Monitoring Dynamics of Agricultural Methane Emissions in the Contiguous US from Sentinel-5P TROPOMI Data

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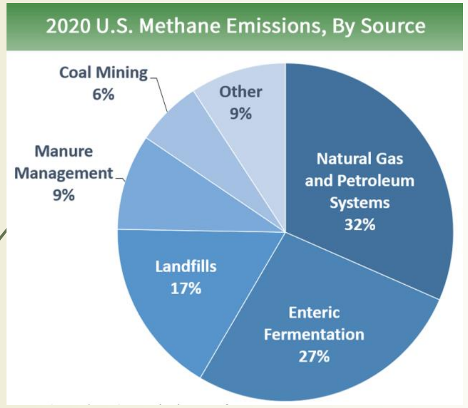
Disclaimer

The Findings and Conclusions in This Preliminary Presentation Have Not Been Formally Disseminated by the U. S. Department of Agriculture and Should Not Be Construed to Represent Any Agency Determination or Policy

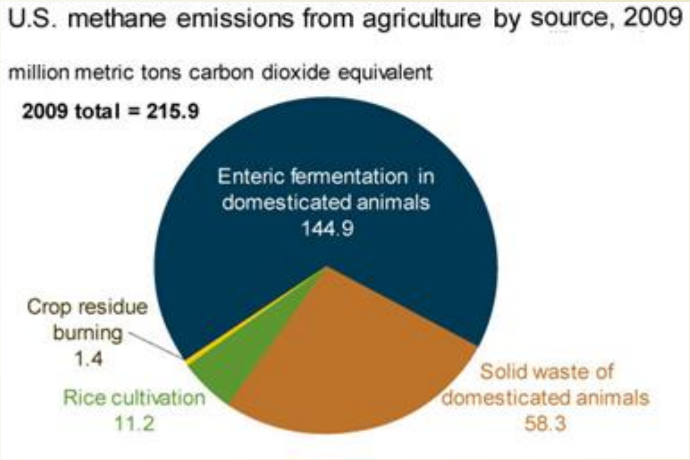
About methane

- Methane (CH_4) is the second most abundant anthropogenic GHG after carbon dioxide (CO_2) but is 25 times more potent than CO_2 at trapping heat in the atmosphere.
- CH_4 is emitted from both natural (e.g., natural wetlands) and anthropogenic (~75%) sources.



https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane

- Crop (e.g., rice cultivation) and livestock production (e.g., intrinsic fermentation and animal waste), is responsible for up to a third of total anthropogenic GHG emissions (Carlson, et al., 2017).



https://www.eia.gov/environment/emissions/ghg_report/ghg_methane.php

- By 2017, agriculture became the largest anthropogenic source of methane emitting to atmosphere (Smith et al., 2021).

- A UNEP Global Methane Assessment Report in 2021 shows that methane emissions from livestock (including cattle) are the largest sources of agricultural emissions worldwide and cattle are the top source of methane emissions in the US (Jones et al., 2021)

Objectives

- Better understanding of the mechanisms and dynamics of CH_4 emissions from agriculture is essential to informed mitigation actions by policy makers, farmers, and ranchers.
- In the U.S., livestock production, in particular Concentrated Animal Feeding Operations (CAFOs), and rice cultivation are key sources of CH_4 emissions from agriculture.
- To examine spatial-temporal patterns of CH_4 emissions and their relationship with agricultural activities, we analyzed data from a variety of sources to account for agricultural contributions to GHG.

