VOC Methane emissions from oil and natural gas production in the Denver-Julesburg basin, Colorado, inferred from TROPOMI observations

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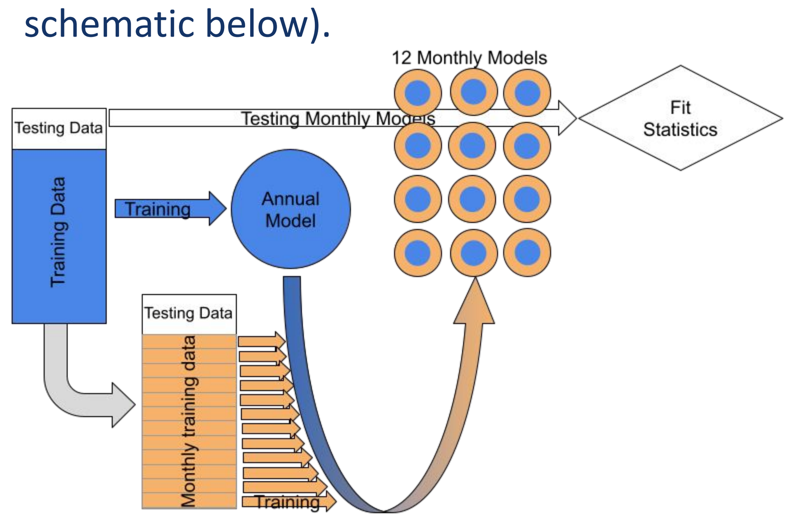
Background

- Oil and natural gas (O&G) production is associated with methane (CH_4) emissions.
- These emissions are generally not well monitored. Satellite observations can help.

Instruments & Methods

- We aim to infer methane emissions from O&G production using CH_4 observations from the TROPOspheric Monitoring Instrument (TROPOMI) and the divergence technique.
- TROPOMI provides daily global coverage at ~1:30pm local time, with a footprint of 7 x 5.5 km^2 for CH_4.
- Divergence Technique: Horizontal gradients in background corrected satellite vertical columns, V_{corr}, multiplied with horizontal boundary layer wind fields, **u**, provide source location and strength of underlying emissions, E (following Sun, 2022 and Veefkind et al., 2023 for background correction): $E = \mathbf{u} \cdot \nabla V_{corr}$
- Tensorflow machine learning (ML) deep transfer learning model framework was used to train an annualized model on 2018-2022 TROPOMI data, then retrained on monthly data subsets. Target data was GOSAT proxy retrieval measurements (see schematic below).



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Acknowledgements

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Case Study Permian basin using TROPOMI CH_4

Sensitivity study for the Permian basin (strong signals/high data coverage) shows:

- Derived emissions vary with boundary layer wind speeds (Fig. 1) - which should not happen in theory.
- As described by Sun, 2022, flux divergence results contain signals caused by changes in the wind fields, which create a bias in calculated emissions and source locations (Fig. 1).

