High spatial and temporal resolution simulations of methane column loadings due to routine emissions and emission events in oil and gas regions

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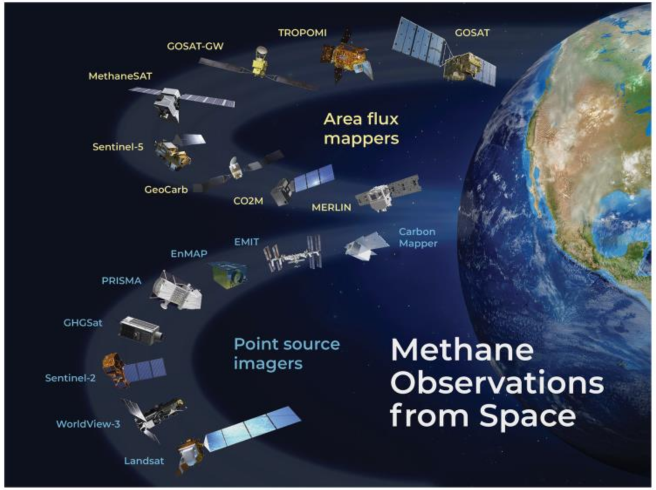
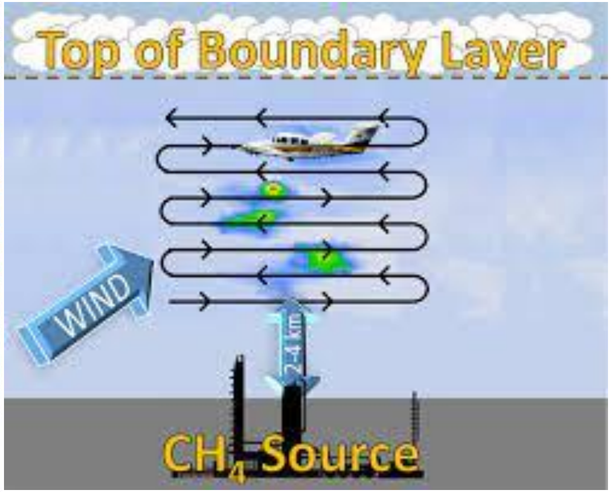
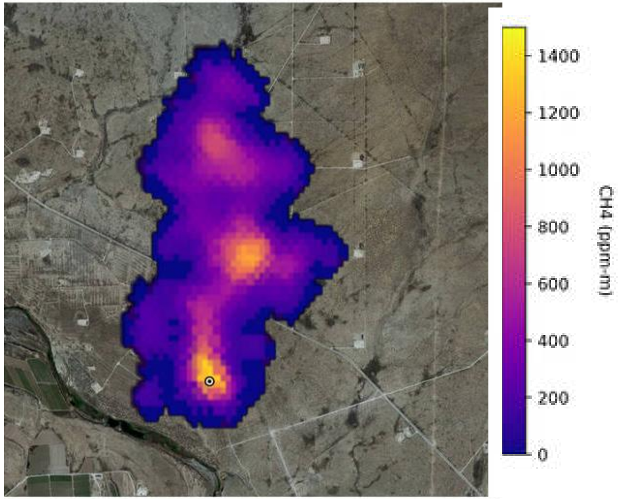
Satellite and other measurement techniques that measure methane column concentrations are increasingly being used to estimate methane emissions, particularly for large emission events (e.g. ‘Super-Emitters’ defined by the EPA as a release with an emission rate > 100 kg/hr)



Jacob et al. ACP, 2022



Lavoie et al. ES&T 2015

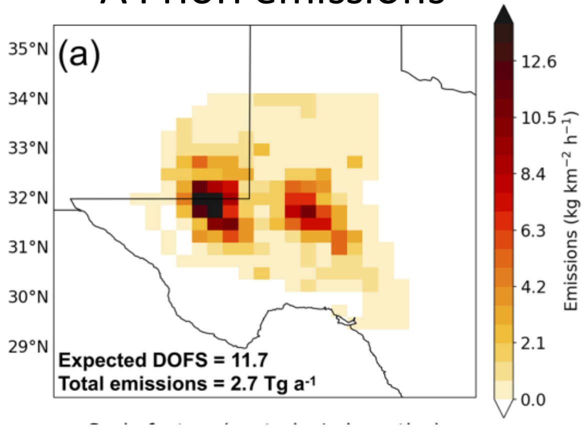


Credits: NASA/JPL-Caltech

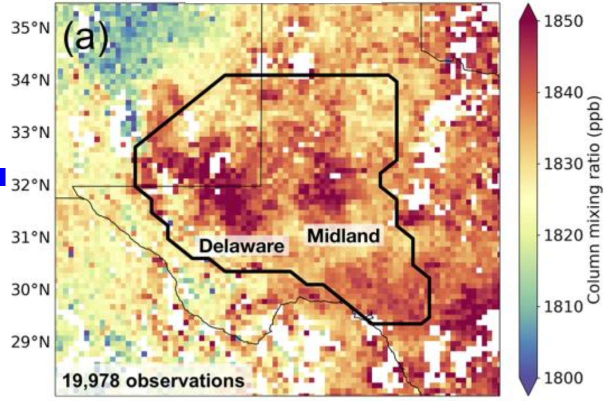
Most of these analysis rely on an inversion of data based on some a priori emission inventory with limited spatial and temporal variabilities.