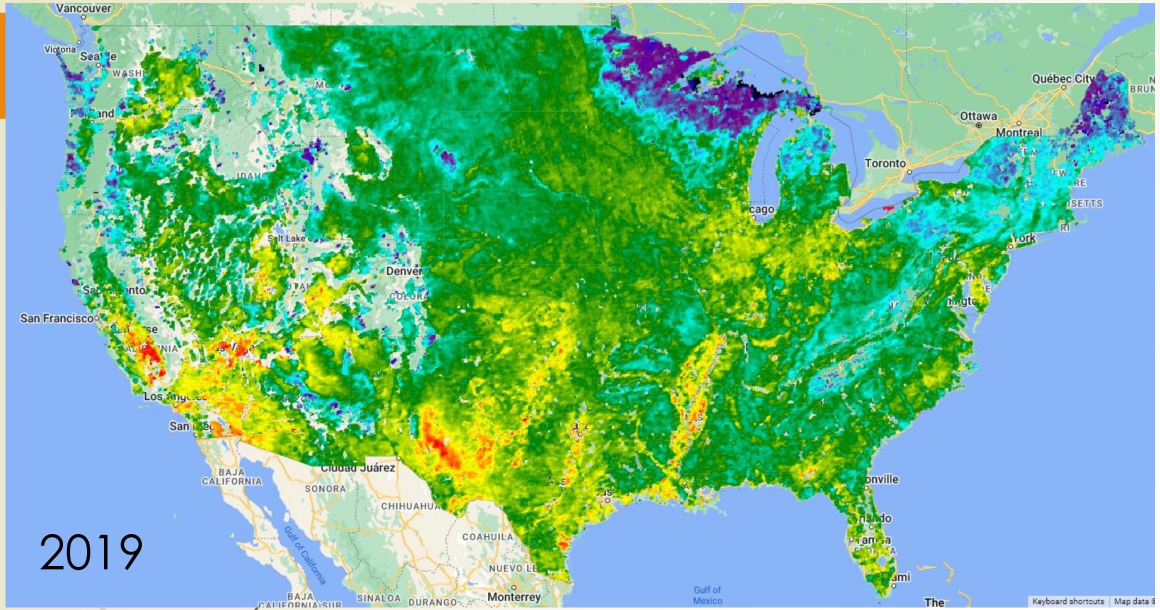
Datasets used for analysis

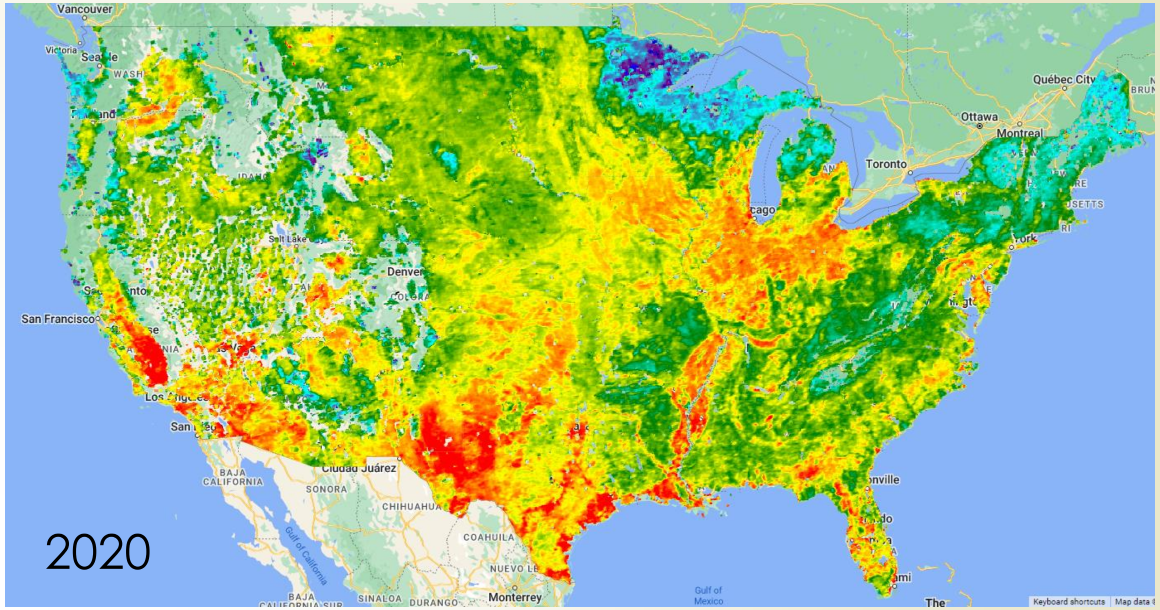
- ESA Sentinel-5P TROPOMI offline L3 CH_4 data ingested on Google Cloud Platform
- MODIS Terra Normalized Difference Vegetation Index (NDVI)
- USDA NASS Cattle on Feed (COF) Reports
- US EPA Concentrated Animal Feeding Operations (CAFOs) distribution data
- USDA NASS Cropland Data Layer (CDL)