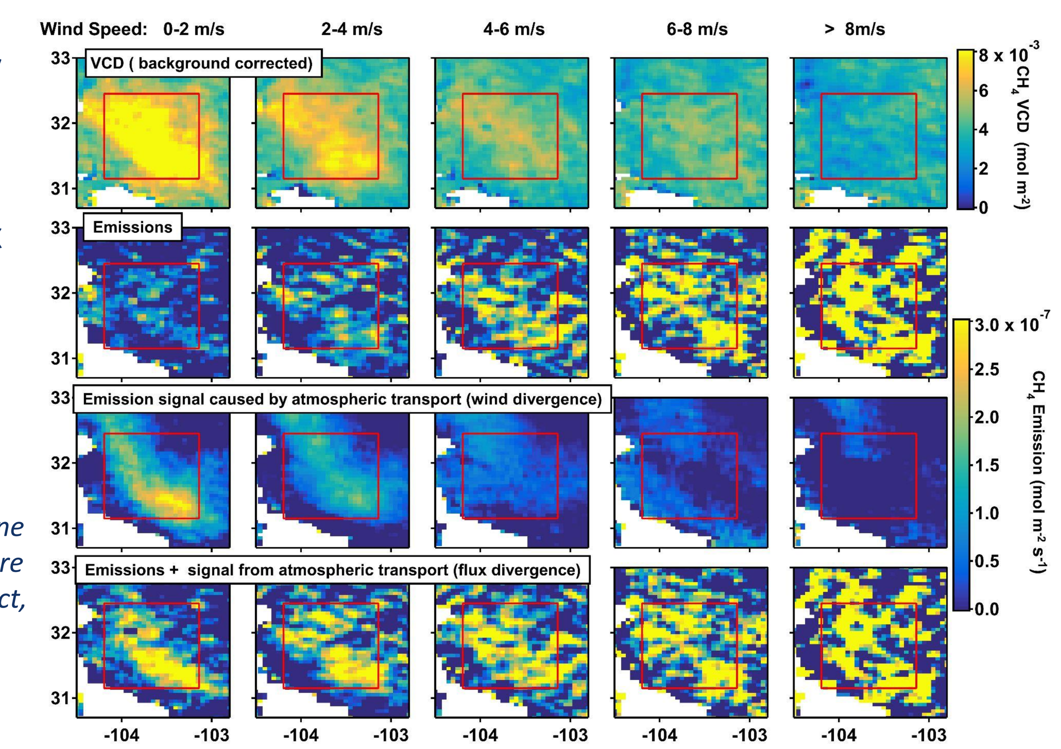


Figure 1: Results of sensitivity study on deriving methane emissions from 2018-2022 CH_4 VCDs over the Delaware sub-basin, using the Bremen WFM-DOAS product, separated by boundary layer wind speed bins.

→ Can we explain this finding?

Case Study Permian Basin using WRF-CHem CH_4

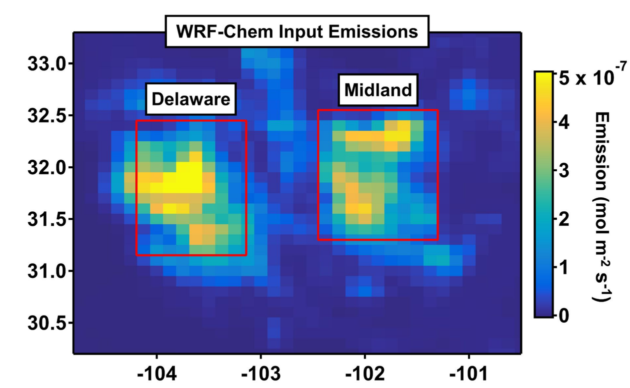
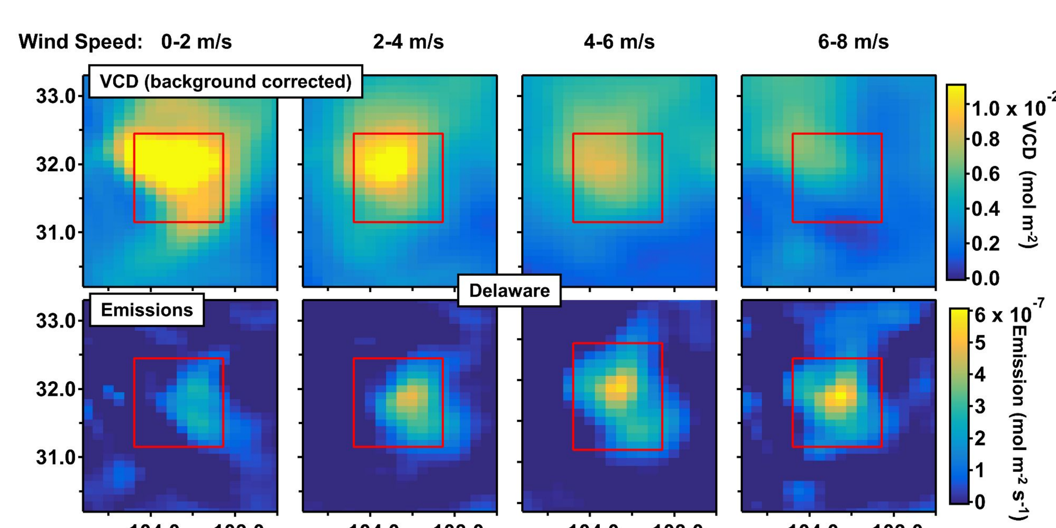


Figure 2: WRF-Chem CH_4 input emissions for the Permian basin. Emission are constant in time. Acknowledgements: WRF-Chem model data: Meng Li and Brian McDonald; FOG data: Colby Francoeur and Brian McDonald.