Relatively coarse spatial resolution and temporal variations at monthly/weekly scale

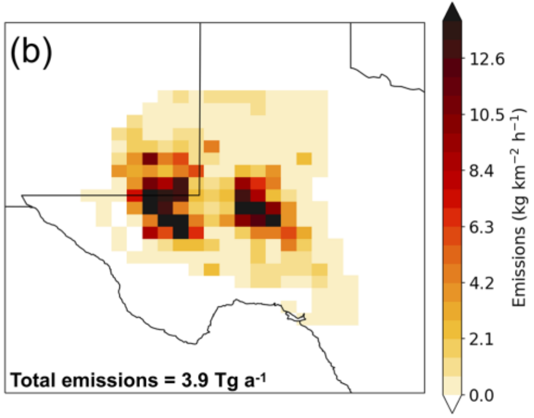
A Priori emissions



Satellite measurement



Posterior emissions

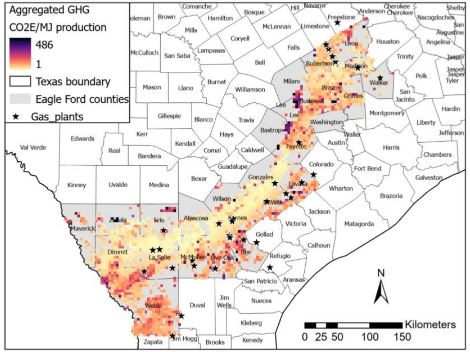


Actual Emissions vary over small spatial and temporal scales

Varon et al. ACP, 2022

- Our approach is forward calculation: start with inventory with site-level resolution and time-varying sources, use chemical transport model (CTM) to calculate methane ground and column concentrations.
- The goal is to better understand how large an emission event needs to be in order to cause a significant perturbation in column concentration and how that is dependent on the spatial resolution of the emission inventory and CTM modeling.

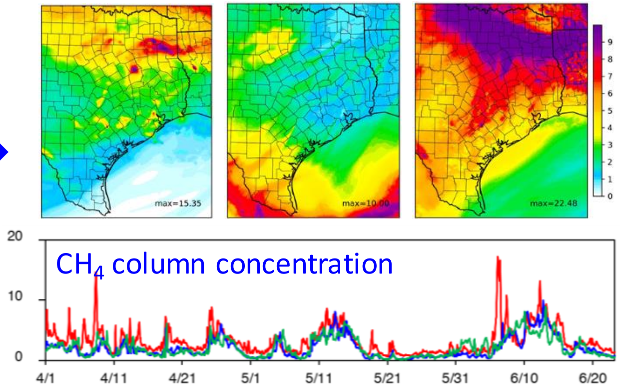
Methane emission inventory at fine scale



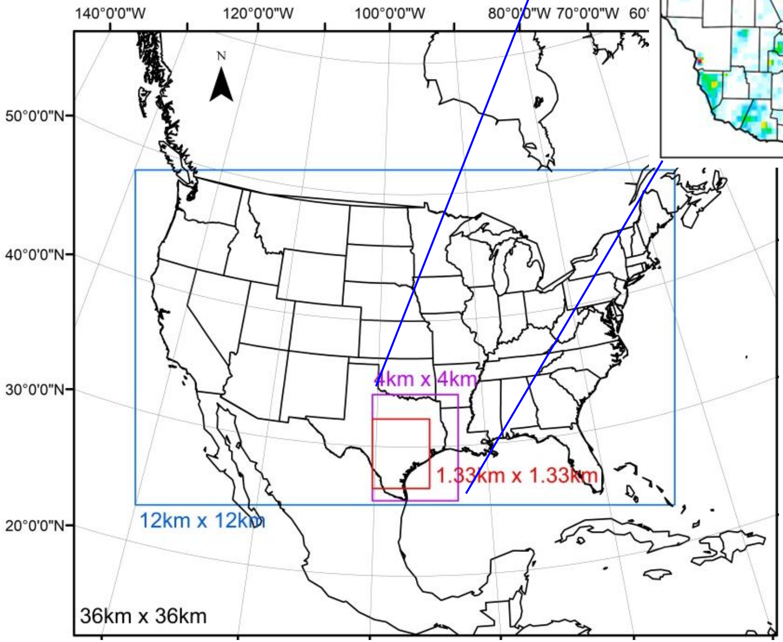
Spatial resolution (36km vs. 12km vs. 4km vs. 1km?)

