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Methane Plume Detection With Remote Sensing

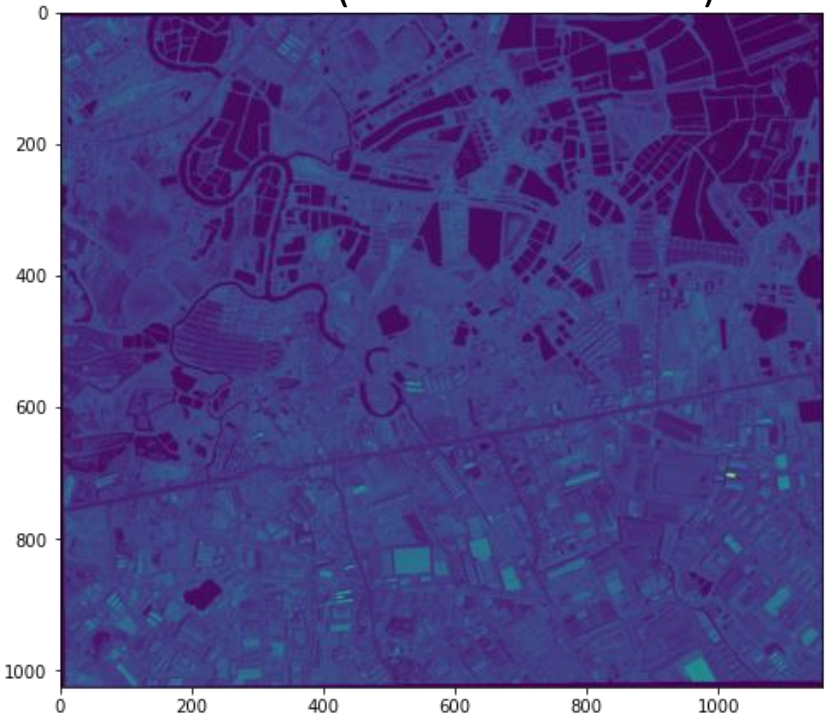
11/1/2022

Remote Sensing

- Remote sensing methane retrieval is a process in which short wave infrared (SWIR) imagery is converted into a theoretical methane concentration.

Aerial (RGB)

Aerial (1 of 8 SWIR bands)



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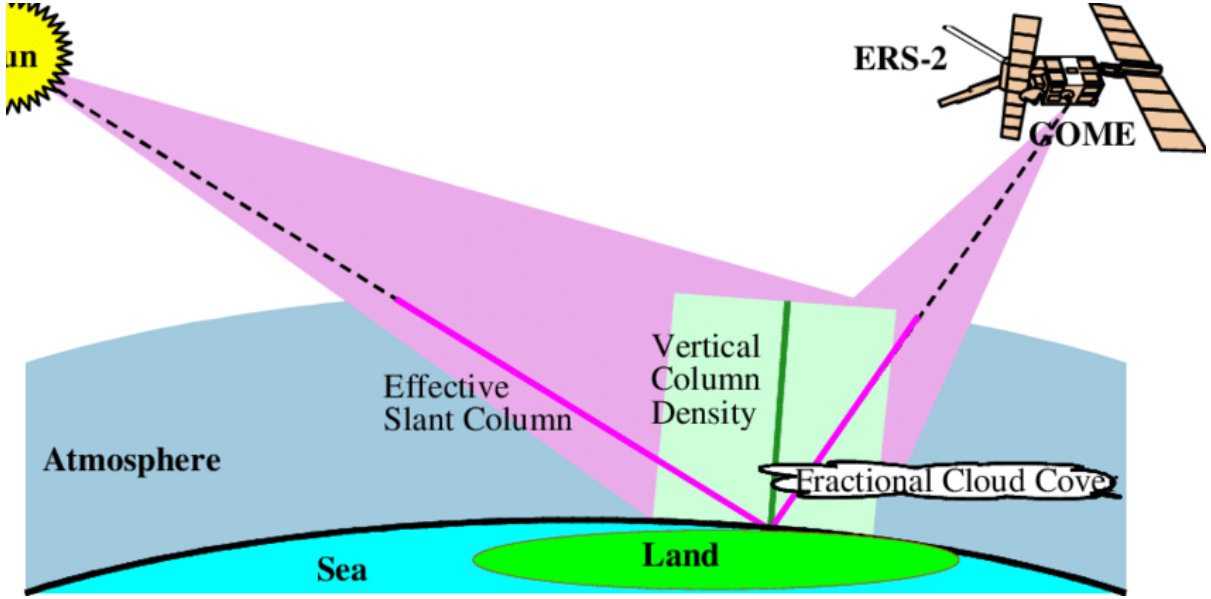
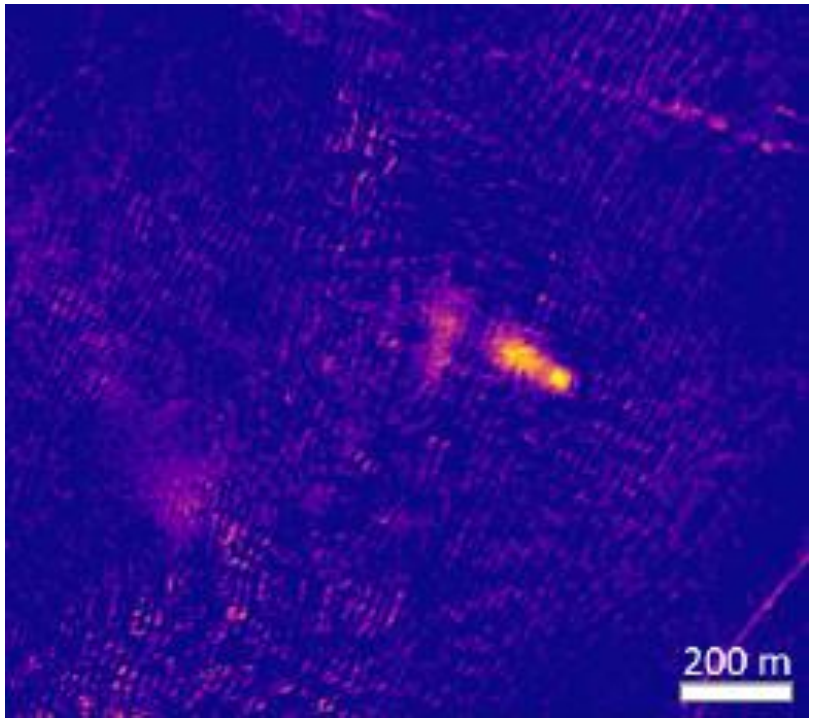
Remote Sensing

- We can convert SWIR imagery into methane concentrations by accounting for methane's absorption of different SWIR wavelengths, atmospheric conditions, and satellite/sun orientation.



Literature example of upstream methane plume detected using DOAS



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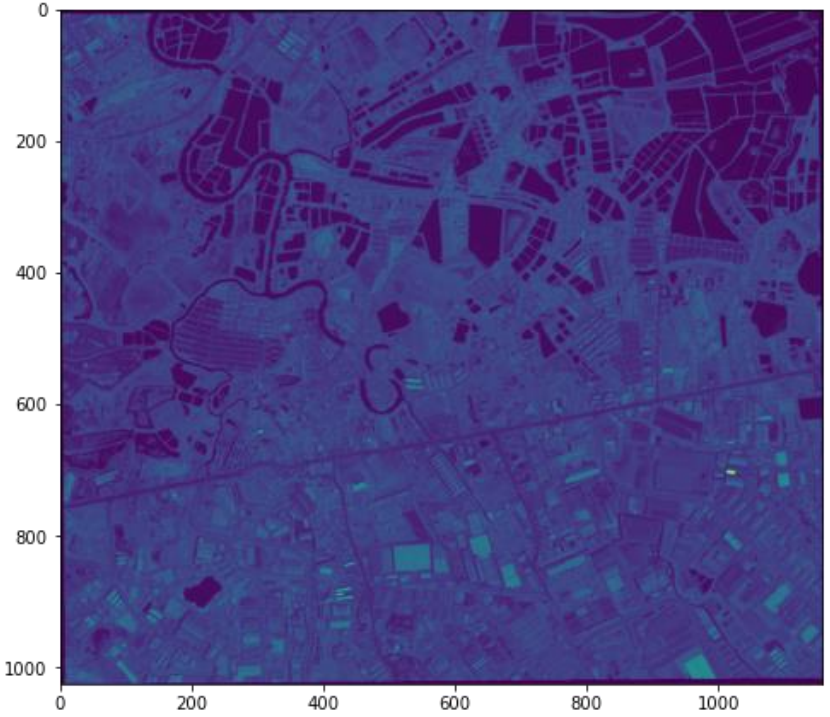
Remote Sensing

- Picarro has evaluated SWIR imagery data sources and determined that the Worldview 3 satellite is best suited for detecting methane sources of the magnitude found in distribution networks due to its high resolution.