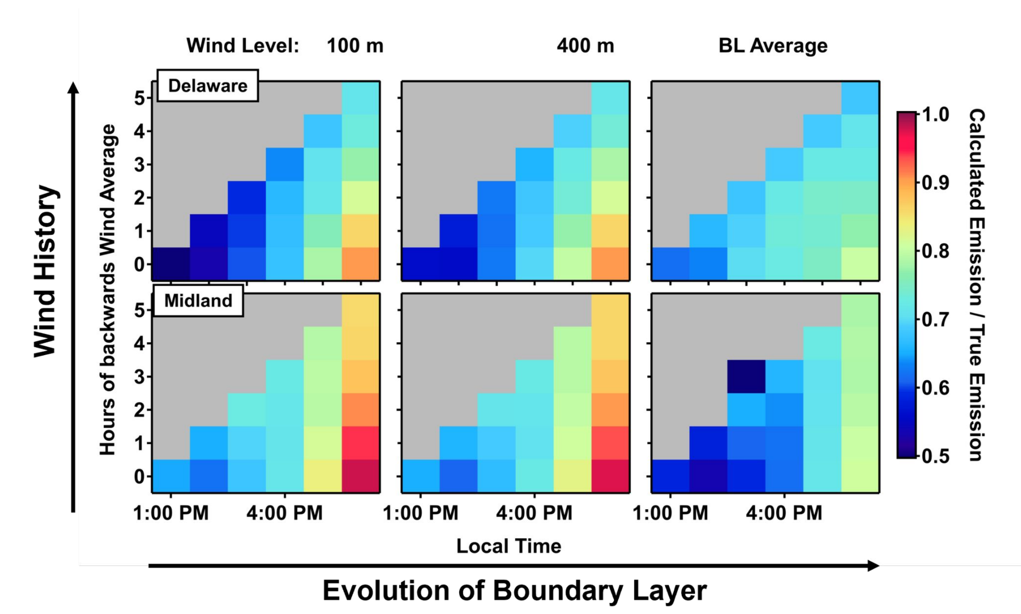
- Simulations for June 1 to August 30, 2018.
- O&G CH_4 emissions from the Fuel-based Oil and Gas (FOG) Inventory (FOG, Francoeur et al., 2021) (Fig. 2).
- Hourly output from 1pm to 6pm local time.

WRF-Chem sensitivity studies show:



- Dependency of calculated emissions on wind speed for Delaware (Fig. 3) and Midland (not shown) sub-basins.
- Results are comparable to TROPOMI data findings (Figs. 1 and 3).

Figure 3: Results of sensitivity study on deriving methane emissions from WRF-Chem CH_4 VCDs over the Permian basin, separated by boundary layer wind speed bins.



- True emission are best reproduced later in the day (Fig. 4).
- Wind history or wind field altitude have a small effect on calculated emissions (Fig. 4).
- Calculated emissions at local TROPOMI overpass time (~1:30 pm) are on average underestimated by 30% - 50%.

Figure 4: Fractions of calculated over true emissions depending on hour of day, altitude of wind fields and wind history. To account for wind history, wind fields are averaged over a select number of past hours.

→ Changes of boundary layer height throughout the day and "pooling" at low wind speeds likely lead to methane gradients that create artefacts in the divergence calculations.

→ The divergence technique tends to underestimate true methane emissions.

→ Can we correct for this?

→ Next step: Trying to account for changing boundary layer height.

Methane Emissions in the Denver-Julesburg basin - a feasibility study

Study questions:

- Can we derive CH_4 emissions for the Denver-Julesburg basin using TROPOMI and the divergence technique?
- Can we deconvolute co-located seasonal non-O&G emissions from O&G emissions? And can our newly developed seasonal albedo bias correction help with this?