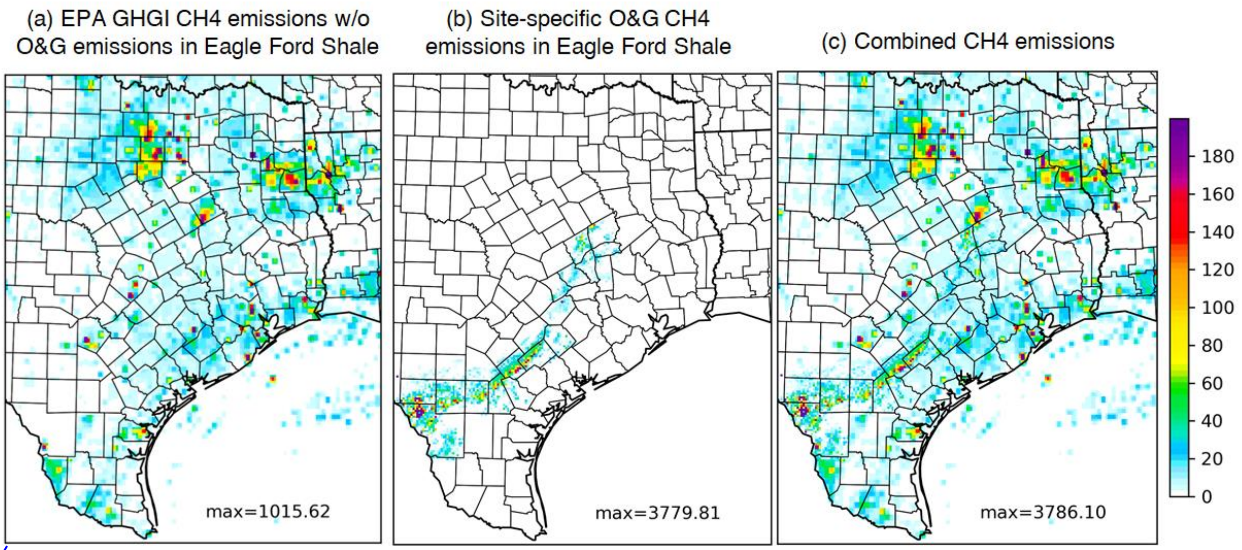
Chemical transport models (e.g., CAMx, CMAQ, WRF-Chem, GEOS-Chem, etc.)

Perturbation in CH_4 column concentration



- Study region: Eagle Ford Shale
- CAMx version 7.10 (TCEQ's platform);
- No CH_4 chemistry;
- No CH_4 from IC/BC;
- Simulation period: April 1st to Oct. 31st, 2019