Aerial (RGB)

Raw satellite data: 1 of 8 SWIR bands



Methane Retrieval – DOAS Method

- Differential Optical Absorption Spectroscopy (DOAS)
  - A methane retrieval method
  - Describes the relationship between incident intensity for vertical column and measured intensity after passing through a light path containing an absorber
  - Equations:

$$T_{\text{plume}}(\lambda) \approx \frac{L}{L_{\text{ref}}} = e^{-\text{AMF}\cdot\sigma_{\text{CH}_4}\cdot\Delta\text{XCH}_4} \qquad \Delta\text{XCH}_4 = \frac{-\log(L/L_{\text{ref}})}{\text{AMF}\cdot\sigma_{\text{CH}_4}}$$

  - AMF
    - Air mass factor
  - σ_{CH4} (ppm^{-1})
    - Methane absorption cross section
  - ΔXCH_4 (ppm)
    - Methane column concentration enhancement
  - L/L_{ref}
    - The radiance of the methane sensitive band and the “methane-free” reference band

Methane Retrieval - DOAS

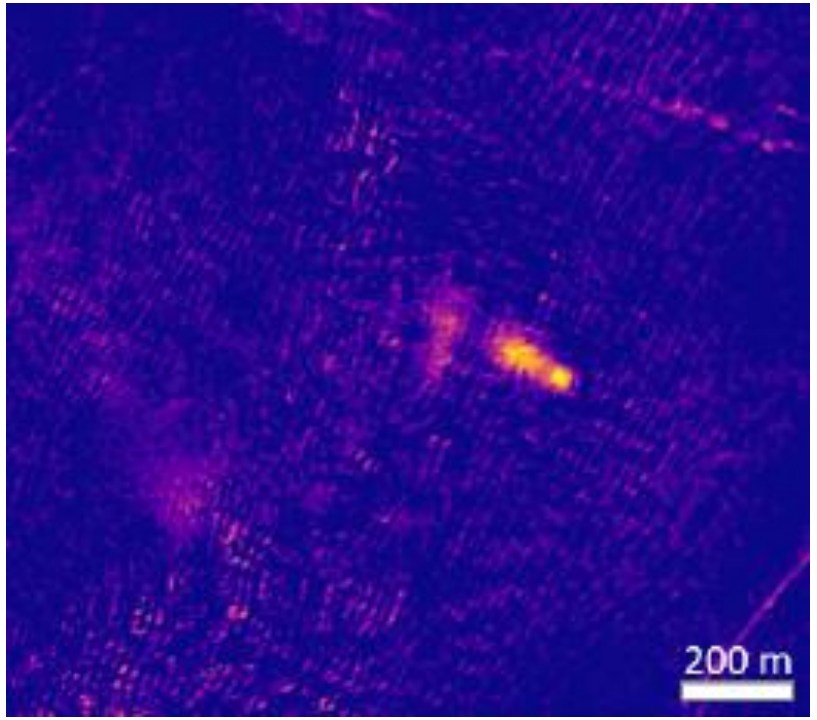
$$T_{\text{plume}}(\lambda) \approx \frac{L}{L_{\text{ref}}} = e^{-\text{AMF}\cdot\sigma_{\text{CH}_4}\cdot\Delta\text{XCH}_4}$$

$$\Delta\text{XCH}_4 = \frac{-\log(L/L_{\text{ref}})}{\text{AMF}\cdot\sigma_{\text{CH}_4}}$$

$$\tau(\lambda) = \sum_{i=1}^{72} \Delta\,\text{VMR}_i\ \text{VCD}_i\ \sigma_{\text{H},i}(\lambda).$$

$$T(\lambda) = \exp\{-A\tau(\lambda)\}$$

- ΔXCH_4 (ratio)
  - Methane column concentration enhancement
  - The increment produced by the plume from the background methane present in the atmospheric column



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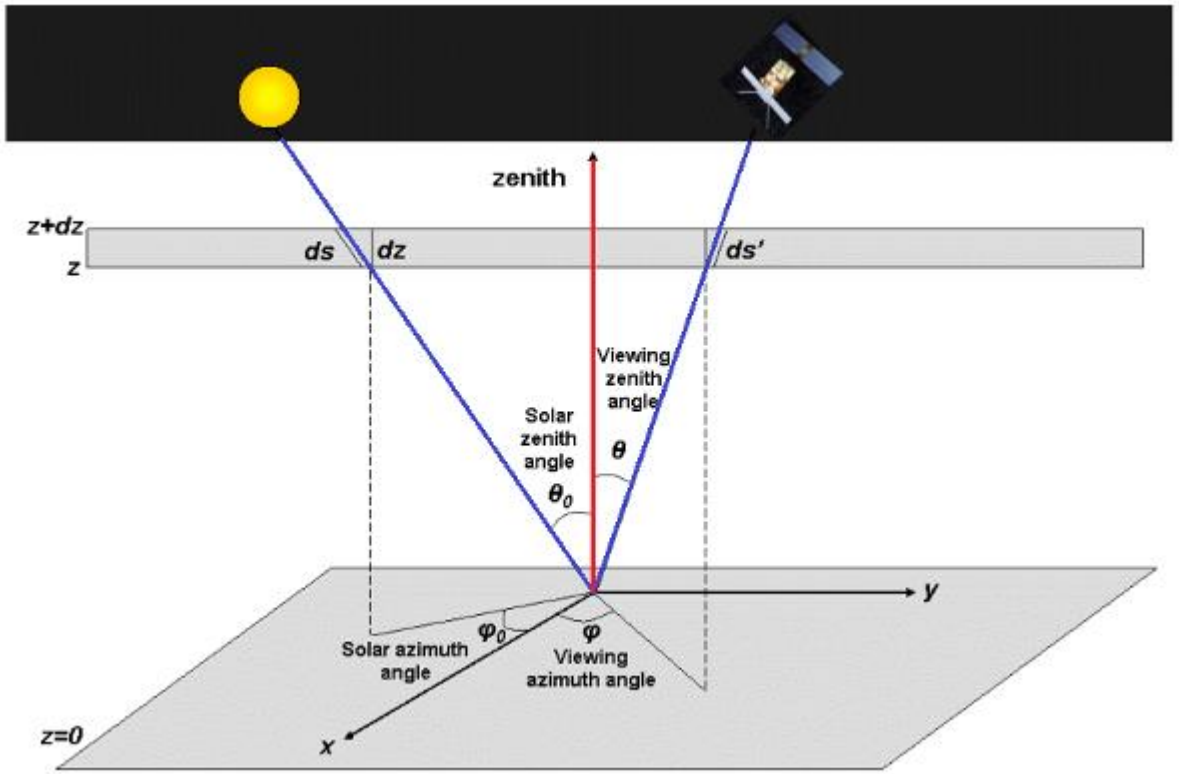
Methane Retrieval - DOAS

$$T_{\text{plume}}(\lambda) \approx \frac{L}{L_{\text{ref}}} = e^{-\text{AMF}\cdot\sigma_{CH_4}\cdot\Delta XCH_4}$$

$$\Delta XCH_4 = \frac{-\log(L/L_{\text{ref}})}{\text{AMF}\cdot\sigma_{CH_4}}$$

- AMF (air mass factor)
  - Translates the slant column density into a vertical column density
  - The ratio between the retrieved slant column (SC) and the atmospheric vertical column (VC): AMF = SC / VC
  - The viewing geometry of the satellite measurement is defined by the solar zenith angle theta and the satellite viewing angle theta_v This defines a geometric air mass factor

