (no trash), and the presence of equipment for moving mined materials. The quarry surface won't generate methane, but there may be energy facilities located at the quarry that generate methane or CO2 plumes similar to a power plant (e.g., GAO20230429t164425p0000).

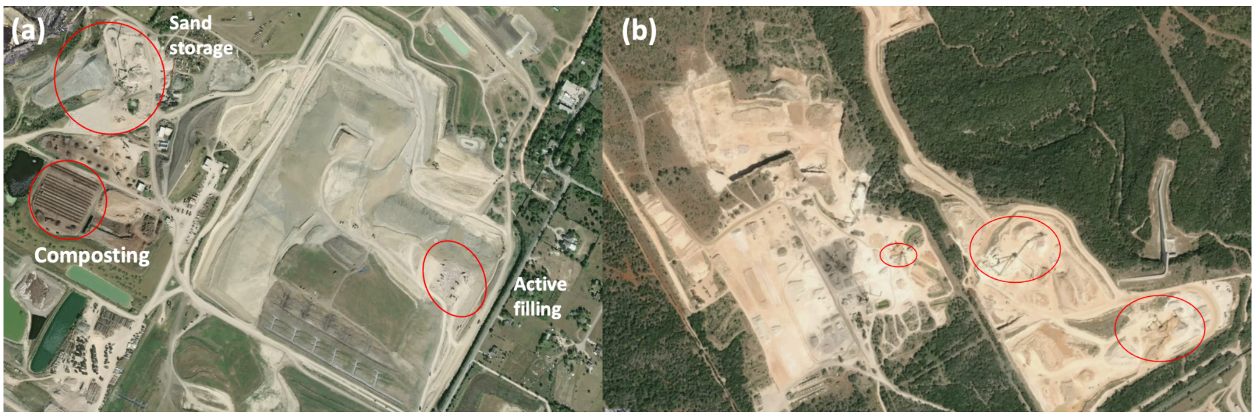


Figure 18: Landfill (a) and quarry (b) examples. The landfill (a) shown has composting, sand storage (sand is used to cover the trash each day), and an active filling area marked in red circles. The quarry (b) has equipment to move materials, circled in red. Note that the equipment used for sand storage at the landfill can look very similar to the quarry equipment.

Compost Facilities

In addition to landfills and dumpsites, some jurisdictions are implementing organic waste diversion where food and green waste are sent to compositing or dry digestion facilities rather than landfills and dumps. These facilities may be located directly next to a landfill, as shown in Figure (a) above. We may see methane plumes from these facilities as shown in the example below. Typically, composting facilities will have rows of brown organic material in the RGB, as shown below.

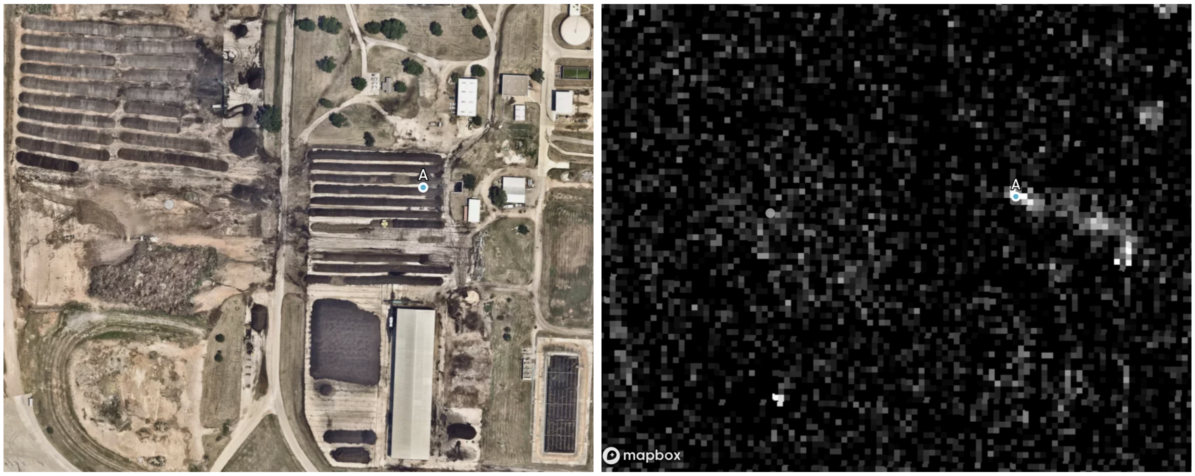
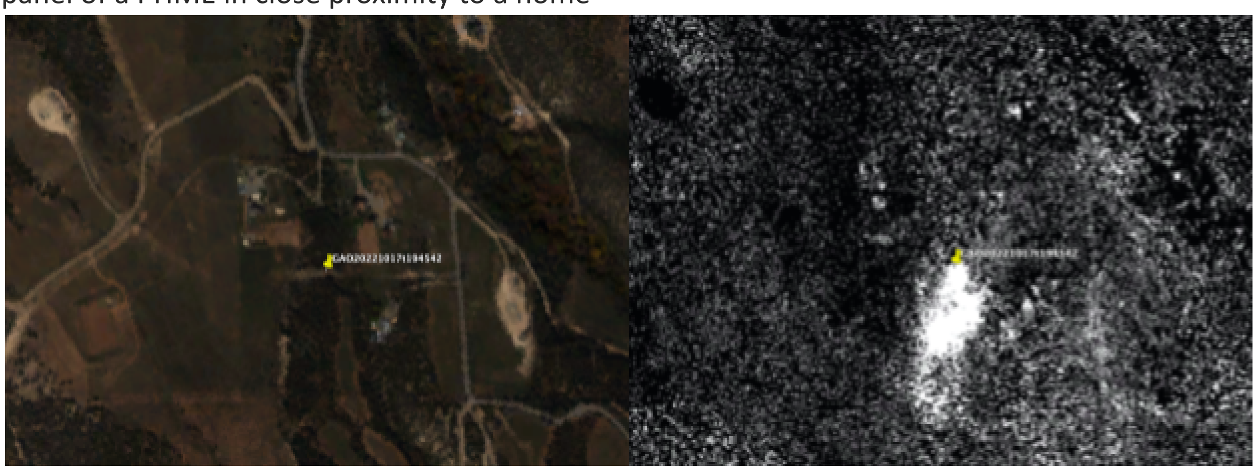


Figure 19: Example of methane plume, marked ‘A’, from compost facility. The brown rows show the organic material that is being composted, generating methane. (GAO20230415t174538p0000)

Potentially Harmful Methane Event

A potentially harmful methane event (PHME) occurs when a methane-containing gas is released to outdoor air and the resulting surface-level concentration of methane or co-emitted HAPs may harm public health and/or safety over a short period (e.g., over a day). Below is a PHME in Colorado, the plume is marked due to close proximity to residences. For the time being, QC analysts should not mark PHMEs internationally or from the US waste sector. For additional guidance on PHME’s, see Carbon Mapper’sPhase 1 Policy here.

Figure 20: A basemap image in the left hand panel and a matched filter image in the right hand panel of a PHME in close proximity to a home



CO_2 Plumes

CO_2 has a variety of sources and is more abundant than methane in our atmosphere. This causes the distribution of discrete CO2 enhancement to be much more complex than they are for methane. This complexity makes it more difficult to quantify CO2 by remote sensing. Generally, diffuse enhancements in CO2 should not be marked as plumes. Rather, analysts should try and identify only discrete point sources of CO2. In most cases, Carbon Mapper detects discrete point source CO2 plumes where combustion is actively taking place, such as at a portable generator, refinery or power plant. This is when incendiary matter such as fossil fuels, refuse incineration, as well as biomass is burned thereby emitting CO_2. Discrete CO_2 plumes most often come from stacks in power plants, refineries, and other CO_2 producing facilities. Sometimes CO_2 can come from chemical reductions in industrial processes and aggregate preparation facilities like cement factories and asphalt plants. When looking at these scenes, it is essential to look for discrete industrial facilities in the RGB. These plumes will also take on a more traditional gaussian shape. In both examples below, you see two plumes next to each other, seemingly coming from stacks at the facility in the RGB/basemap.