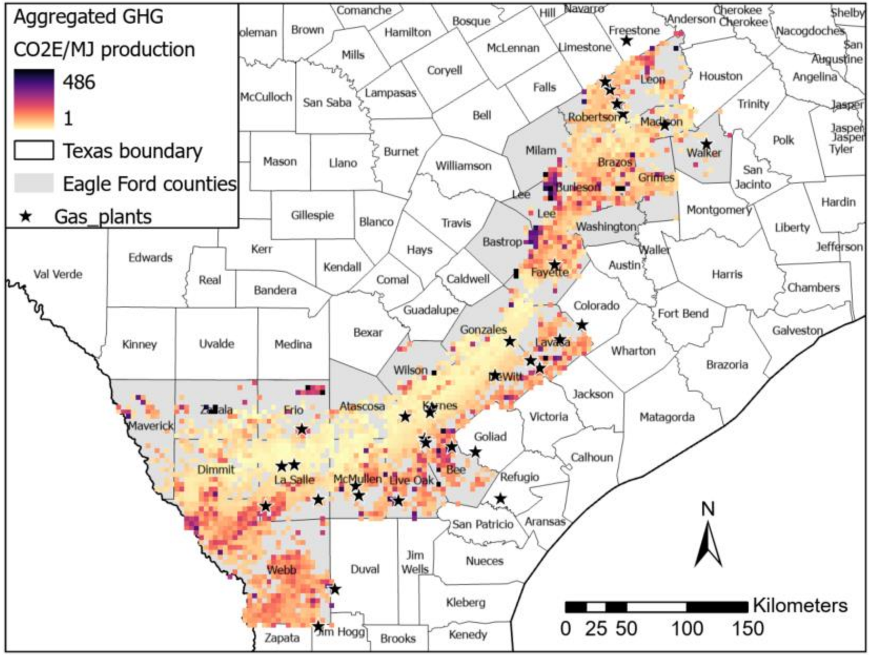


CH_4 Emission inventory used

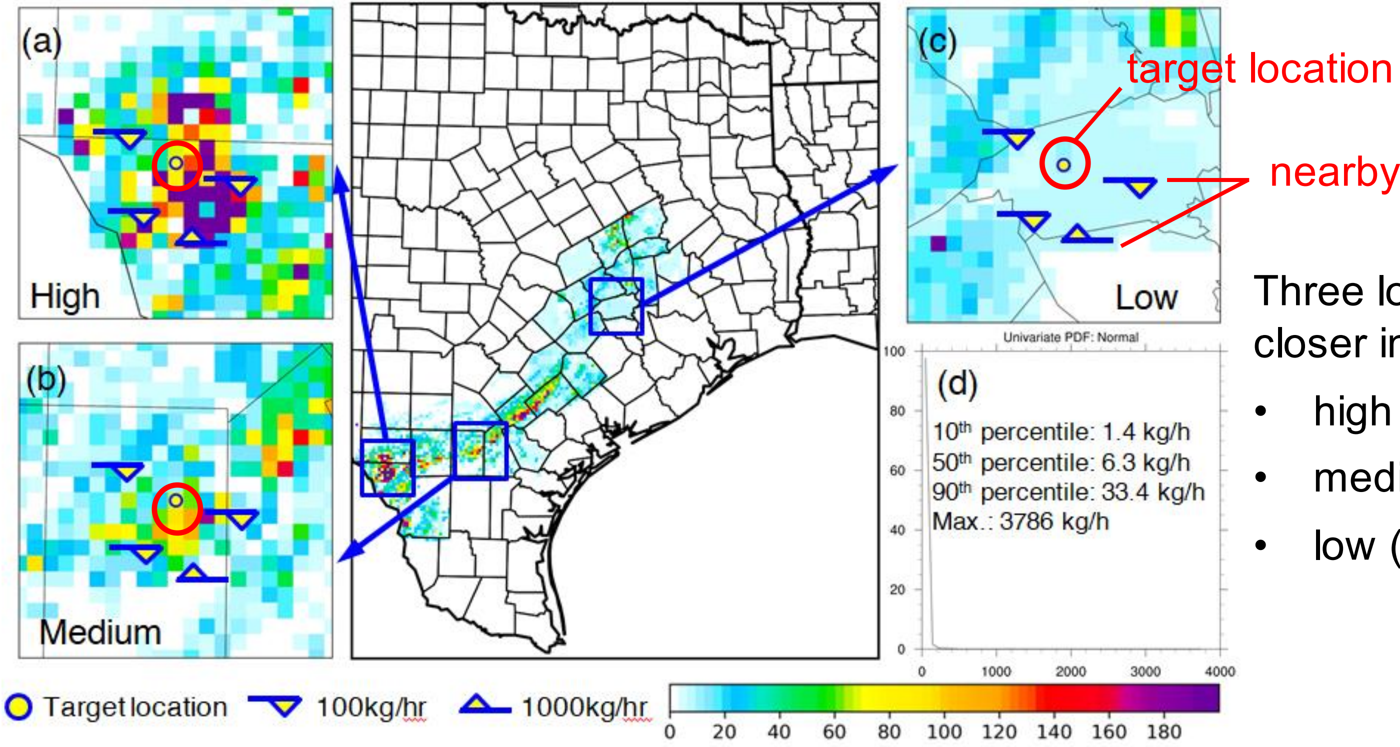
Emission Source Category	Source of data	Spatial resolution	Calendar year data represent
Oil and gas sources in Eagle Ford counties (b)	Chen et al. (2021)	Emissions modeled as point sources at wells, gathering facilities and gas processing plants	2013 basin-level inventory
All other sources (a)	Gridded EPA GHGI (Maasakkers, et al., 2016)	0.1 by 0.1 degree	2012 national greenhouse gas inventory
Meteorological data	TCEQ (2023)	4 km in eastern Texas and 1.33 km in Eagle Ford	April 2019 – October 2019

Eagle Ford Shale

- Methane emission inventory from Oil and Gas sources
- Fine spatial resolution



Emission sources	Emission component	Emission locations
Liquid unloading	CH_4	~20000 Well sites
Well drilling	CH_4	
Chemical injection pumps	CH_4	
Equipment leaks	CH_4	
Pneumatic controllers	CH_4	
Water tank flash	CH_4	
Fuel combustion on well site operations	CH_4, CO_2, N_2O	
Condensate tank flash	CH_4	
Gathering	CH_4, CO_2	Gathering facilities (assumed one facility per 4x4 km grid)
Gas processing leaks	CH_4	34 Gas plants
Processing equipment venting	CO_2	
Fuel combustion in gas processing	CH_4, CO_2, N_2O	



Three locations selected for closer investigation:

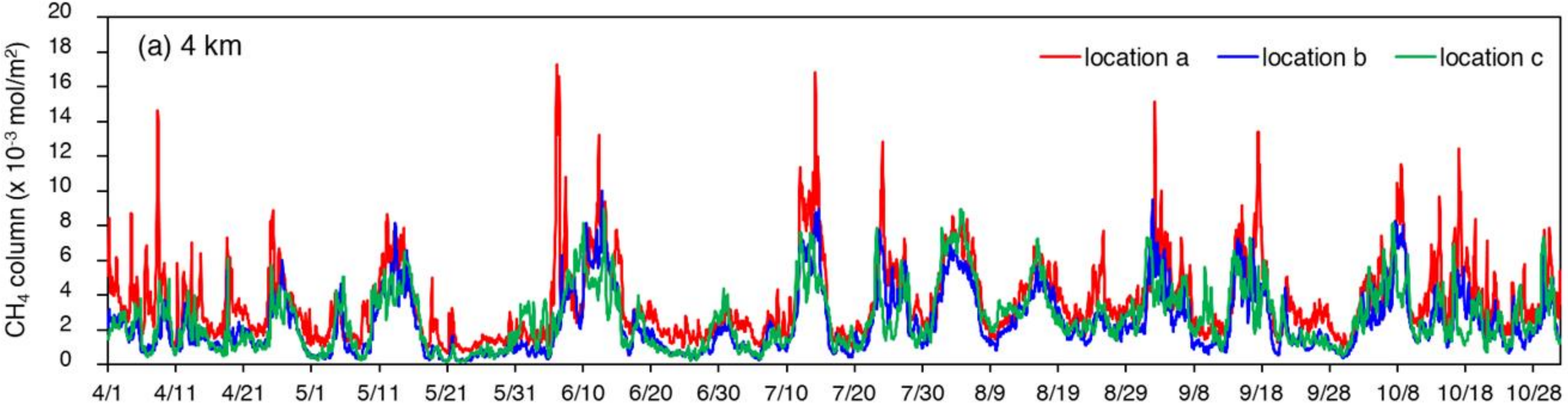
- high (~300 kg/hr/km^2)
- medium (~50 kg/hr/km^2)
- low (~10 kg/hr/km^2)