$$(\cos^{-1}\theta + \cos^{-1}\theta_v)$$



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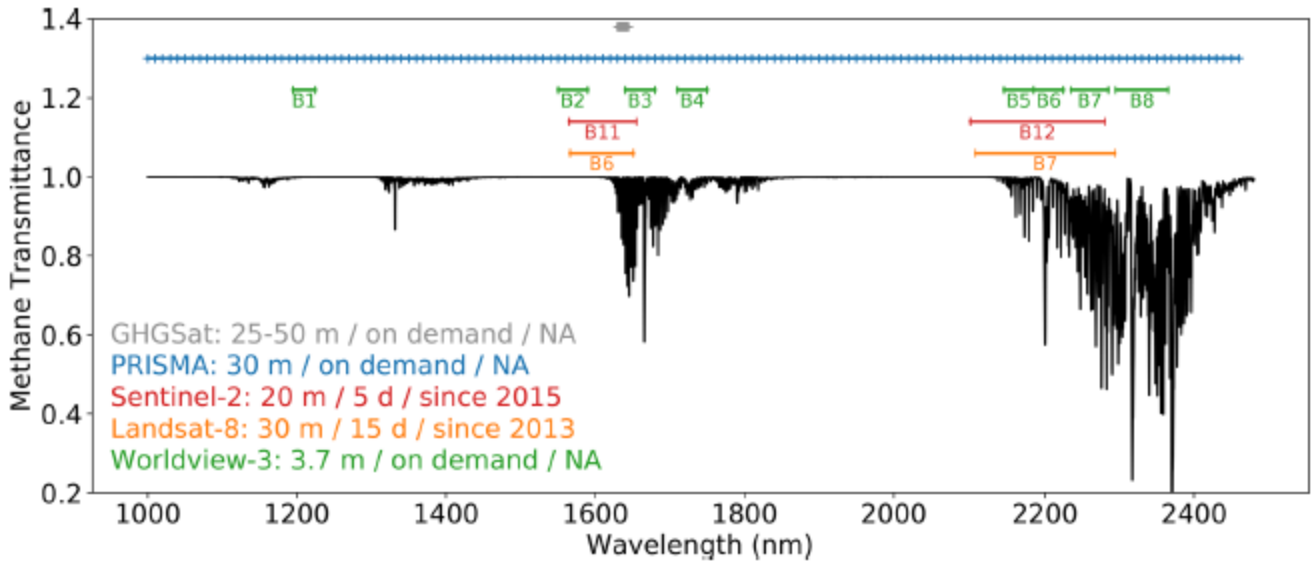
Methane Retrieval - DOAS

$$T_{\text{plume}}(\lambda) \approx \frac{L}{L_{\text{ref}}} = e^{-\text{AMF}\cdot\sigma_{CH_4}\cdot\Delta XCH_4}$$

$$\Delta XCH_4 = \frac{-\log(L/L_{\text{ref}})}{\text{AMF}\cdot\sigma_{CH_4}}$$

- L/L_{ref}
  - The radiance of the methane sensitive band and the “methane-free” reference band
  - How much methane absorption occurred?
  - Equivalent to $B7/B7_{MLR}$
    - B7 = The 7th band of SWIR wavelengths measured by Worldview 3 (see figure below)
    - $B7_{MLR}$ = a multi linear regression of B1 - B6 for B7
    - Simple version: L/L_{ref} = B7/B5



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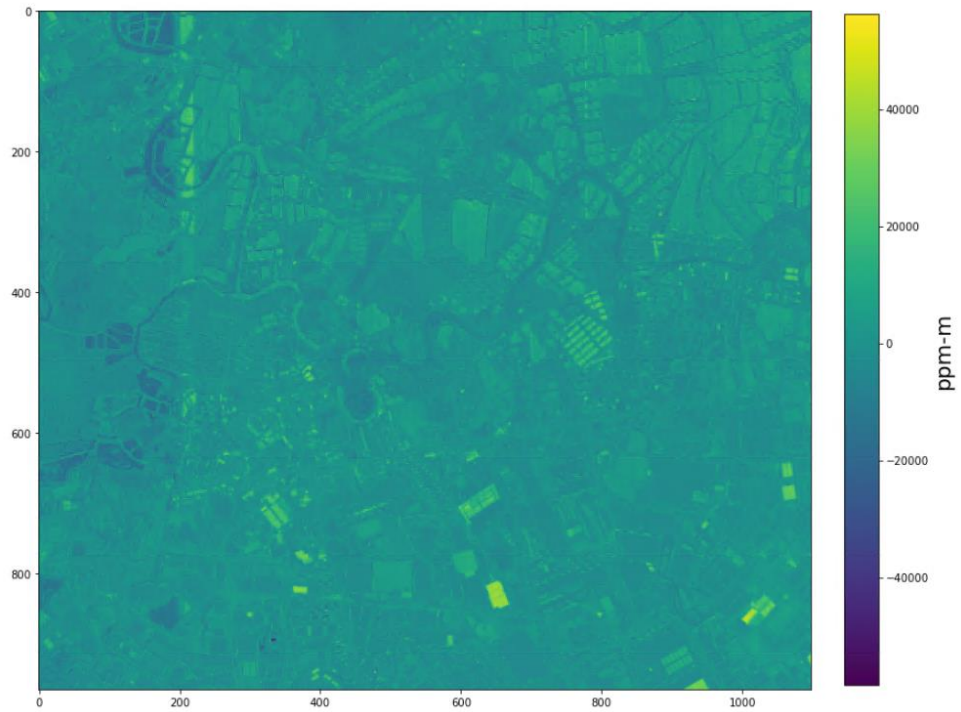
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- By applying the DOAS methane retrieval algorithm on sample data from Worldview 3 (left) theoretical methane concentrations (right) are generated.
  - Units: ppm-m (parts per million per meter)
    - ppm-m units are needed to describe the concentration along the entire air column (i.e. concentration * air column length)

Aerial

Methane



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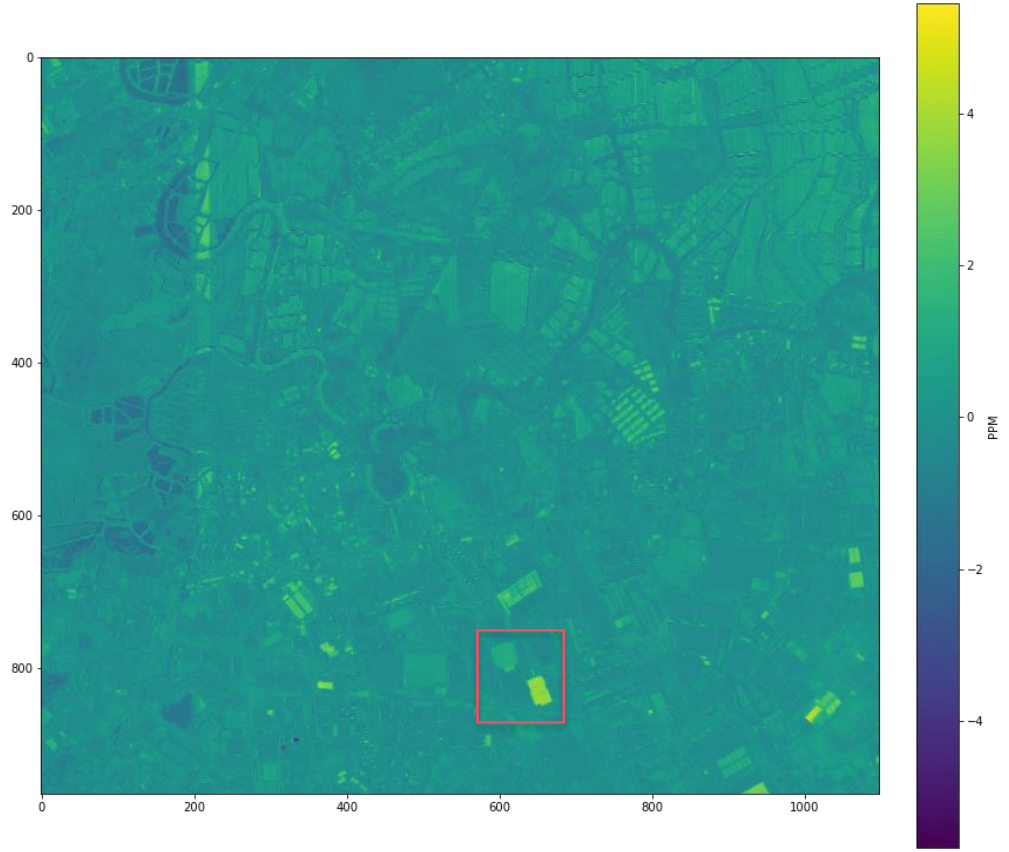
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- Note the variability of methane concentrations in the overall image. The methane concentration image (right) is showing high methane concentration; however, the aerial image (left) tells us that this is a rooftop.