When a discrete CO2 plume is identified, it is important to also look for similar plumes in the methane match filter results. Generally, methane will be absent if burning is well oxygenated and hot, but methane is a possible co emission in all CO2 plumes. This is an emerging area of research and when plumes of both gasses are seen, the analyst should flag the plumes for additional QC.

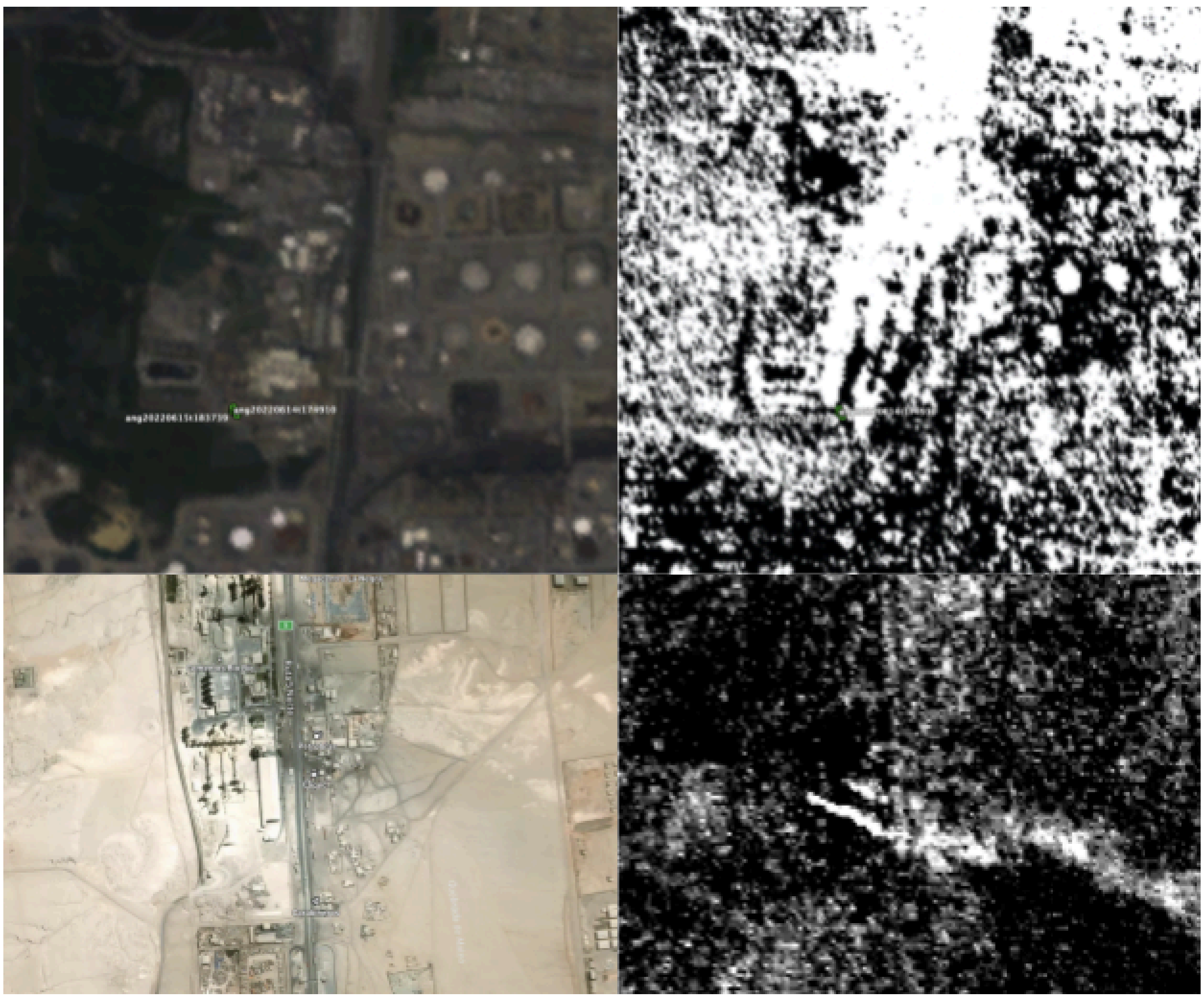


Figure 21: An RGB image in the upper left panel, and a corresponding matched filter image in the upper right panel. A basemap image in the lower left panel, and its corresponding matched filter image in the lower right panel

Electricity Generation/Refining

Most CO2 plumes will come from electricity generation (power plants) or refining. In the first example below you can see CO2 plumes in the RGB, and then again in the matched filter.

Because the matched filter is so noisy, it would be important to look at the RGB for stacks to make sure that a plume is there rather than just an enhancement or an artifact. Wind direction can also be used to determine if these are CO_2 plumes and not just noise. If there are multiple plumes, all should be showing an agreement in direction, like the two below and the two in the example above. When doing QC, most CO_2 plumes will fall under *Electricity Generation* or *Oil & Gas* in the *Sector Attribution* drop down.

Figure 22: Basemap image of a stack circled in red, and a matchfilter image of the stack again circled in red

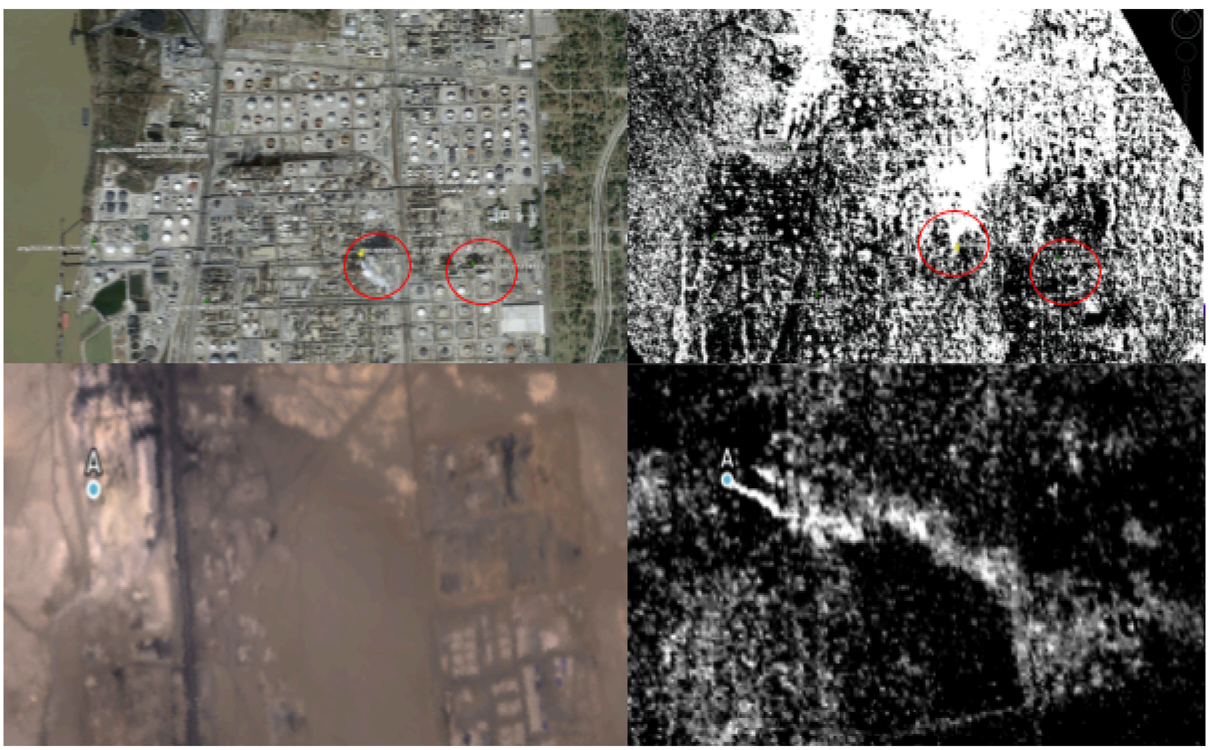


Figure 23: An RGB image in the upper left panel, and a corresponding matched filter image in the upper right panel. A basemap image in the lower left panel, and its corresponding matched filter image in the lower right panel. Stacks in the upper panels are circled in red

Other

Petro Chemical

Petro chemical production, which includes… can have both CH_4 and CO_2. how to identify it… add example image
Petro Chemical facilities, when definitively identified in base map imagery, should be categorized as “other” and not as oil and gas.