Study Setup:

- 2018-2022 averages filtered for wind speed < 2m/s.
- Region of Interest, ROI, defined by estimated best quality results (ROI ~ 50% of total Denver-Julesburg O&G production).

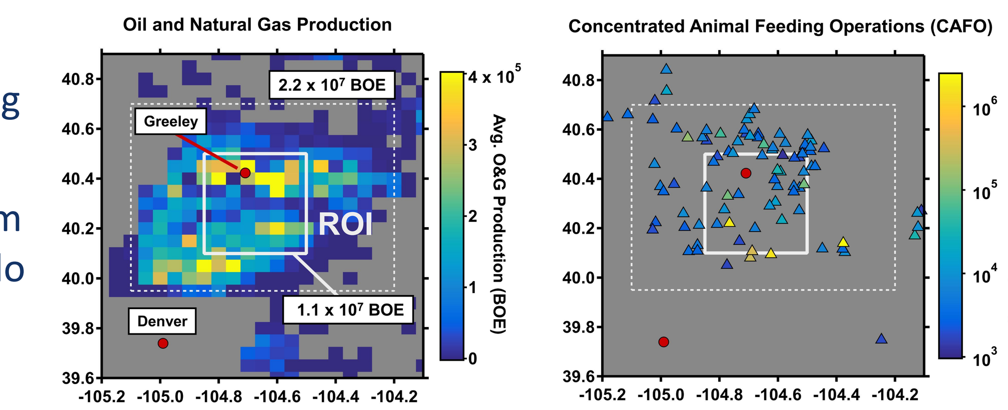


Figure 5: Denver-Julesburg O&G production (Enverus/DrillingInfo) and locations of cattle feedlot operations (non-O&G methane source).

Results of calculated CH4 emissions for the Denver-Julesburg basin (weak signals/low data coverage) shows:

- Calculated emissions differ by data set (Bremen WFM-DOAS or operational) and by applied corrections (Fig. 6).
- All but uncorrected operational data show higher summer emissions (Fig. 7), consistent with seasonal CAFO emissions.