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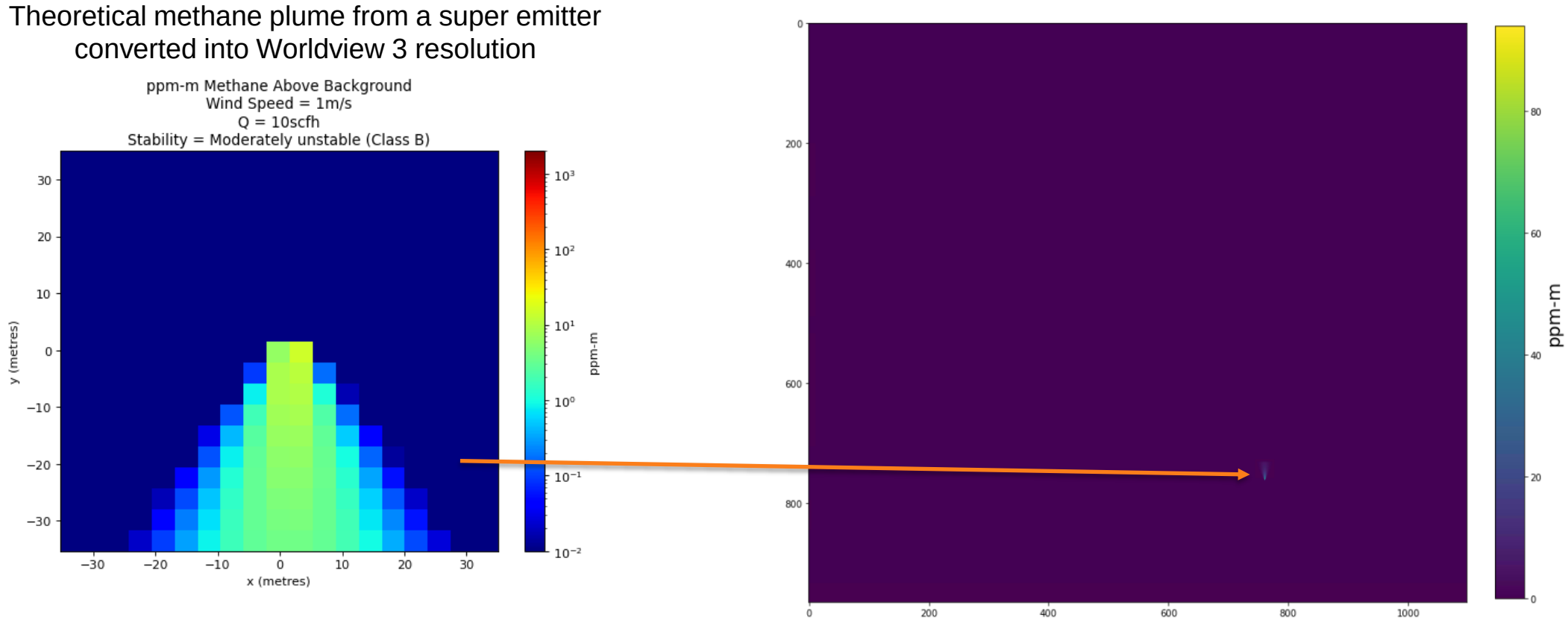
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- Can we detect methane plumes of magnitudes found in a distribution network? We can test this by adding a synthetic methane plume to the methane concentration image.

Theoretical methane plume from a super emitter converted into Worldview 3 resolution



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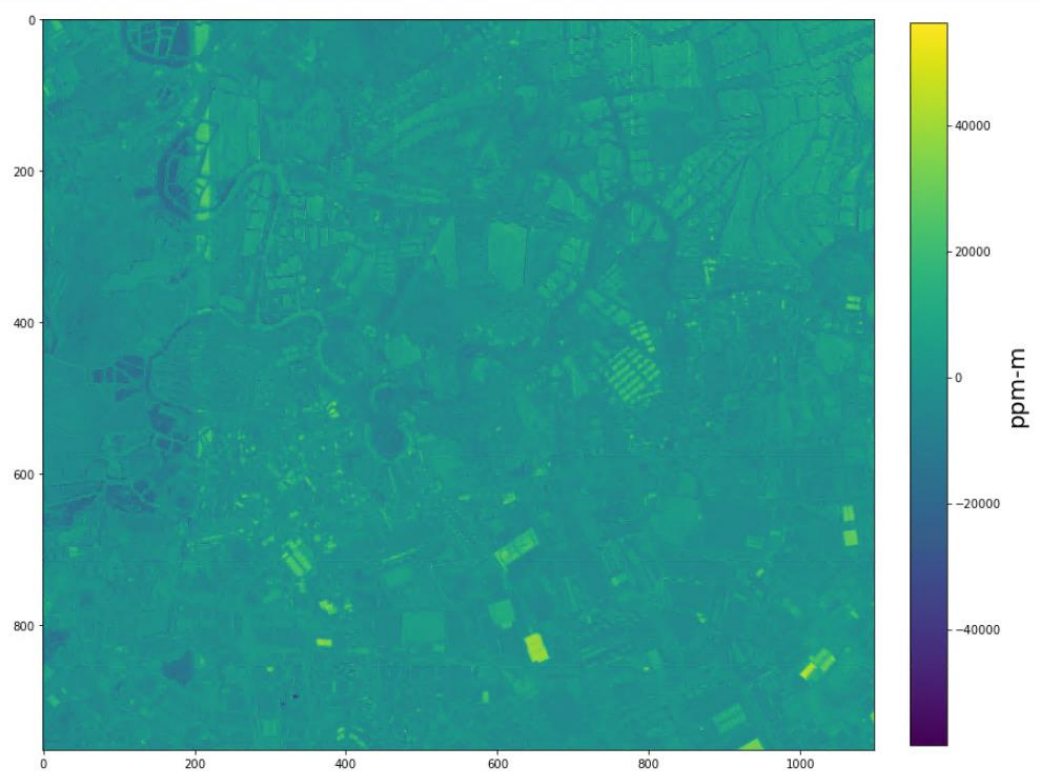
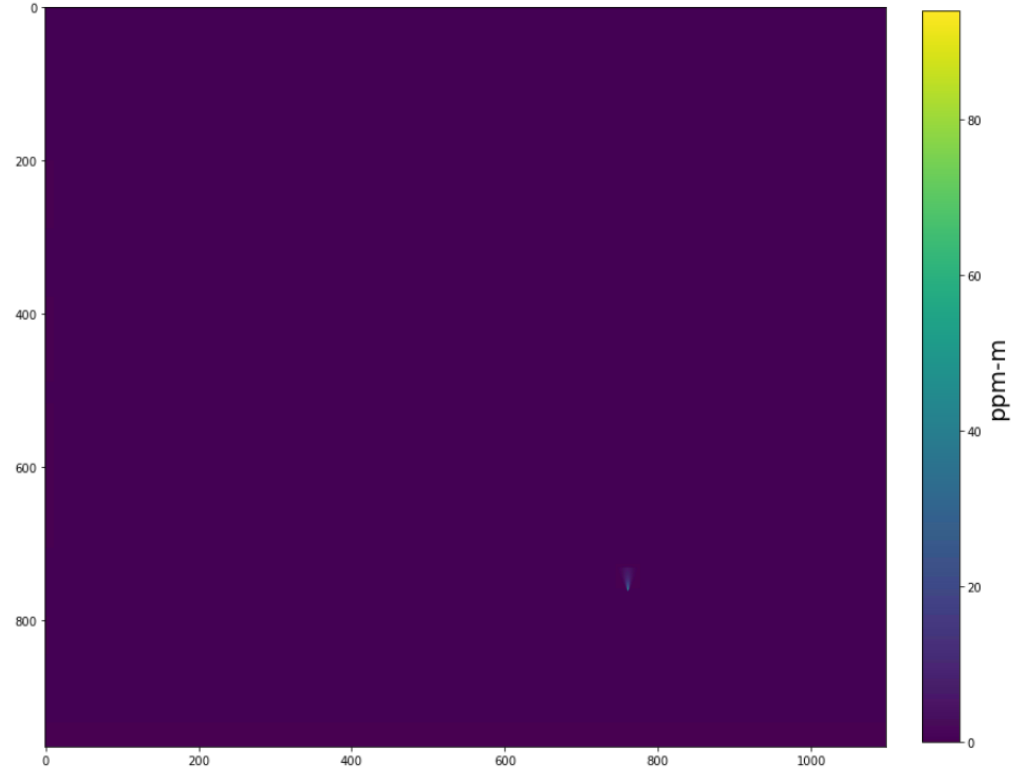
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- Can we detect methane plumes of magnitudes found in a distribution network? We can test this by adding a synthetic methane plume to the methane concentration image.