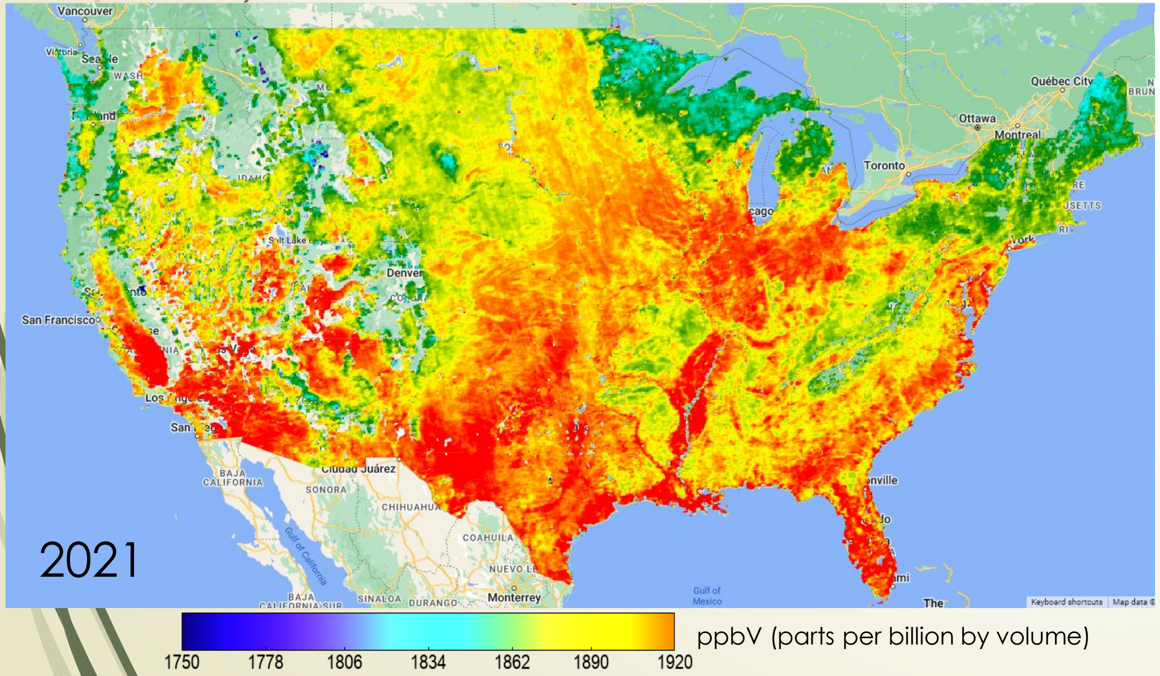
TROPOspheric Monitoring Instrument (TROPOMI)

- Sentinel-5 Precursor, launched in October 2017, is an Earth observation satellite developed by European Space Agency (ESA) as part of the Copernicus Program dedicated to monitoring the atmosphere.
- TROPOspheric Monitoring Instrument (TROPOMI) is a satellite instrument on board this satellite.
- TROPOMI uses absorption information from the Oxygen-A Band (760nm) and the SWIR spectral range to measure CH_4 column concentration with sufficient accuracy for CH_4 abundance monitoring at global, continental, or national scales.