Cement

Cement looks… how to identify it… add example image

Flares

Many types of facilities can have flares. Flares are used to burn off unwanted gas and to prevent dangerous gas buildups. Flares are most often found in the oil and gas sector, on well pads and at gas plants and refineries. However, flares can also be found at petrochemical facilities, among other industrial locations. Flares are combustion sources and can have discrete CO_2 plumes, if the flare is working properly, or can have plumes of methane if the flare is unlit. Poorly functioning flares can have plumes of both gasses. Any case of simultaneous emission of both CO_2 and methane is of particular interest and should be flagged for additional QC. Flares can often also be identified by their temperature and Carbon Mapper is in the process of refining an algorithm for this purpose.

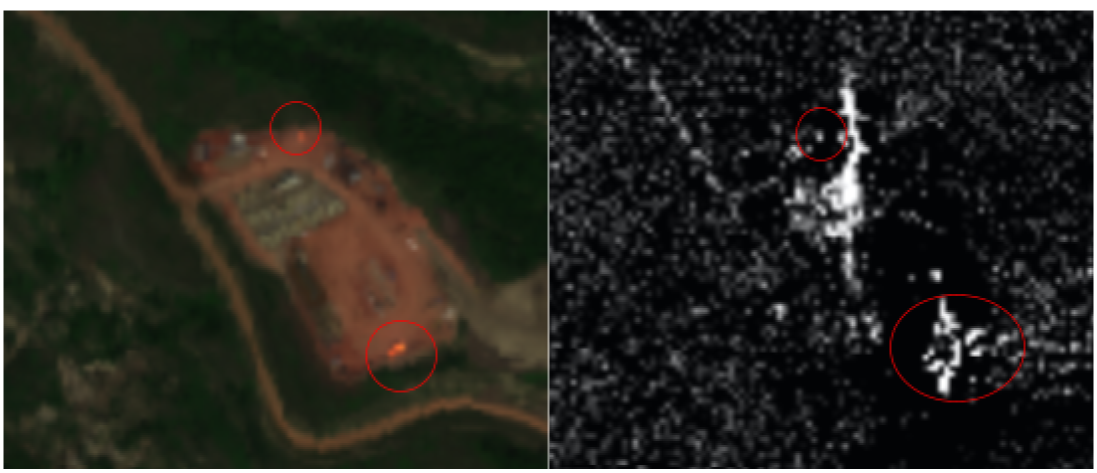


Figure 24: RGB image in left hand panel and corresponding matched filter image in right hand panel. Flares are circled in red in both panels

How to Identify Artifacts vs Plumes

PlumePortal will ask you in the Image and Artifact Assessments to distinguish real plumes from artifacts or spurious signals. There are two key classes of artifacts:

1) Confusion with real features in the scene that are not methane plumes (e.g., high radiance surfaces like roofs, roads or surface mineral signatures that mimic methane).

2) Systematic errors in the retrieval itself like "sine wave pattern" (ringing) that results from a very specular radiance in the science like flares or solar panels). These artifacts, sometimes caused by “column artifacts” are especially prevalent in matched filter-based retrievals. In this case, very few anomalous spectra that result from atypical processes or

surface features (e.g., flares; solar panels) may corrupt the mean and covariance statistics that drive the matched filter algorithm. The result is that a systematic artifact propagates across an entire column.

The former is often best recognized by comparing the geometrical pattern between the CH4 image and surface RGB and the latter can be recognized by the distinctive sine wave pattern in the CH4 image (which is only present in some retrievals)Below are examples of artifacts you might see in PlumePortal.

Image Artifacts

Glint

Because of the sun, sometimes data will 'drop out'. Sunglint is a bright mirror like reflection off water, metal roofs, or other flat reflective objects. In some cases it can cause a disruption across the whole sensor array resulting in poor quality data. It is a bright reflection in the RGB below.

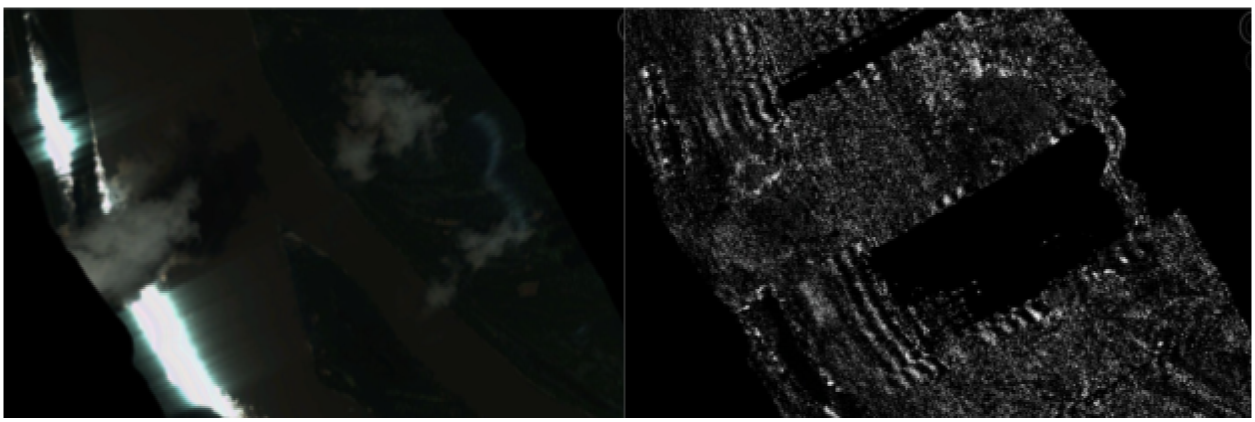
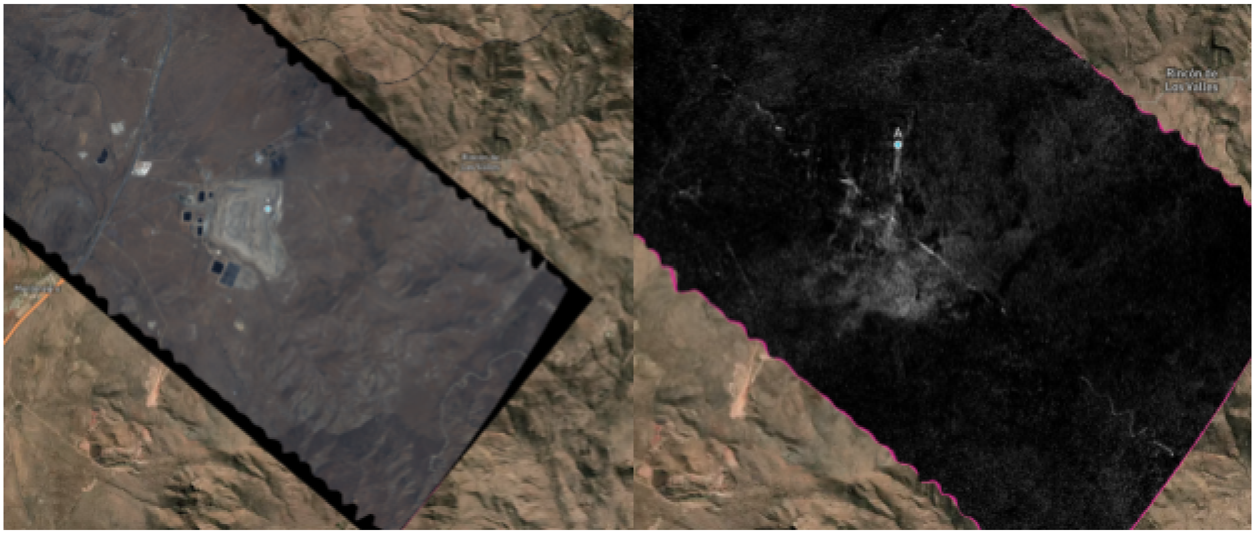


Figure 25: Glint in the left hand RGB image, and the matched filter in the right hand panel

Column Artifact

Column artifacts will show up in a scene as a line or squiggle through the matchfilters. They can be easy to mistake as plumes. A tell tale sign of a column artifact is if it's not consistent through different matched filters and it goes through a large portion of a scene. The enhanced squiggly line going through the matched filter is a column artifact. Sometimes these artifacts can be enhanced by plumes in the scene, plum



e “A” is enhancing this artifact.