Original methane concentrations



Synthetic plume from super emitter (note the different scale)



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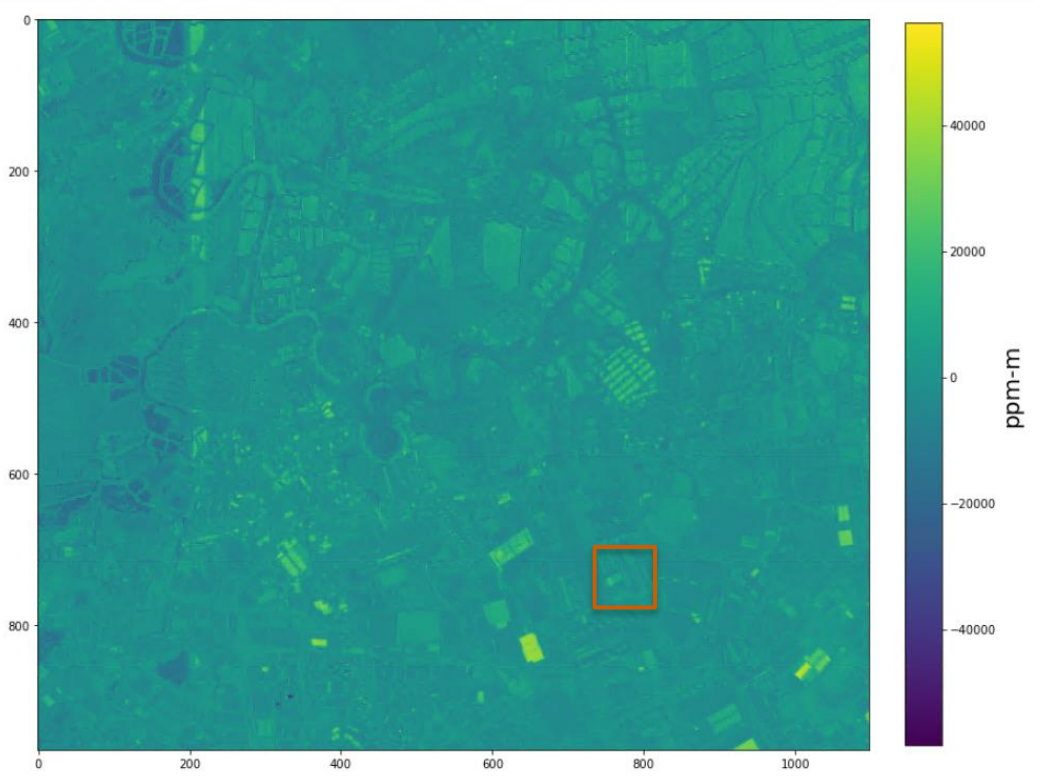
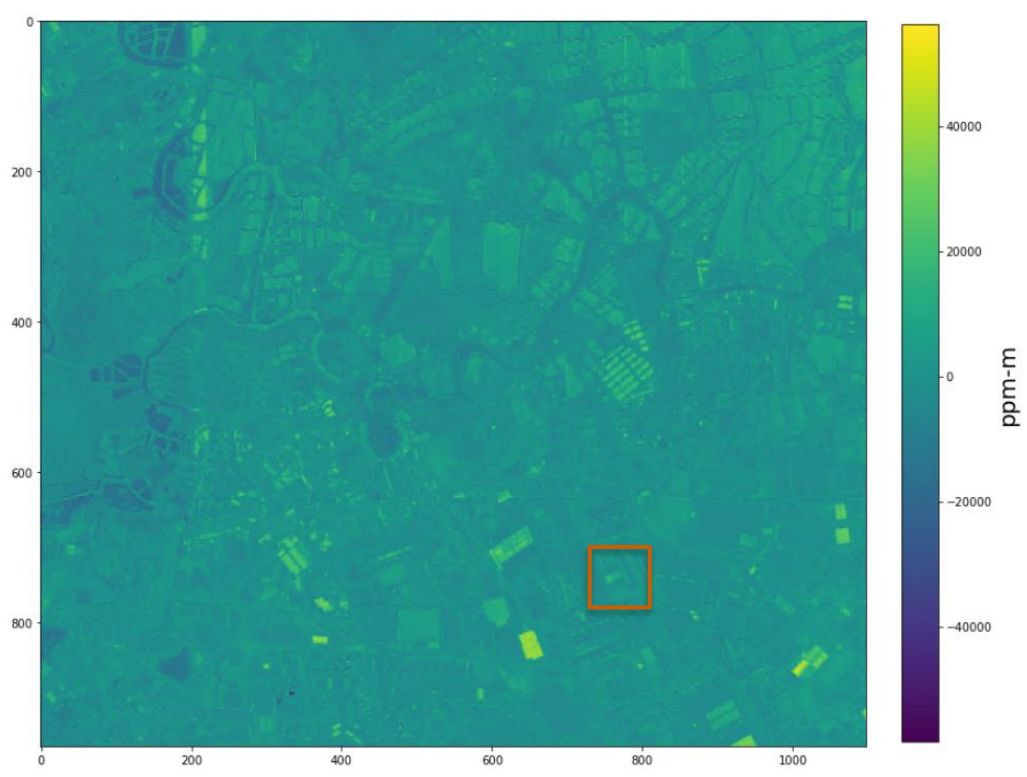
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- After adding in the synthetic methane plume we don’t see a visible difference.

Original methane concentrations



Methane concentrations with synthetic plume added



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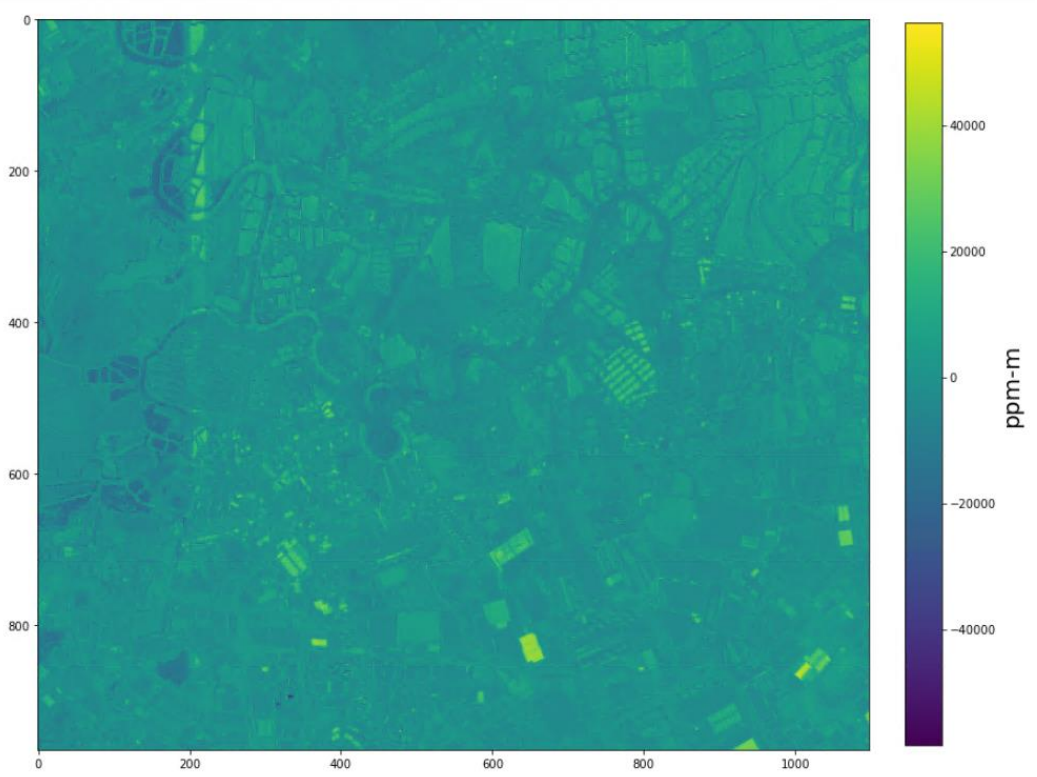
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