Annual methane concentrations derived from Sentinel-5P OFFL CH_4 dataset

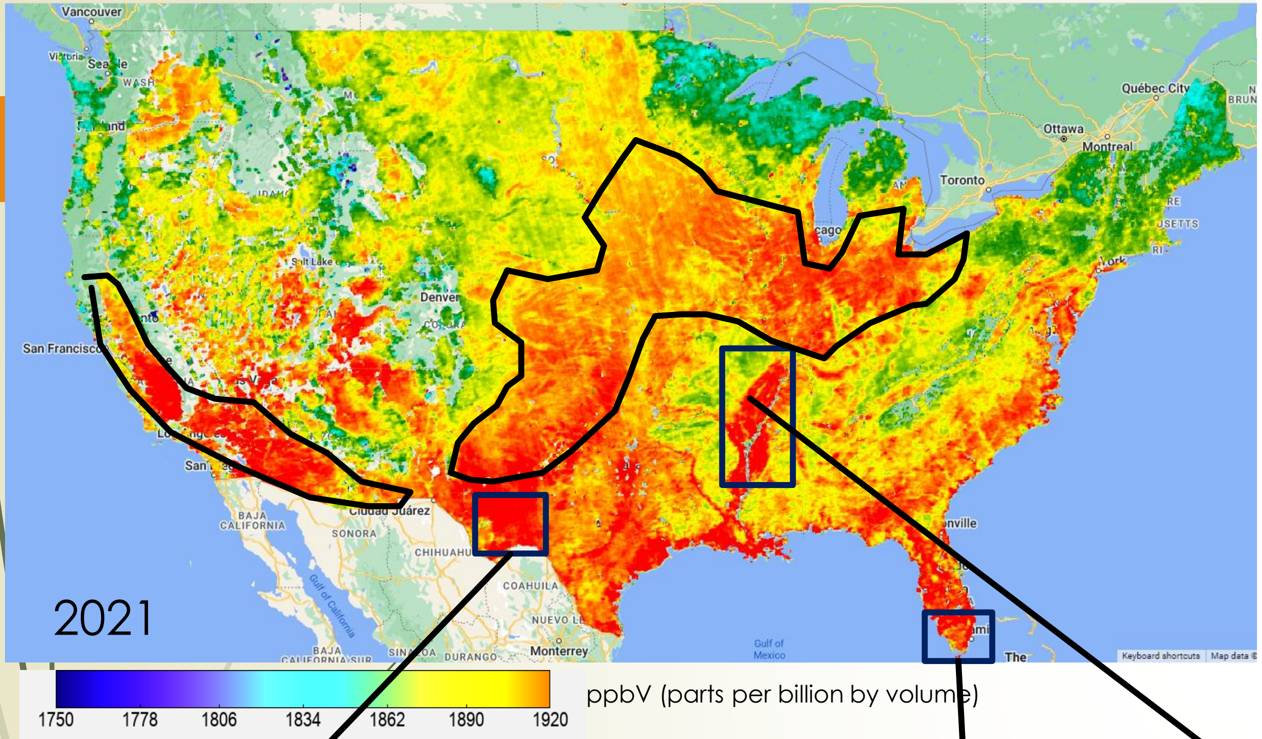


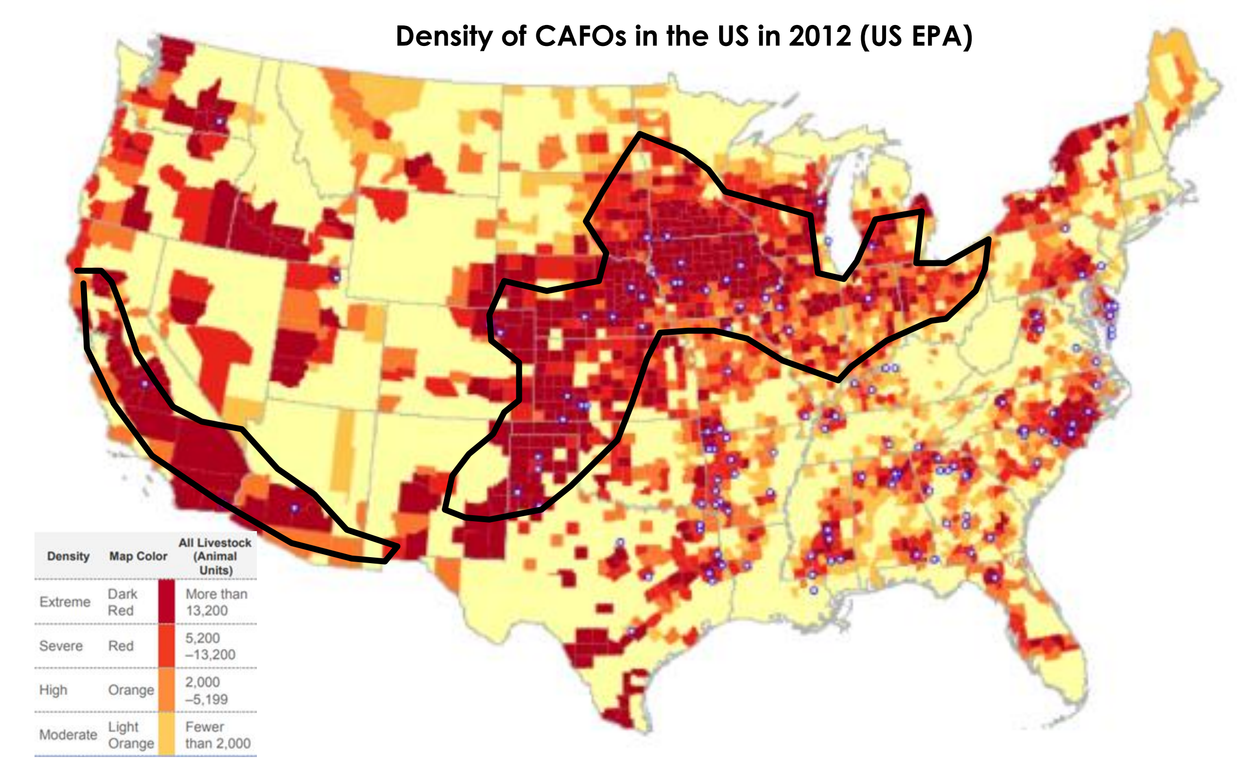


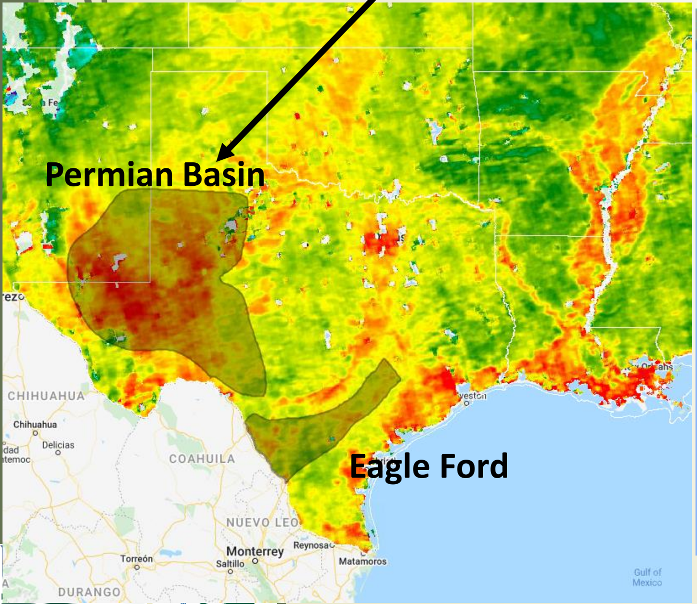


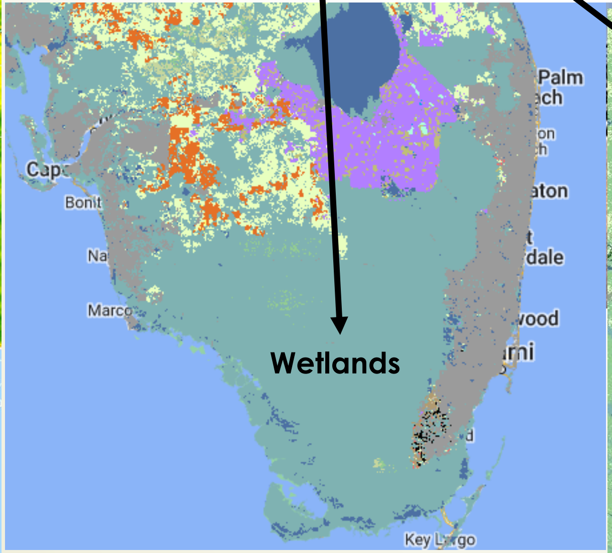
- We processed Sentinel-5P OFFL CH_4 dataset ingested by Google Earth Engine and generated annual methane concentrations for 2019, 2020 and 2021.
- TROPOMI measured CH_4 concentrations increased across most parts of the contiguous US from 2019 through 2021.