Figure 26: Column artifact in the left hand RGB image, and the matched filter in the right hand panel

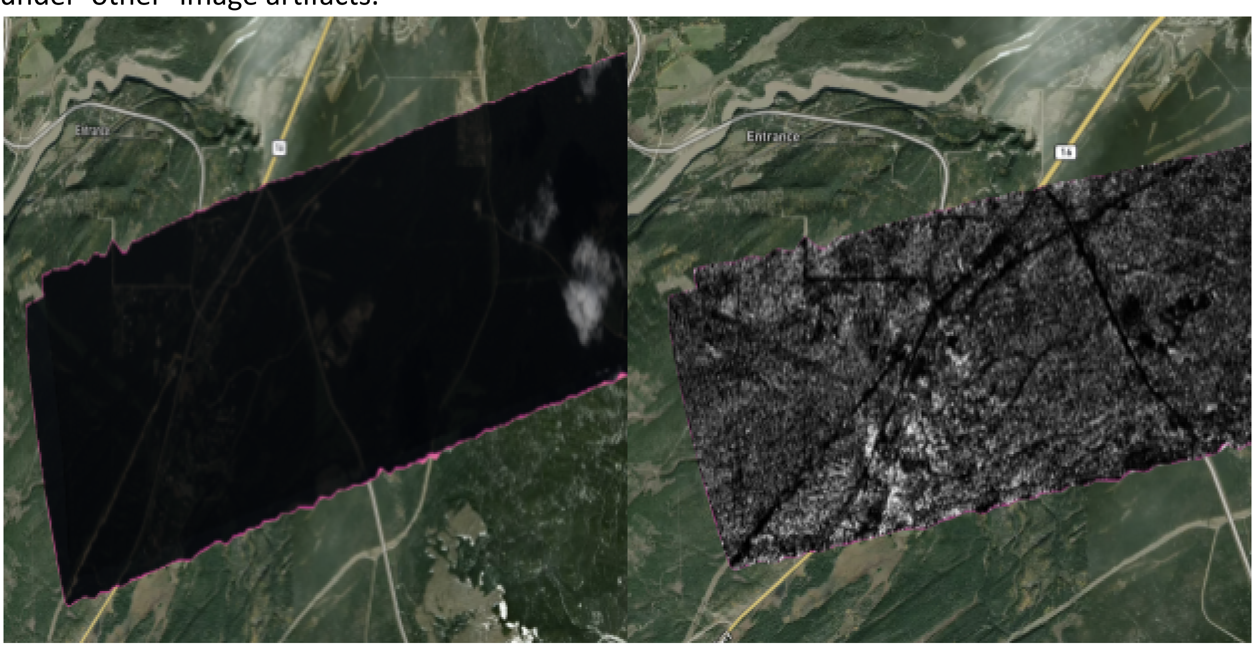
Contrast

When an RGB is particularly dark and it's hard to look at the scene, we would mark it as low contrast. Low contrast can be caused by multiple factors like clouds, lots of vegetation that soaks up the sun, and flying at certain times of day. A scene with low contrast will appear very dark in the RGB, like the one below.

Figure 27: Scene with low contrast in the left hand RGB image, and the matched filter in the right hand panel

Other

Other unexpected or unaccounted for artifacts not included in the provided examples would fall under ‘other’ image artifacts.



Atmospheric Artifacts

Clouds and cloud shadows

Cloudy scenes often appear to look like artifacts or even plumes in the product overlays, but are clearly clouds in the RGB. Some scenes like the one below may also have cloud shadows underneath or near the clouds themselves, which might look like dark spots in the product overlays.

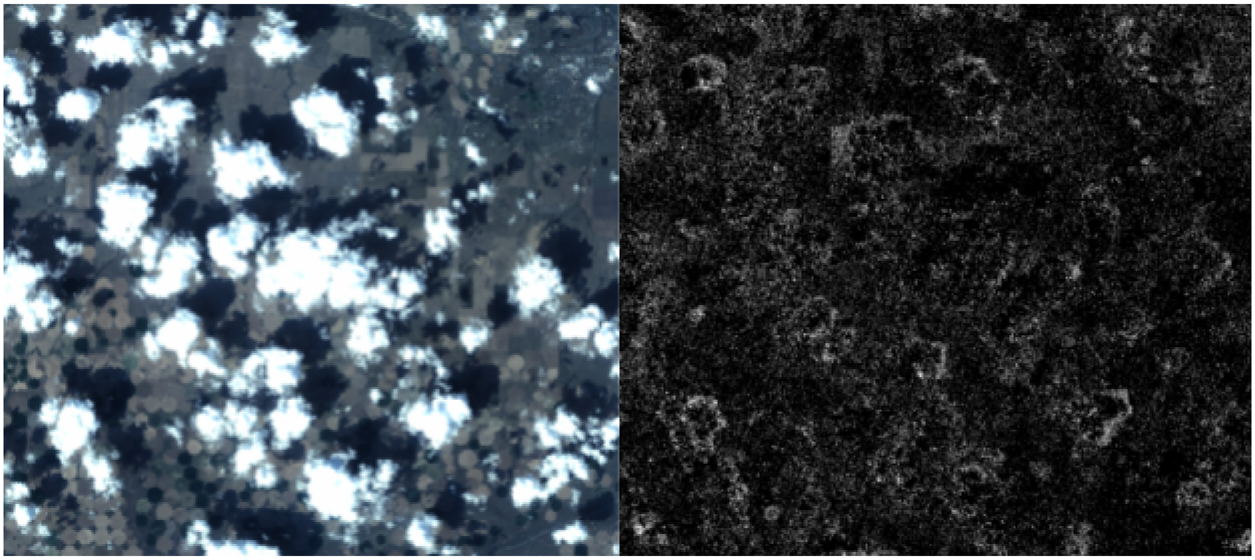


Figure 28: Clouds and cloud shadows in the left hand RGB image, and the matched filter in the right hand panel

Smoke

Smoke can come from smoke stacks, wildfires, and other combustion. They will appear similar to a plume in the matched filter, but can be properly discerned by comparing to the RGB.