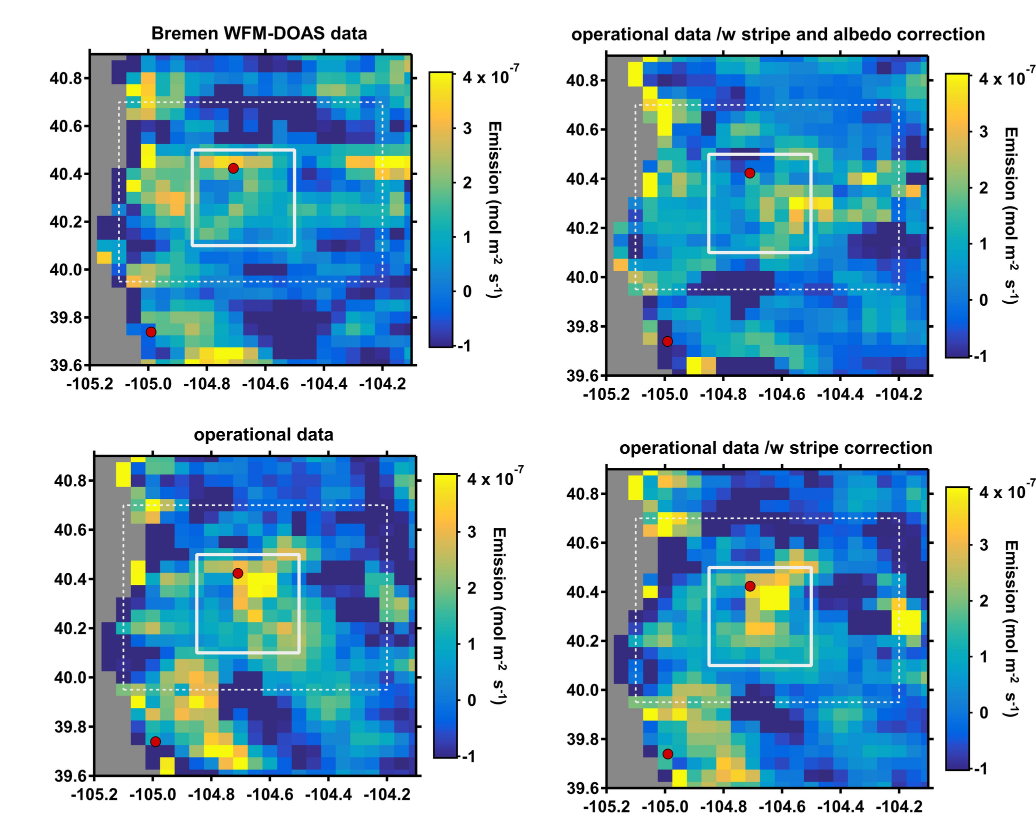


Figure 6: Methane Emissions calculated with the divergence technique.

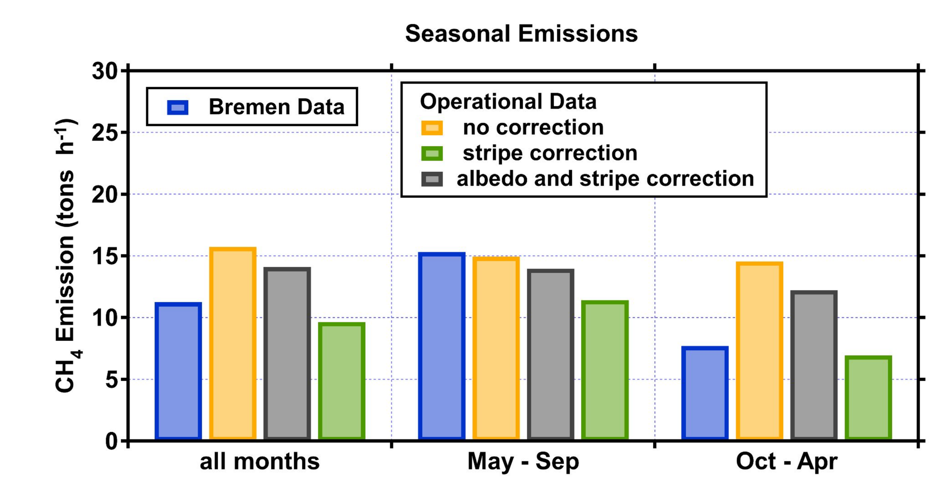


Figure 7: Total ROI methane emissions.

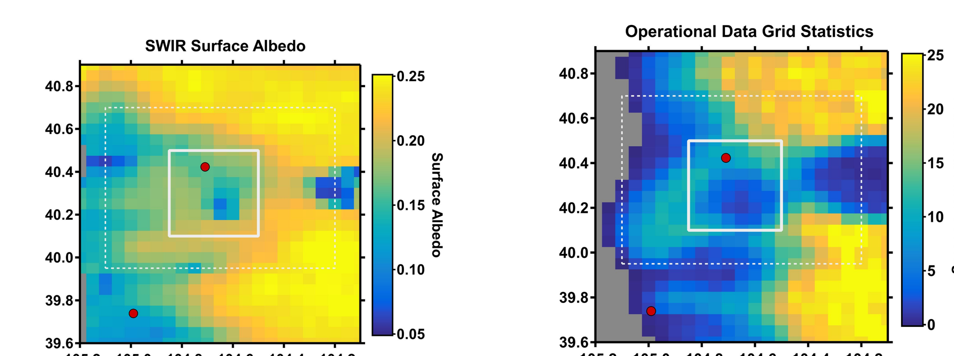


Figure 8: Surface Albedo and data statistics.

→ What is the effect of varying data statistics across the ROI?

→ Can we defined a total uncertainty of calculated emissions?

Seasonal Albedo-bias Correction

Application of seasonal methane albedo correction:

- Is based on trained machine learning model with TROPOMI and GOSAT data.
- Provides best correction of seasonal albedo bias compared to other correction methods (Fig. 9).