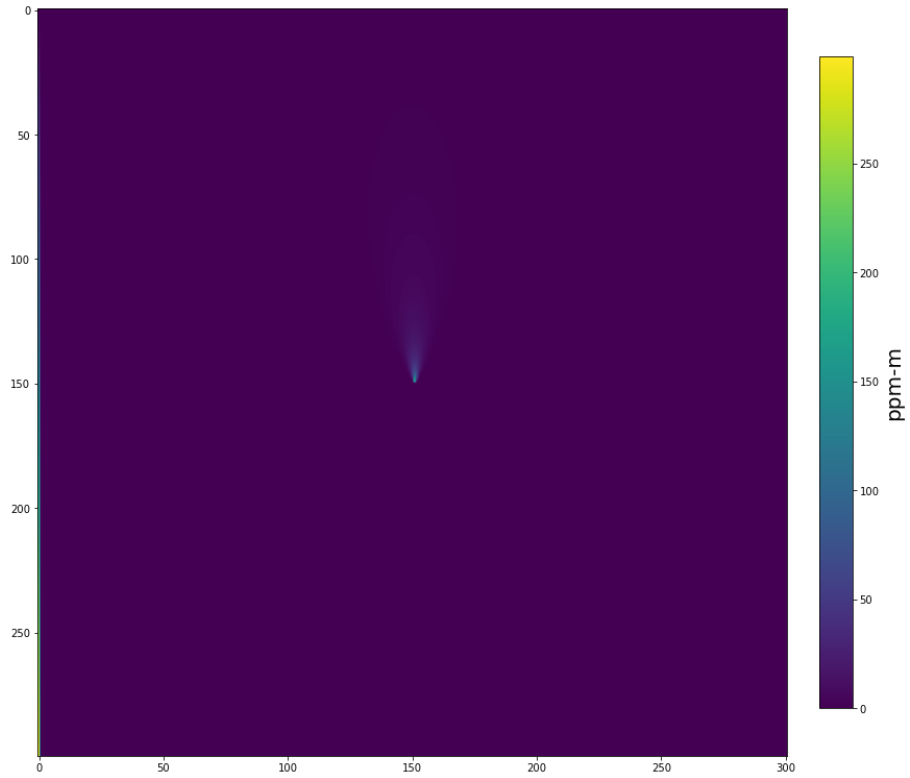
- What happens when we add in a 100 scfh leak?

Original methane concentrations



+

Synthetic plume from 100 scfh super emitter (note the different scale)



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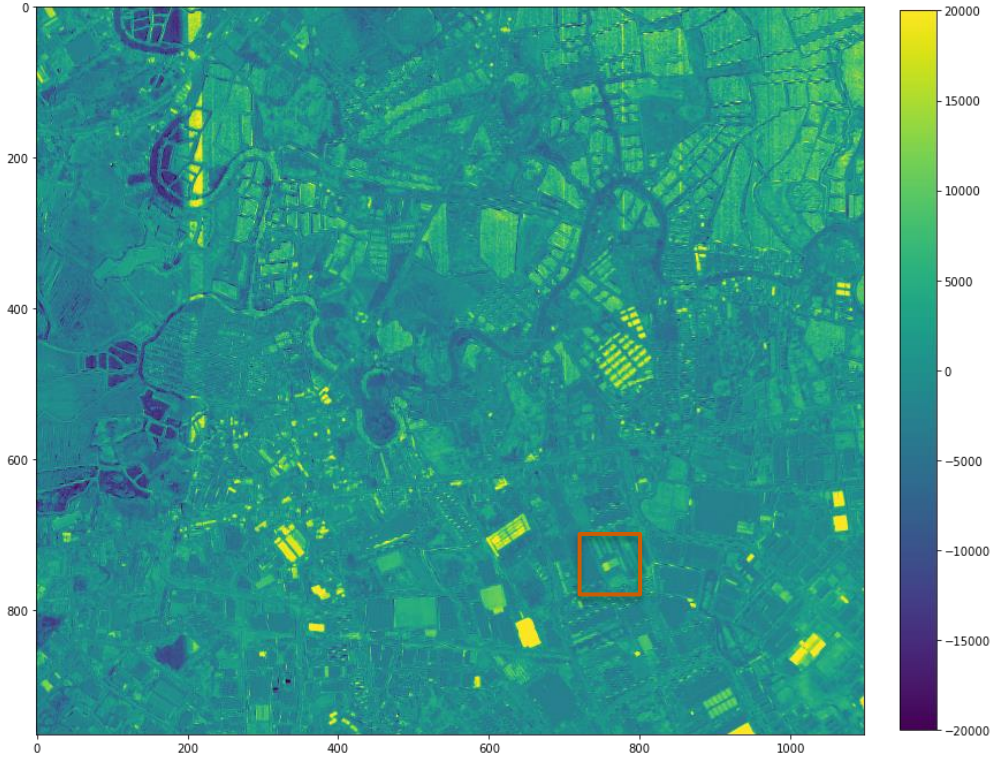
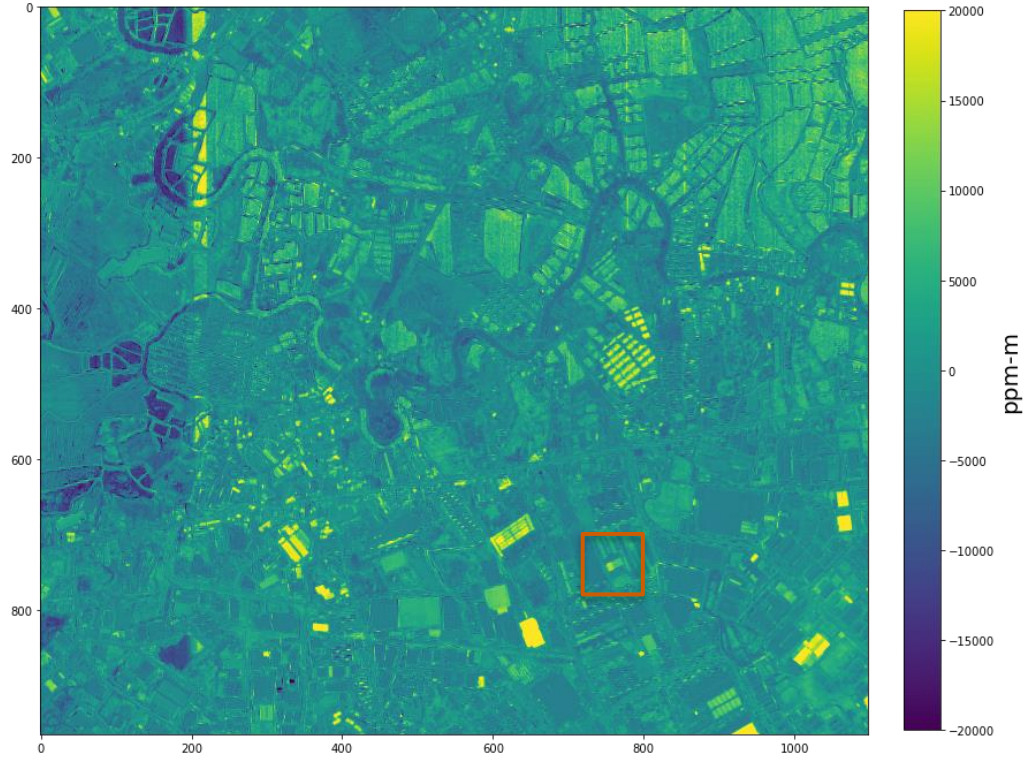
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- After adding in the 100 scfh synthetic methane plume we don’t see a visible difference.