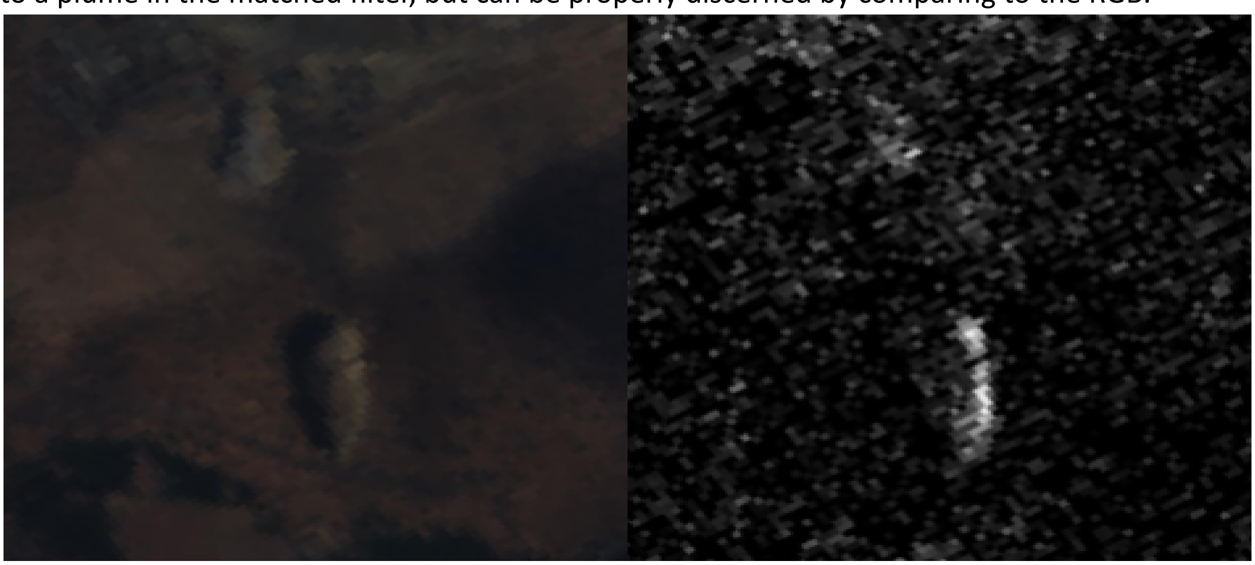


Figure 29: Smoke in the left hand RGB image, and the matched filter in the right hand panel

Haze

Haze can come from clouds or other artifacts in the scene. Haze is typically see-through unlike clouds, which are clear and will not be see-through. Haze will look lighter than the rest of the scene. The haze below is in the lower right of the scene.

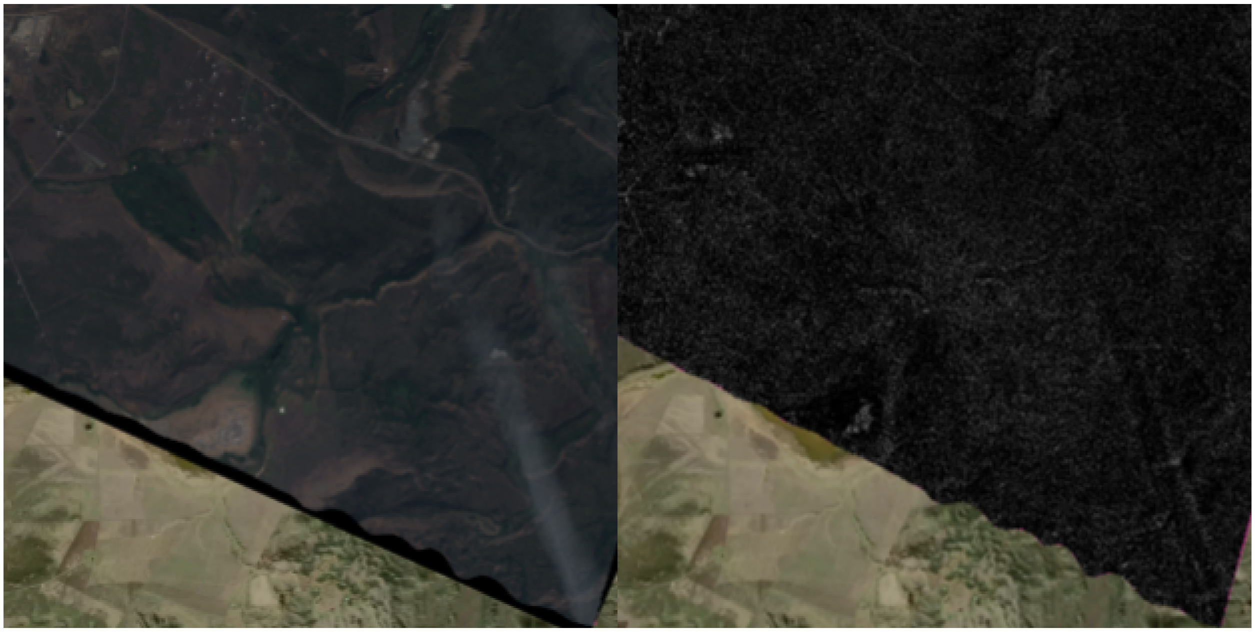


Figure 30: Haze in the left hand RGB image, and the matched filter in the right hand panel

Other

Other unexpected or unaccounted for artifacts not included in the provided examples would fall under ‘other’ atmospheric artifacts.

Other

Low SNR

Scenes with low signal to noise ratios will look very grainy, making it hard to find plumes. The photo below has a very low signal to noise ratio, making it difficult to discern a plume from noise in the scene. Most CO2 scenes are very noise and have low SNR so most of them will need to be flagged as low SNR; but methane scenes are more variable and so more effort is required to assess whether a methane scene is low SNR.

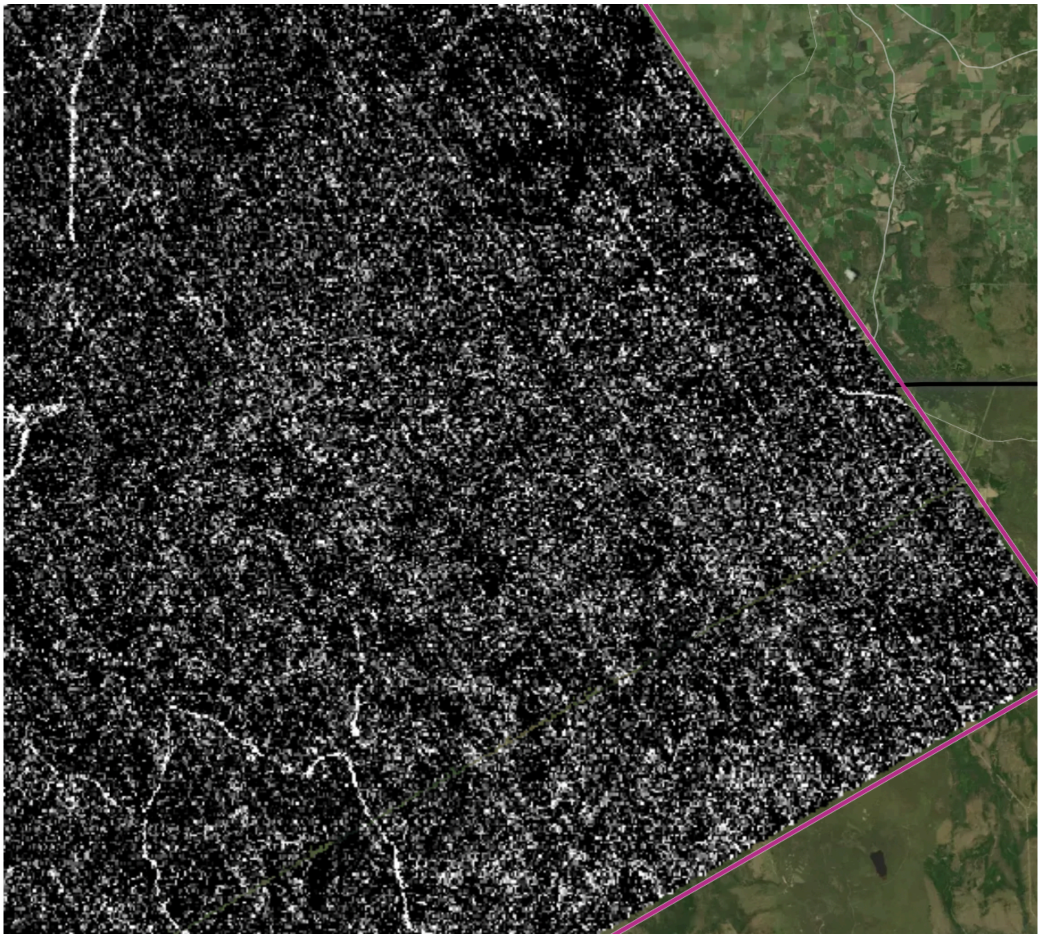


Figure 31: Low SNR scene in the matched filter image

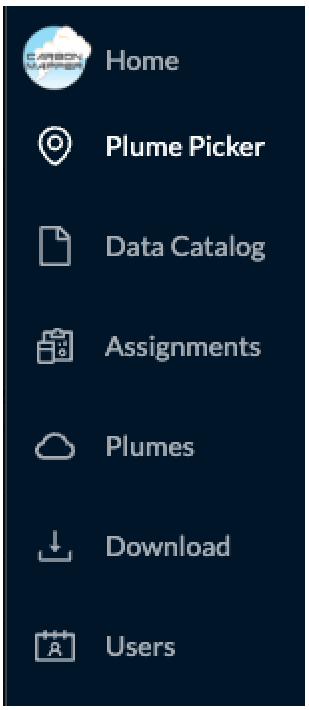
Geolocation Error

Sometimes what we see on PlumePortal doesn't always match what's on the basemap. This can happen because of elevation changes, mountains, and other factors. It can be important to compare the basemap to the RGB, so the two should be relatively accurate to each other. In 30m resolution imagery, If the RGB is more than 60m offset from the basemap, it is a geolocation error. Notice how this RGB image is off from what the basemap looks like. The road that goes through the scene is off from the basemap.