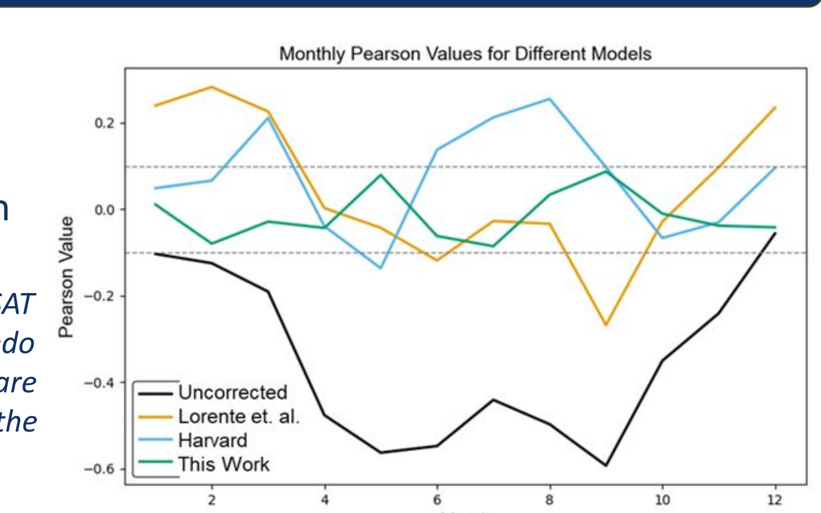


Figure 9 : Pearson value compares (GOSAT XCH_4 / TROPOMI XCH_4) and surface albedo SWIR data. -0.1 < Pearson values < 0.1 are considered "no correlation" and are the ideal goal.

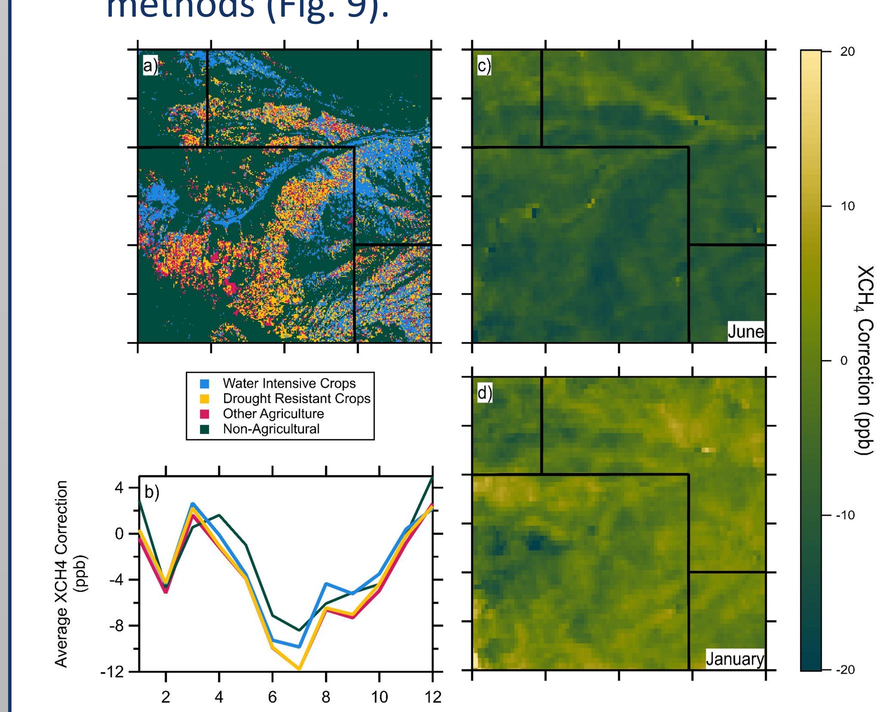


Figure 10: Agricultural land-use a) is reflected in albedo corrected CH_4 columns for summer c) and winter d). The magnitude of correction, b), has a clear seasonal cycle and is dependent on crop type.

Analysis of albedo corrected methane columns finds:

- Albedo corrected methane data shows dependence on underlying land-use structures, where different kinds of agriculture (water intensive crops: corn, sugarbeets, etc. drought resistant crops: winter wheat, dry beans, etc) tend to require different correction values (Fig 10a/c/d).
- Average correction values over each land-use type are distinctly different and show seasonality across the entire year, with larger corrections needed in the summer and smaller corrections needed in the winter (Fig. 10b).