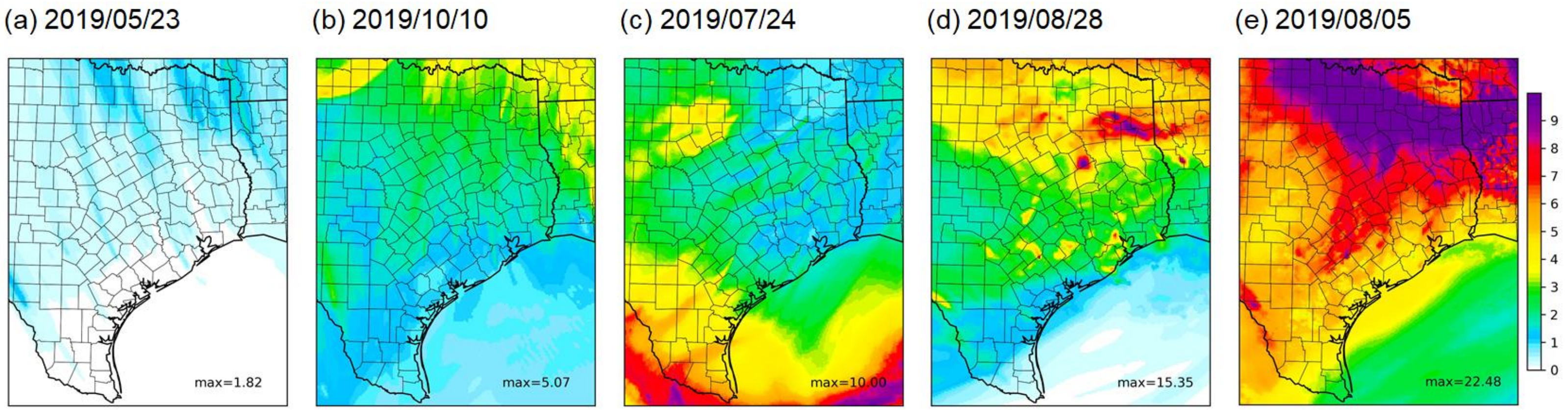
A total of 20 CAMx runs

CAMx simulation scenarios (with finest resolution at both 4km and 1.33km):

- Baseline simulation (i.e. routine emissions);
- Two emission rates (100 kg/hr and 1000 kg/hr) added in each of three different locations;
- Simulations with emission events near the primary emission events

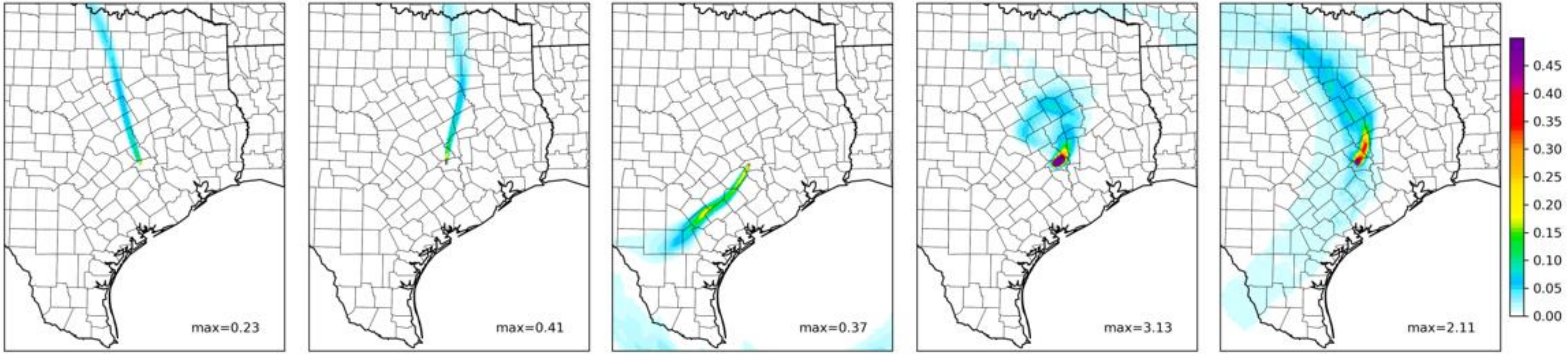
Simulated CH_4 column concentration from **routine constant** emissions exhibits large temporal and spatial variations due to changing meteorology.