Figure 32: Basemap image in the left hand panel, and the RGB image in the right hand panel

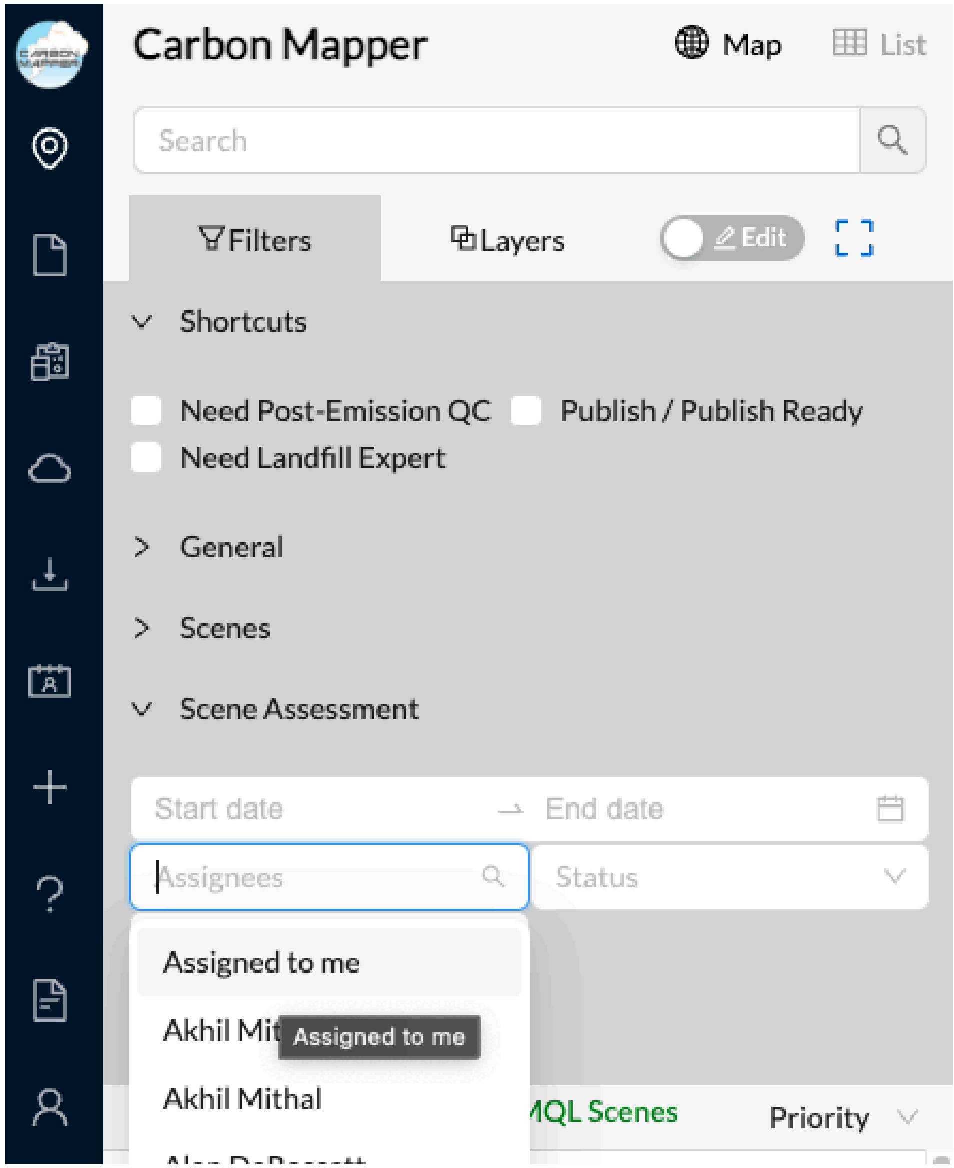
How to access assignments on PlumePortal:

Now that we've looked over how to identify plumes and artifacts, it's time to access our assignments and QC! Remember to use this guide for reference when looking for plumes and that it's okay to ask questions. Looking for plumes can be difficult, and it takes time to get good at it. With practice, you'll get it down in no time.

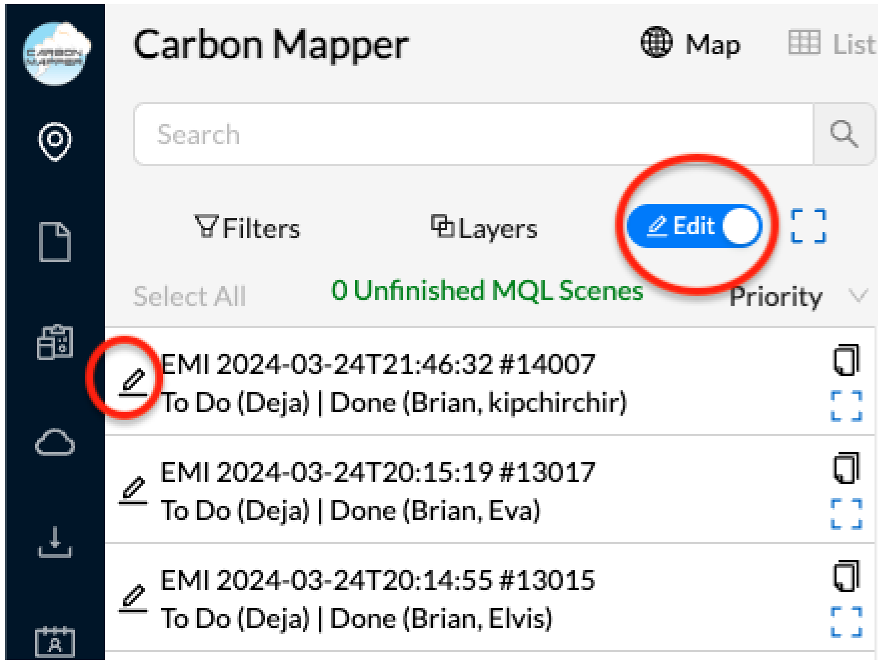
1. Go to the Carbon Mapper Data Portal to login: https://platform.carbonmapper.org/account/login/
    a. Log in with your credentials
2. Go to *Plume Picker* in left hand panel
    a. 