Methane concentrations derived from Sentinel-5P OFFL CH4 dataset

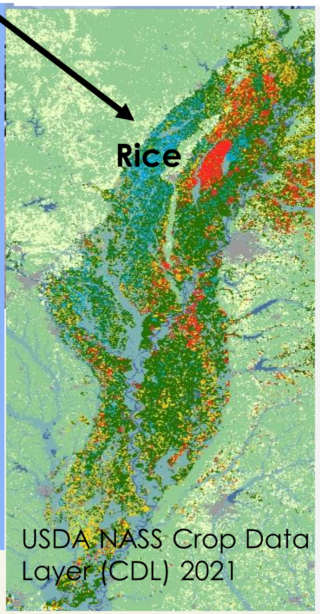


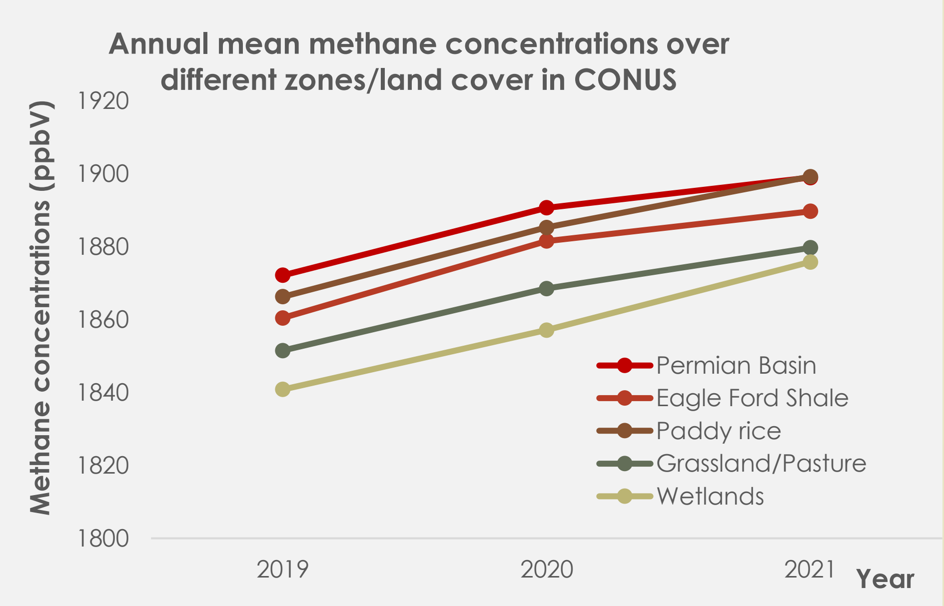




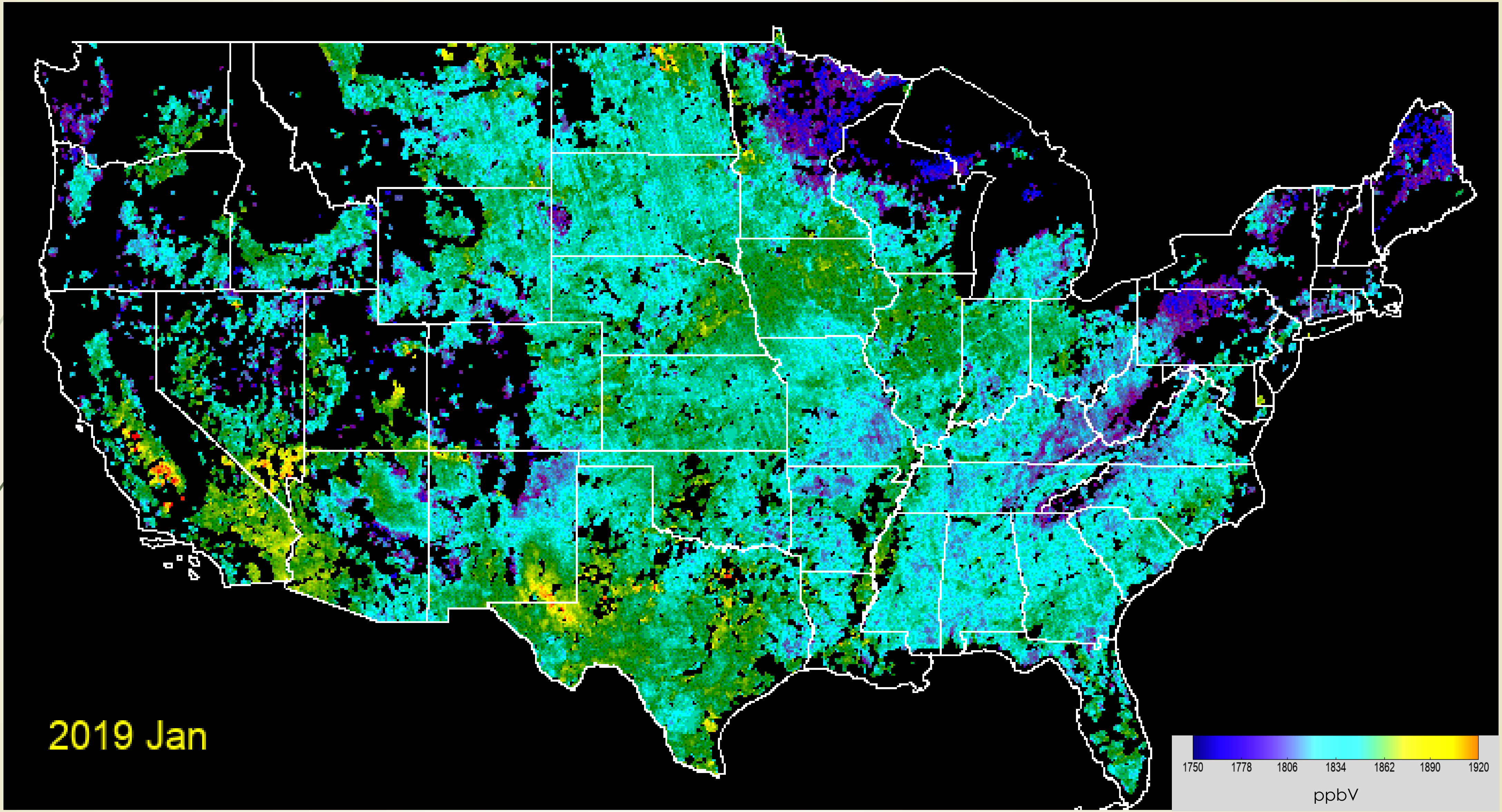