Original methane concentrations



Methane concentrations with 100 scfh synthetic plume added



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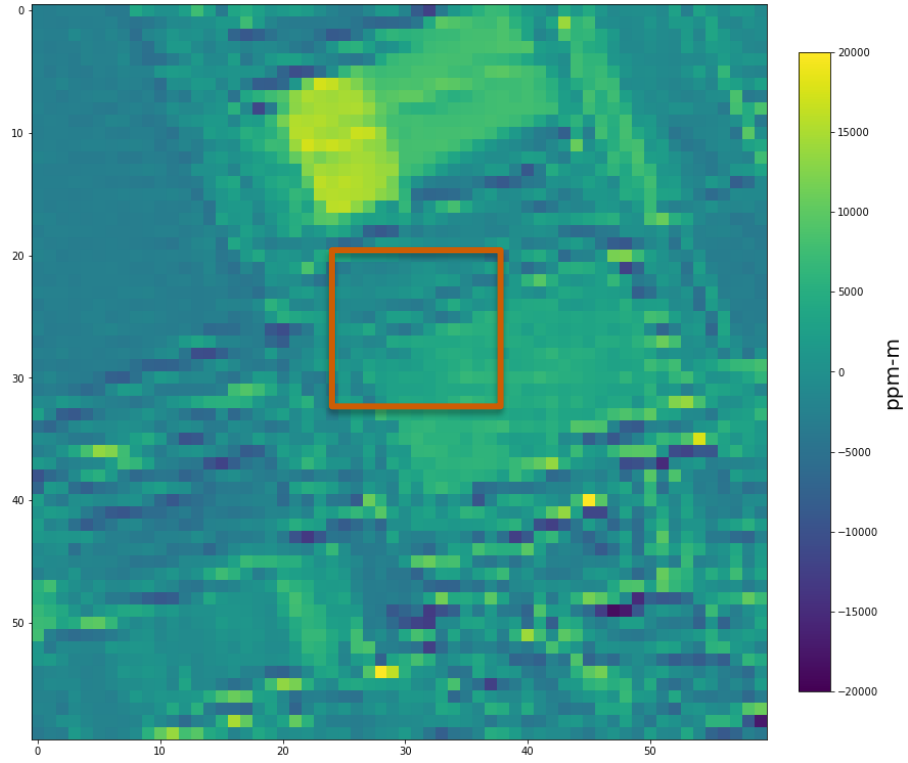
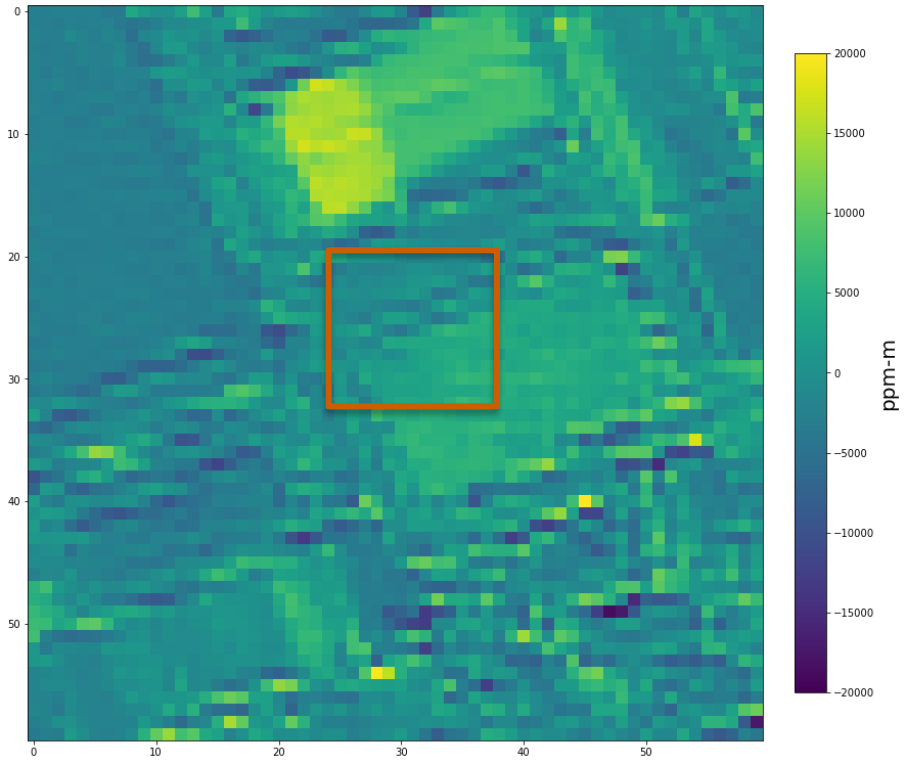
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- After adding in the 100 scfh synthetic methane plume we don’t see a visible difference.

Original methane concentrations



Methane concentrations with 100 scfh synthetic plume added



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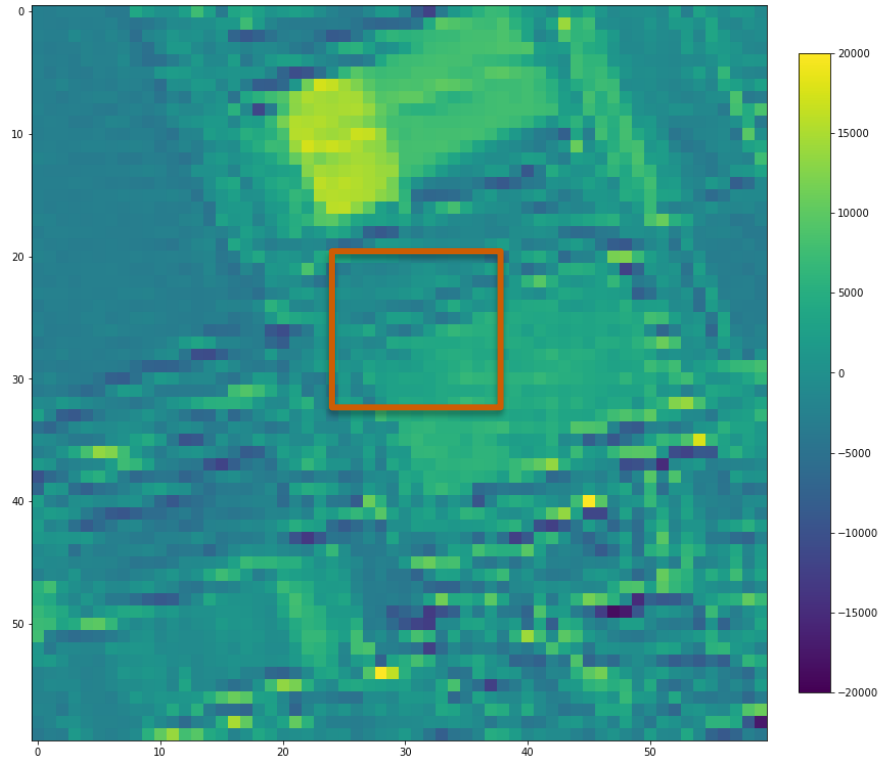
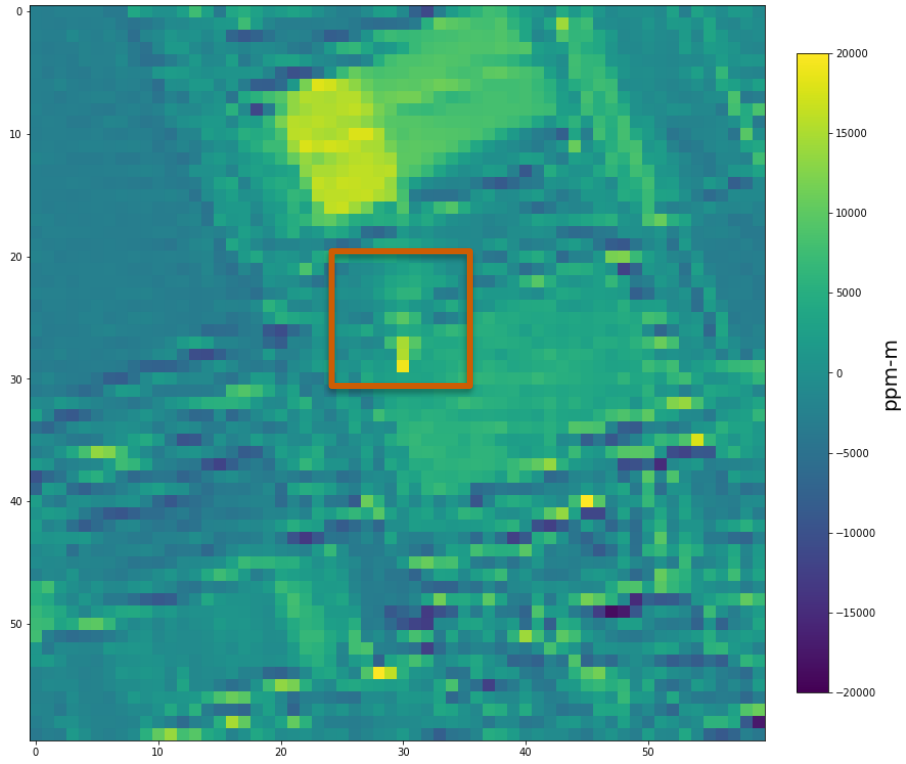
Methane retrieval with Worldview 3 Data Sample - Bangkok, Thailand

- How about a 10,000 scfh leak?