How to QC on PlumePortal:

1. Go to Plume Picker < Filters < Scene Assessment < Assignee < Assigned to me

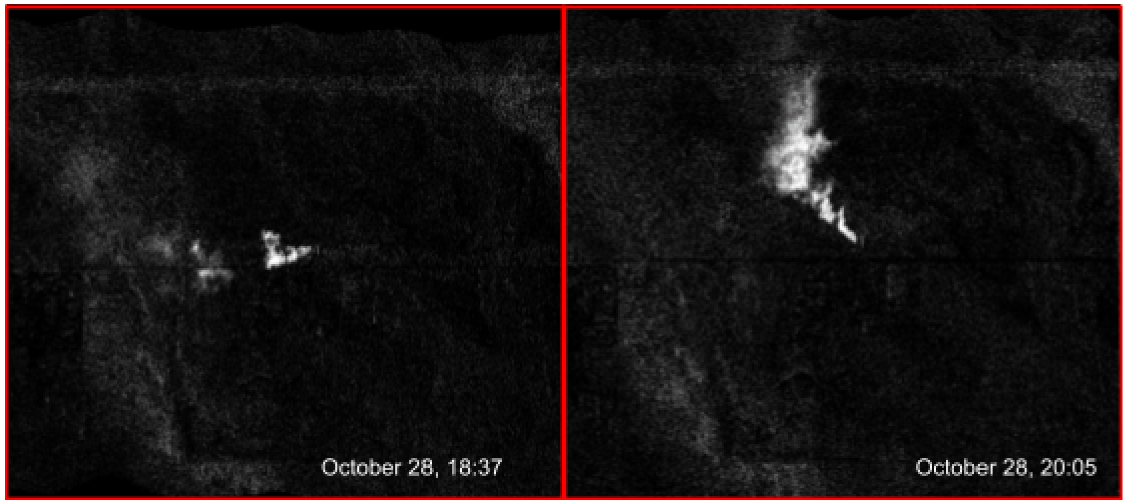


2. Click the edit handle (in red) next to layers, and the drawing toggle next to the flight line. Click the blue box to zoom (in blue) to its overlay. Always QC unfinished MQL scenes before QC'ing anything else. Be sure the dropdown is also set to Priority, to see these scenes first followed by scenes in order of QC priority

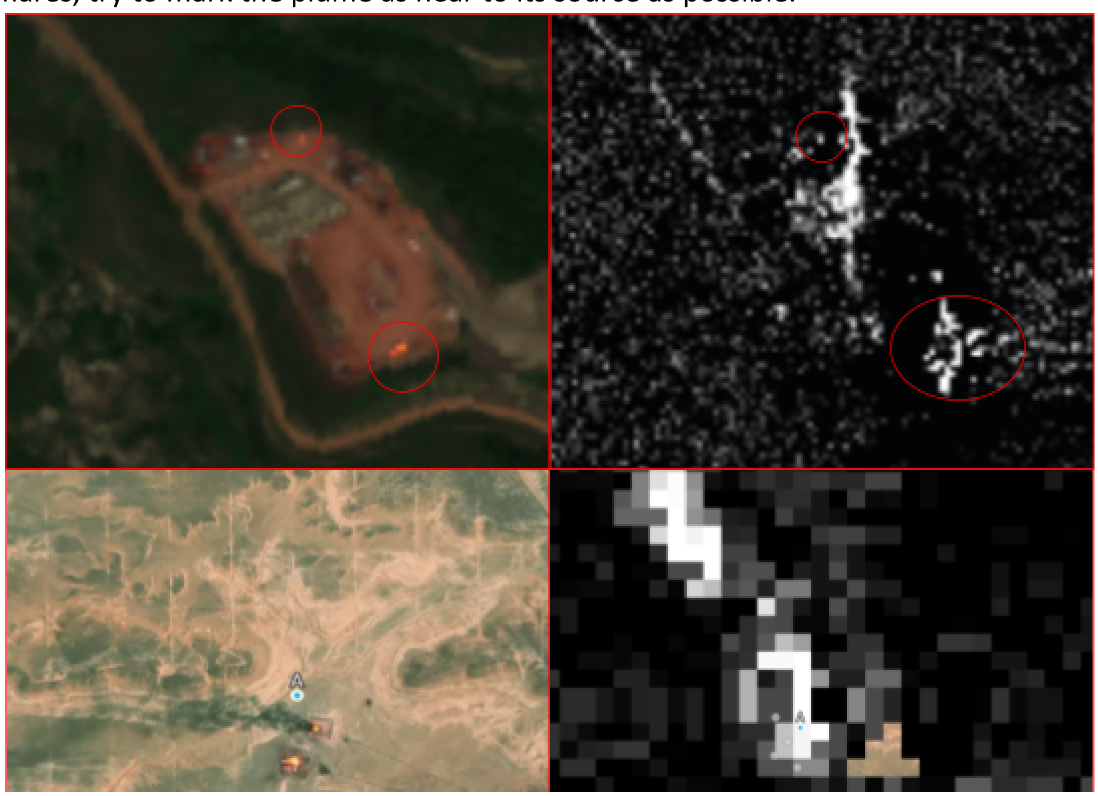


3. Look for plumes in the scene.
    a. Zoom to full scene to assess overall quality
    b. Choose an end of the scene and zoom in to the image.
        Before turning on matched filters, it's helpful to quickly scan the RGB for facilities methane or CO_2 might be likely to come from (landfills, CAFO's, coal mines, etc.)
    c. Pan through the image locating bright enhancements within the matched filter
    d. Determine if enhancement corresponds to a ground feature using RGB layers. The basemap is higher resolution and can be used too, but note the RGB is the most updated layer.
        Is it a false enhancement caused by a confuser on the ground?
        Tip: if an enhancement exactly matches a ground feature like a piece of land or a building, and there's no enhancement outside of it, it's likely just an artifact.
    e. Determine if the various matched filters agree on the enhancement
        If the enhancement isn't in multiple matched filters, this is likely an artifact or issue with the retrieval
        Tip: If you are unsure whether an enhancement is a plume, sometimes looking at scenes that cover the enhancement from different dates or times can help determine if the plume is consistent or not. The photos

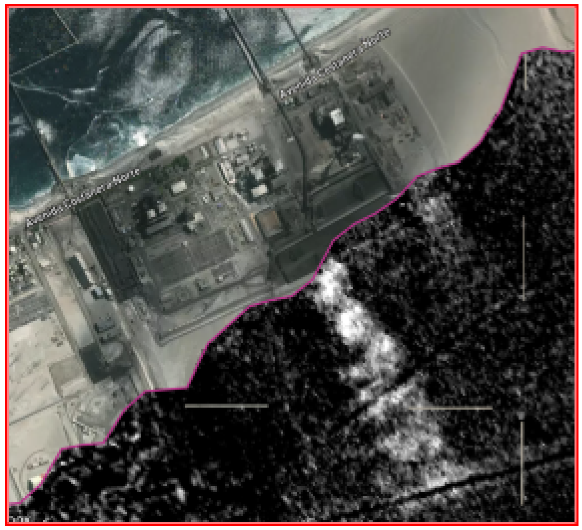
below are from different times, but the plume is consistent.



If you see odd markings next to a plume, check the RGB to see if it's a flare. Flares are combusted/burned gas. They look like small fires in the RGB, and like linear cross hatched patterns in the matched filters. They are enhancements. Below there is a flare at a station in the top panel. It shows up as a column of fire in the RGB, and as a cross hatch in the matched filter that doesn't resemble the plume nearby. Both are circled in red. Flares usually show up in the methane matched filters rather than the CO_2 matched filter. In the bottom panel, there is pixel dropout from a flare stack, and beside it is a plume. In the event pixels drop out from flares, try to mark the plume as near to its source as possible.



If you see an obvious enhancement, but there is no source in the scene, no need to mark it, but if you do mark it, mark its sector as *'None'*. If you suspect where it's coming from on the basemap, note that in *Scene Notes*. Below you see CO_2 in the scene that could be coming from the facility northwest of it, but the facility isn't in the scene. In this instance, don't mark the enhancement, but mention in the *Scene Notes* where the enhancement could be coming from.