Add emission events of 100 and 1000 kg/hr to the routine emissions

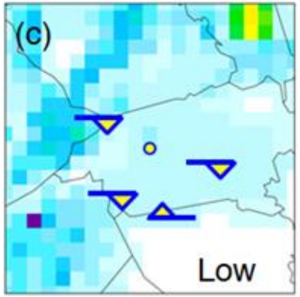
(a) 2019/05/23 (b) 2019/10/10 (c) 2019/07/24 (d) 2019/08/28 (e) 2019/08/05



Results for 1000 kg/hr emission events at low background concentration location

Enhancement ratio (ER) of methane column concentration due to events:

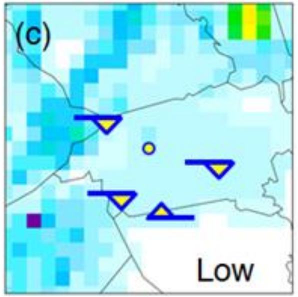
$$ER = \frac{Column\ CH_{4\ event} + Column\ CH_{4\ routine\ emissions}}{Column\ CH_{4\ routine\ emissions}}$$



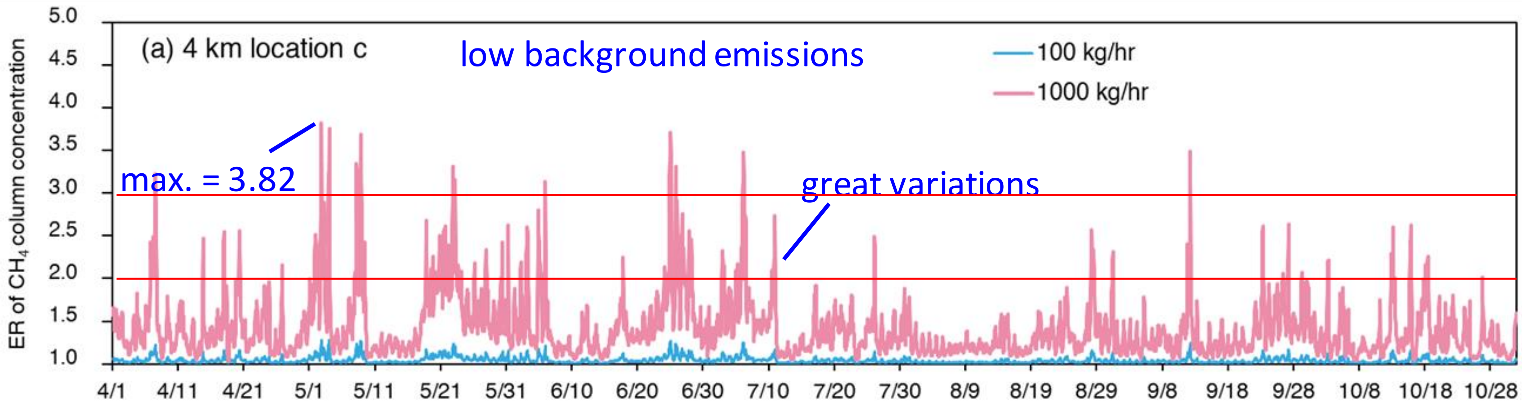
low (~10 kg/hr/km^2)

Add emission events of 100 and 1000 kg/hr to the routine emissions

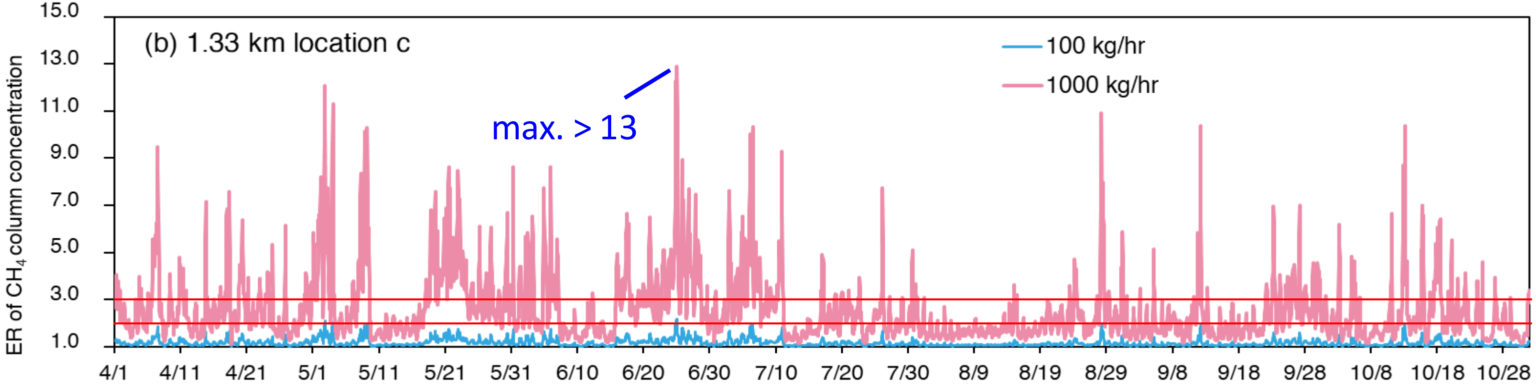
$$ER = \frac{Column\ CH_{4\ event} + Column\ CH_{4\ routine\ emissions}}{Column\ CH_{4\ routine\ emissions}}$$



low (~10 kg/hr/km^2)

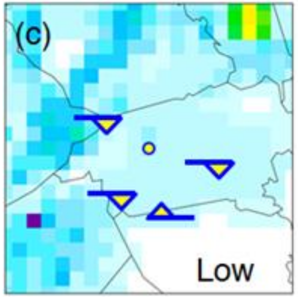


@ 4 km resolution
ER average = 1.42
for 1000 kg/hr
event



@ 1.33 km
resolution
ER average = 2.56
for 1000 kg/hr
event

- At 4 km resolution, ER only exceeds 2 in 6.9% of the simulation hours and exceeds 3 in 0.7% of the simulation hours;
- At 1.33km resolution, ER exceeds 2 in 54.7% of the simulation hours and exceeds 3 in 24.3% of the simulation hours;
- At 1-2 pm, the ER exceeds 2 in 47.0% of 1300-1400 simulation hours with a 1.33 km resolution.