Original methane concentrations



Methane concentrations with 10,000 scfh synthetic plume added



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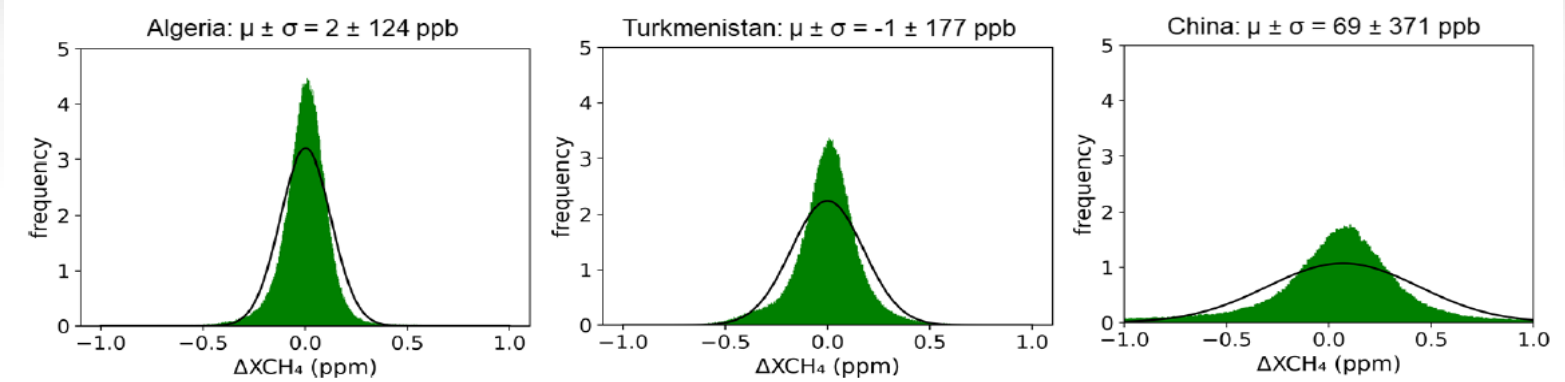
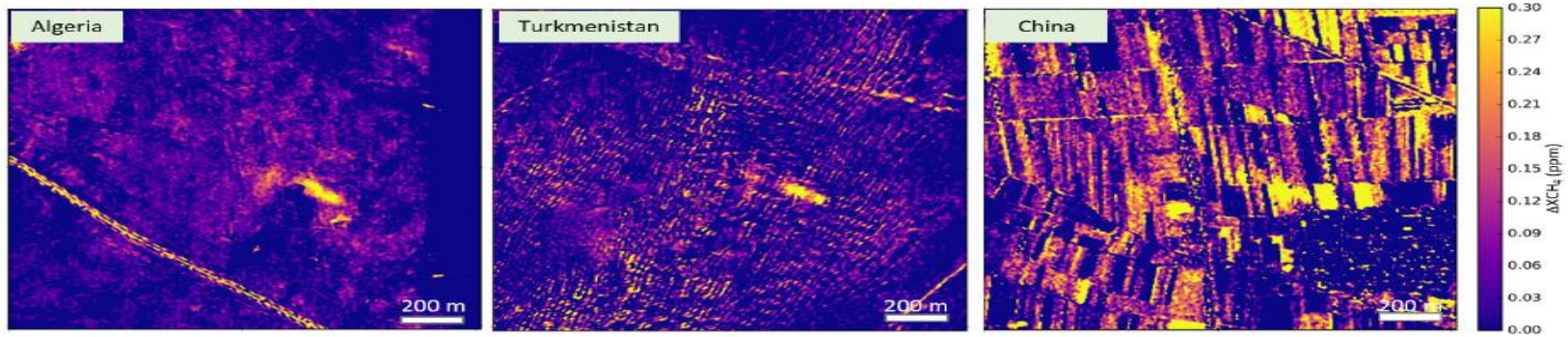
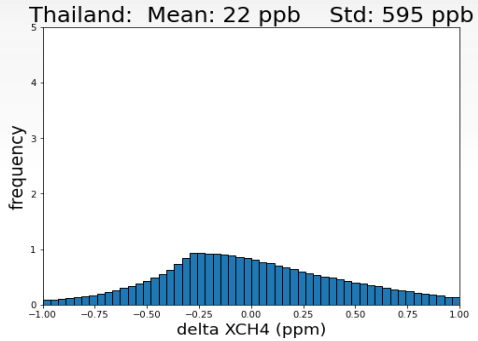
Picarro Worldview 3 Methane Retrieval vs Literature

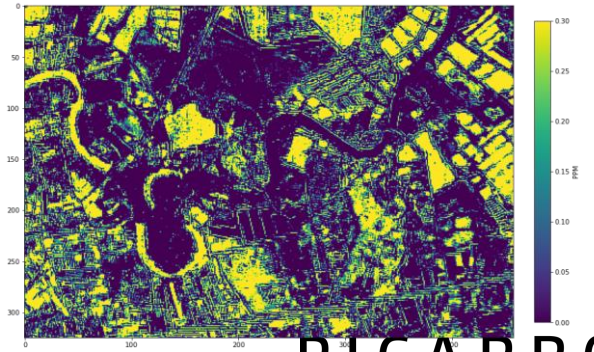
Literature





Picarro





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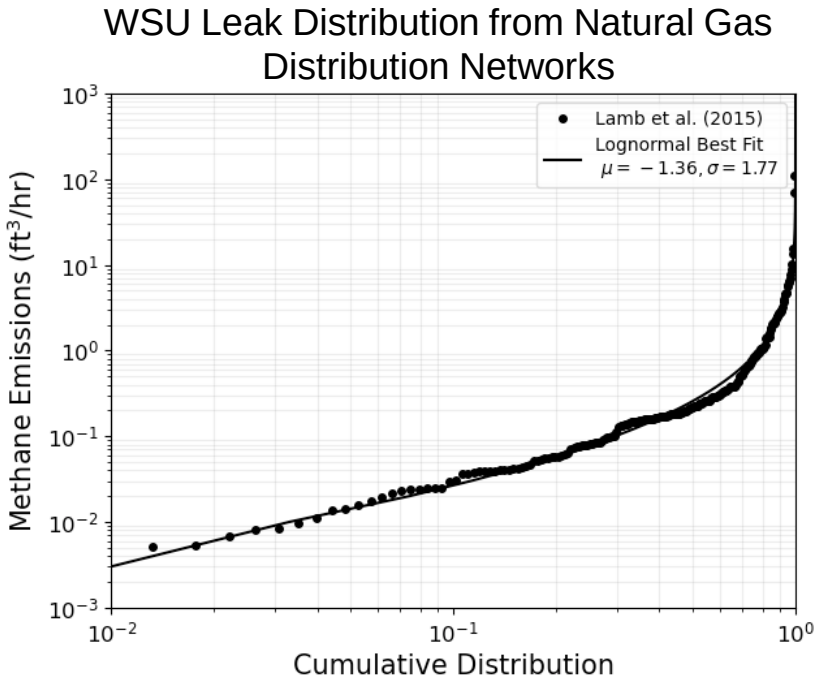
Remote Sensing Methane Leak Detection

- The magnitude of leaks which can be detected by Worldview 3 data is on the order of 10,000 scfh.
- Gas distribution networks usually don’t have leaks larger than 100 scfh.



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Remote Sensing Methane Lower Detection Thresholds

Scientific literature and Chevron LDTs are in line with Picarro's analysis.

Source	Lower Detection Threshold (kg/hr)	Lower Detection Threshold (SCFH)
Chevron[1]	100	6400
Thomas A Fox et al[2]	250	16000
Garcia et al[3]	< 100*	< 6400
Collins et al[4]	500	32000

1. Chevron Corp., 2022 Methane Report, https://www.chevron.com/-/media/shared-media/documents/chevron-methane-report.pdf
2. Thomas A Fox et al 2019 Environ. Res. Lett. 14 053002
3. Sánchez-García, E., Gorroño, J., Irakulis-Loitxate, I., Varon, D. J., and Guanter, L.: Mapping methane plumes at very high spatial resolution with the WorldView-3 satellite, Atmos. Meas. Tech., 15, 1657–1674, https://doi.org/10.5194/amt-15-1657-2022, 2022.
4. Collins et al Monitoring methane emissions from oil and gas operations Optics Express 24326 Vol. 30, No. 14 / 4 Jul 2022

* Lowest plume detected was 30 kg/hr; however, this study was not meant to develop a lower detection threshold.

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Conclusion

- While Worldview 3 appears to be the best current candidate for methane plume detection in a distribution network, it appears that the pixel level methane concentration variability is too large to detect leaks on the order of ~100 scfh or smaller.
- The current generation of remote sensing instruments do not appear to be viable for leak detection in distribution networks.