1. 

f. See if you can determine which direction wind appears to be moving

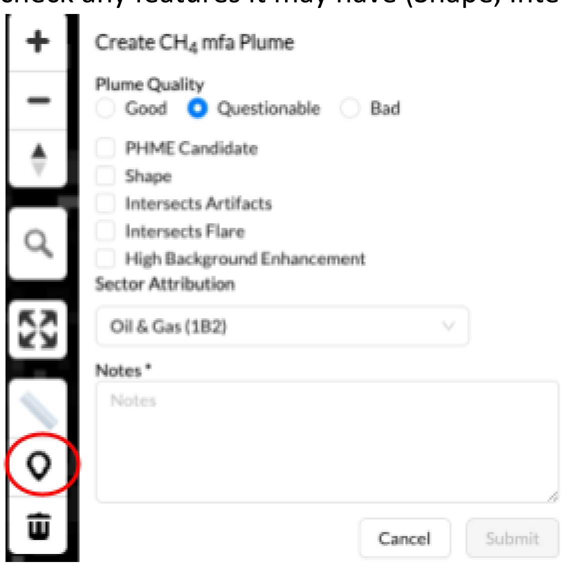
   Plume will be strongest near the source and become more diffuse downwind. Additionally if you see a plume moving in one wind direction, all other plumes in that scene will typically also move in that direction

g. Using the RGB layer, determine if the plume is coming from an obvious ground feature or source

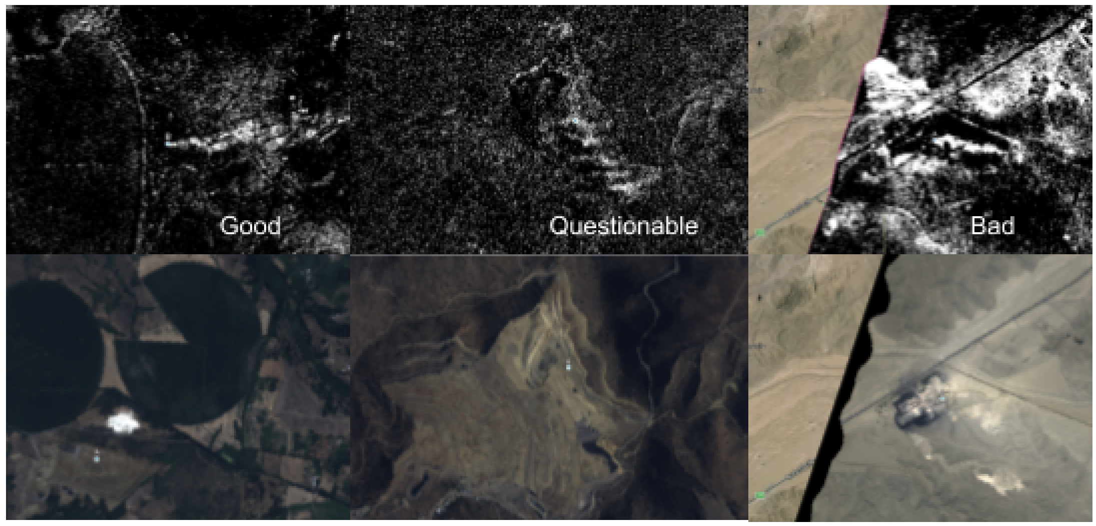
   Mark the plume at the highest concentration/enhancement nearest the ground source

   If there is no obvious source, mark plume at highest concentration/enhancement

h. Drag marker tool to plume and fill out the *Create CH4 Plume* box in left hand panel. If the plume is *Questionable* or *Bad,* describe why in the notes box and check any features it may have (Shape, Intersects Artifacts, etc.)



   Here's an example of a good, questionable, and bad plume. We use good, questionable, and bad in the detection process as follows: "good" == unambiguous plume with a well defined shape and little artifacts. "questionable" == unambiguous plume but with some issues that could affect quantification - e.g., odd plume shape, some retrieval artifacts, etc. "bad" == uncertain if it is a plume. "Bad" is not a terminal state - after initial QC review, an additional layer of QC occurs (we sometimes call this post-emission QC) that will determine whether to delete the plume or move it to the "questionable" bin. The post-emission QC process will make the determination if "questionable" plumes will also determine if we publish an emission rate, or just a detection.



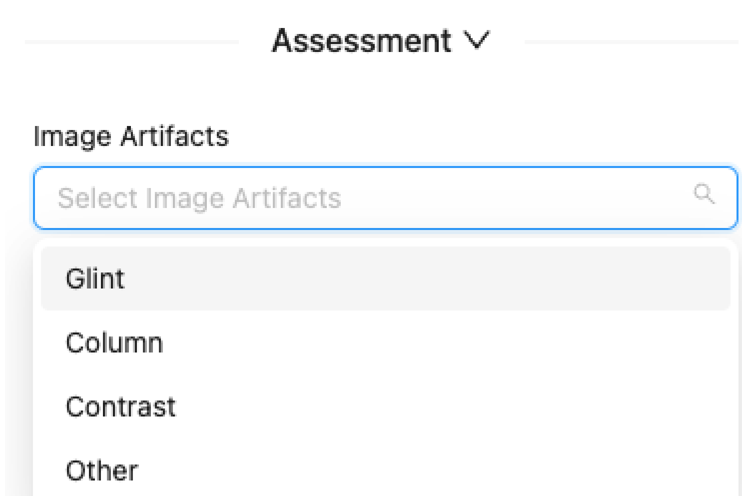
Examples of notes you might put in the notes box are "Landfill plume, can see road artifact downwind of plume", "Large CO2 plume at power plant", "Unsure if plume, near CAFO, but could be building artifact".

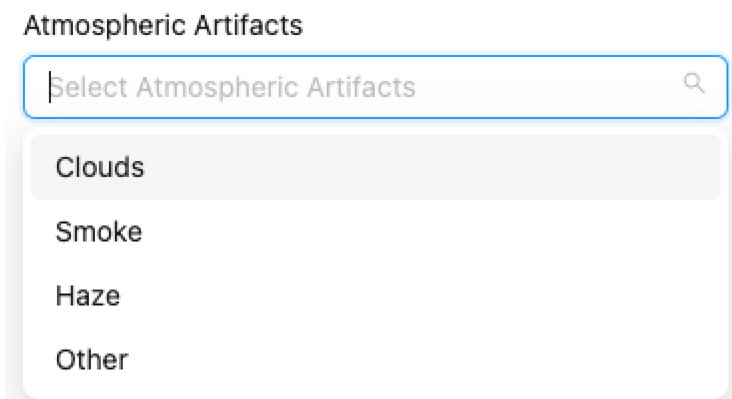
In the *Sector Attribution* dropdown, select the sector of the source of the plume. The table below takes from the 1996 IPCC National Guidelines for Greenhouse Gas Inventories. If you see a plume that is >20m (airborne) or >120m from a source or does not have a visible source, mark the sector as *"None"*

Main CH4 Emitting Sectors	**Facility/Infrastructure**
1A1 (Electricity Generation)	Power Plants, Refineries, Liquified Natural Gas Facilities
1B1a (Coal Mining)	Open Pit Mines, Coal Vents from Underground Mines, Coal Processing/Prep Plants
1B2 (Oil and Gas)	Wellpads, Pipelines, Compressor Stations, Refineries, Processing Plants
4B (Livestock)	Dairies, CAFOs
6A (Solid Waste)	Landfills, Dumps, Compost facilities
6B (Wastewater)	Wastewater Treatment Plants
Other	Common ones: Chemical Plants, Fertilizer Plants, Renewable Natural Gas facilities next to landfills/dairies
Main CO2 Emitting Sectors	
1A1 (Electricity Generation)	Power Plants, Liquified Natural Gas Facilities
1B2 (Oil and Gas)	Refineries
Other	Common ones: Cement Plants, Renewable Natural Gas Facilities at Landfills

** This table takes light guidance from the *1996 IPCC National Guidelines for Greenhouse Gas Inventories*.

4. Click on the *Overlays* and look for artifacts in the scene (clouds, georeferencing errors, low SNR, etc.) If there are artifacts in the scene, mark the corresponding options under *Image* and *Atmospheric Artifacts* in the *Assessment* pane. Often artifacts such as flares are more noticeable in the matched filters than the RGB. In *Scene Notes*, describe the artifacts found in the scene. If there are no artifacts, leave the notes box blank. If there are clouds in the scene, be sure to fill out what percentage of the scene is cloudy in the *Cloud Cover* option. Click *Save Assessment* when done.





Examples of things you might put in scene notes are “Clouds throughout the scene”, “Road artifact on left of scene”, “Scene is hazy”, etc.

5. Click *Mark as Done* when done. Repeat for each scene assigned to you.