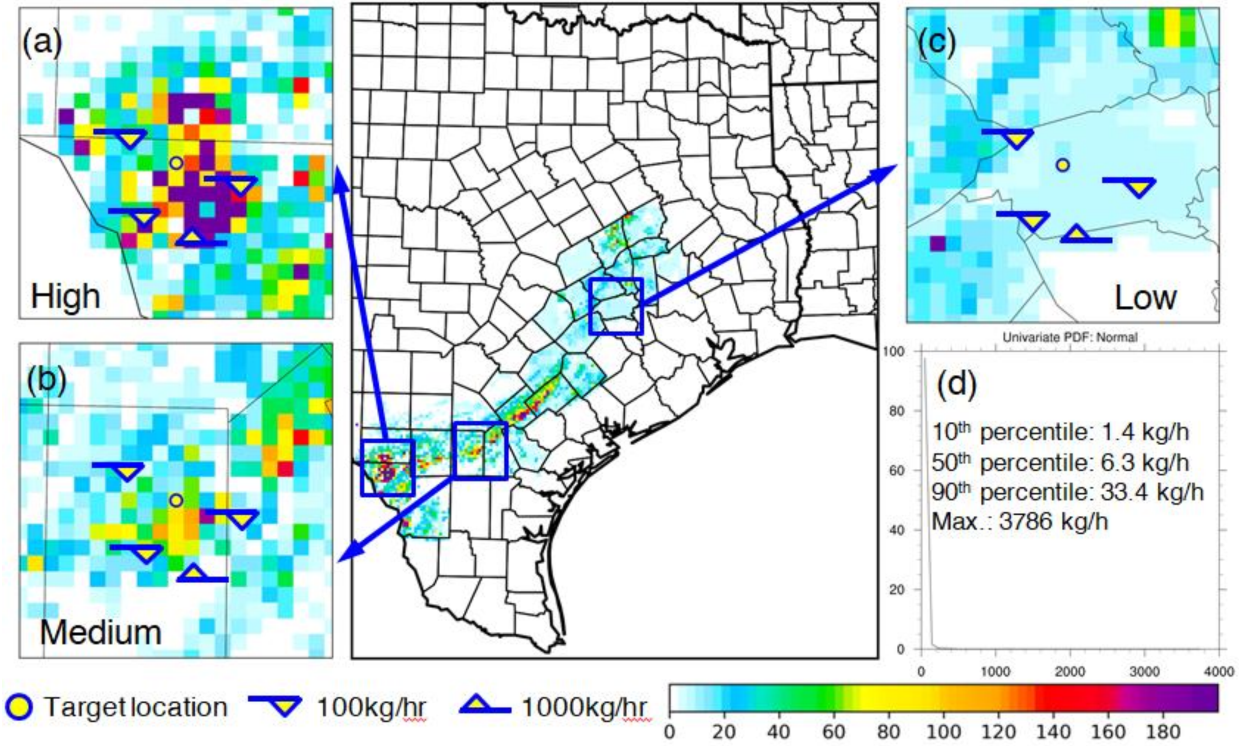


Summary of ER statistics at location c under different scenarios

Location c (low routine emissions)	4km		1.33km	
	100 kg/hr	1000 kg/hr	100 kg/hr	1000 kg/hr
avg. ± std.	1.04+/-0.04	1.42+/-0.36	1.16+/-0.14	2.56+/-1.4
maximum	1.28	3.82	2.19	12.9
ER > 2 (all hours)	0.0%	**6.9%**	0.1%	**54.7%**
ER > 2 (6AM-6PM)	0.0%	4.7%	0.0%	49.9%
ER> 2 (1PM-2PM)	0.0%	2.8%	0.0%	**47.0%**
ER> 3 (all hours)	0.0%	**0.7%**	0.0%	24.3%

Finding: Emission inventories and modeling at ~1 km resolution will be necessary to reliably distinguish 1000 kg/hr events from routine background emissions using column loadings.

Beginning with Simulated CH_4 column concentration from **routine constant emissions**



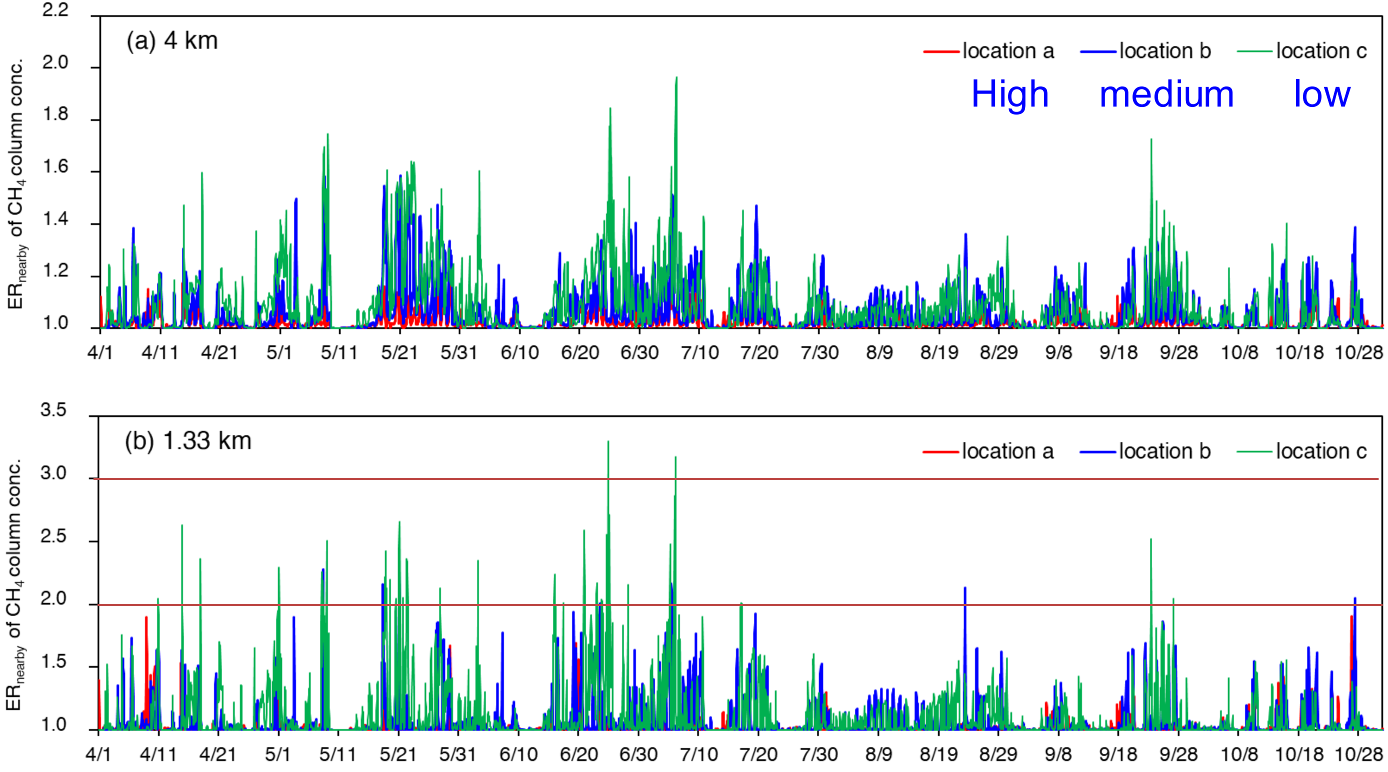
Add 3 emission events of 100 kg/hr one event of 1000 kg/hr to the routine emissions within 25 km radius of the target emission

Enhancement ratio (ER) of methane column concentration due nearby events:

$$ER = \frac{Column\ CH_{4\,nearby} + Column\ CH_{4\,routine\ emissions}}{Column\ CH_{4\,routine\ emissions}}$$

Enhancement ratio due to nearby emission events (ER_{nearby}):

$$ER = \frac{Column\ CH_{4\,nearby} + Column\ CH_{4\,routine\ emissions}}{Column\ CH_{4\,routine\ emissions}}$$



Finding: Nearby events may occasionally interfere with column measurements at specific locations, but generally ER is small.

Enhancement ratio due to nearby emission events (ER_{nearby}):

- At 4 km resolution, nearby emission events only increase local column concentrations at location c by 9%; this value goes up to 11% at 1.33 km resolution;
- ER_{nearby} is even lower when the time period for analysis is restricted to daylight hours;
- Interference from nearby emissions events is not a dominant contributor to overall background levels.

Summary of ER_{nearby} statistics at different locations under different scenarios

location	Location a		Location b		Location c	
resolution	4km	1.33km	4km	1.33km	4km	1.33km
avg.+ std	1.03 ± 0.03	1.03 ± 0.08	1.06 ± 0.08	1.06 ± 0.14	1.09 ± 0.12	1.11 ± 0.23
maximum	1.18	1.91	1.59	2.33	1.96	3.3
ER > 2 (all hours)	0.0%	0.0%	0.0%	0.3%	0.0%	1.4%
ER > 2 (6AM-6PM)	0.0%	0.0%	0.0%	0.4%	0.0%	0.8%
ER> 2 (1PM-2PM)	0.0%	0.0%	0.0%	0.2%	0.0%	0.7%
ER> 3 (all hours)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Major findings

- Measurements and modeling at a spatial resolution less than 1.33 km would be needed to distinguish large emission events (100~1000 kg/hr) from routine emissions.
- Currently baseline methane column concentration datasets at fine spatial and temporal resolution are limited.
- Coupling fine resolution methane emission inventories with fine resolution chemical transport modeling could lead to significant improvements in emission event detection capabilities.
- Future work is to develop an expanded dataset with more emission events.

Acknowledgments

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