USDA NASS Crop Data Layer (CDL) 2021



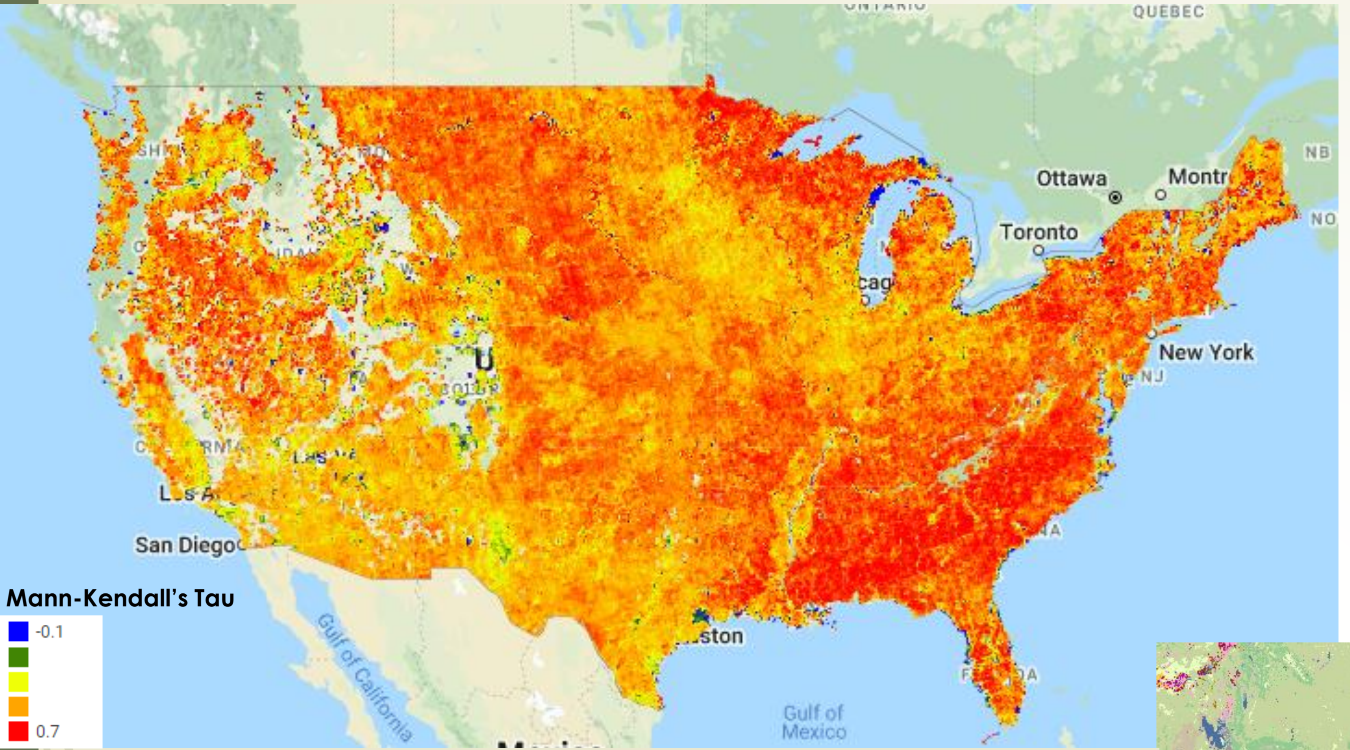


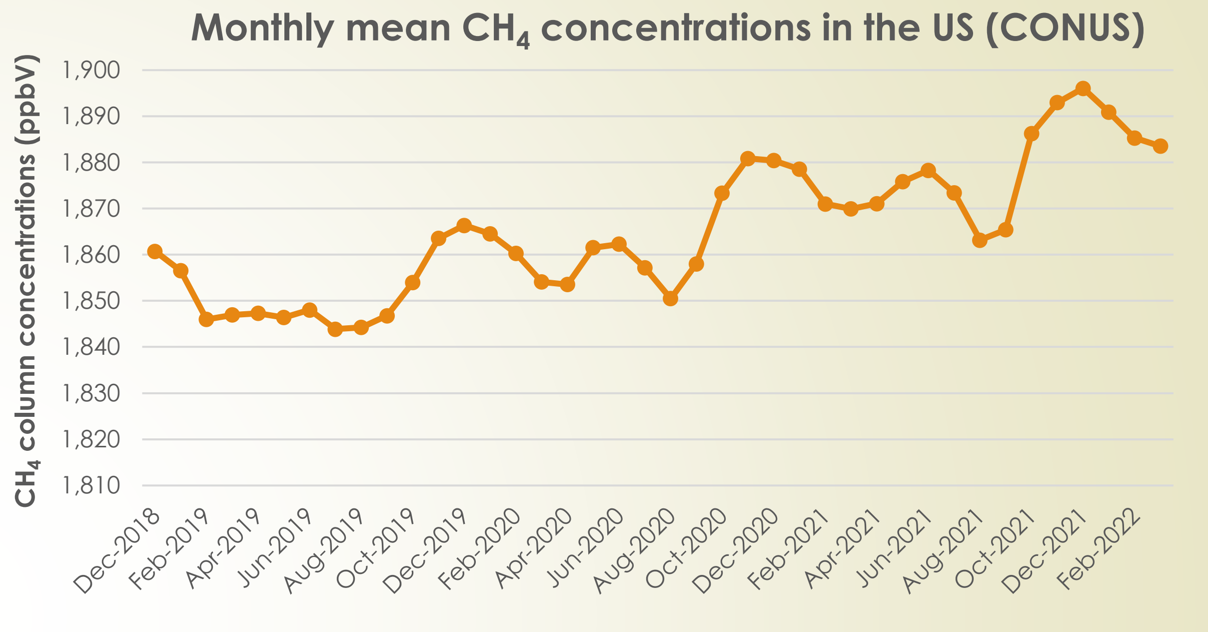
Monthly methane concentrations from Jan 2019 to Apr 2022 derived from Sentinel-5P OFFL CH4 dataset



We generated 40 monthly images (from Jan 2019 to Apr 2022) for CONUS using Google Earth Engine.

Trends of monthly methane concentrations Feb 2019 – Mar 2022

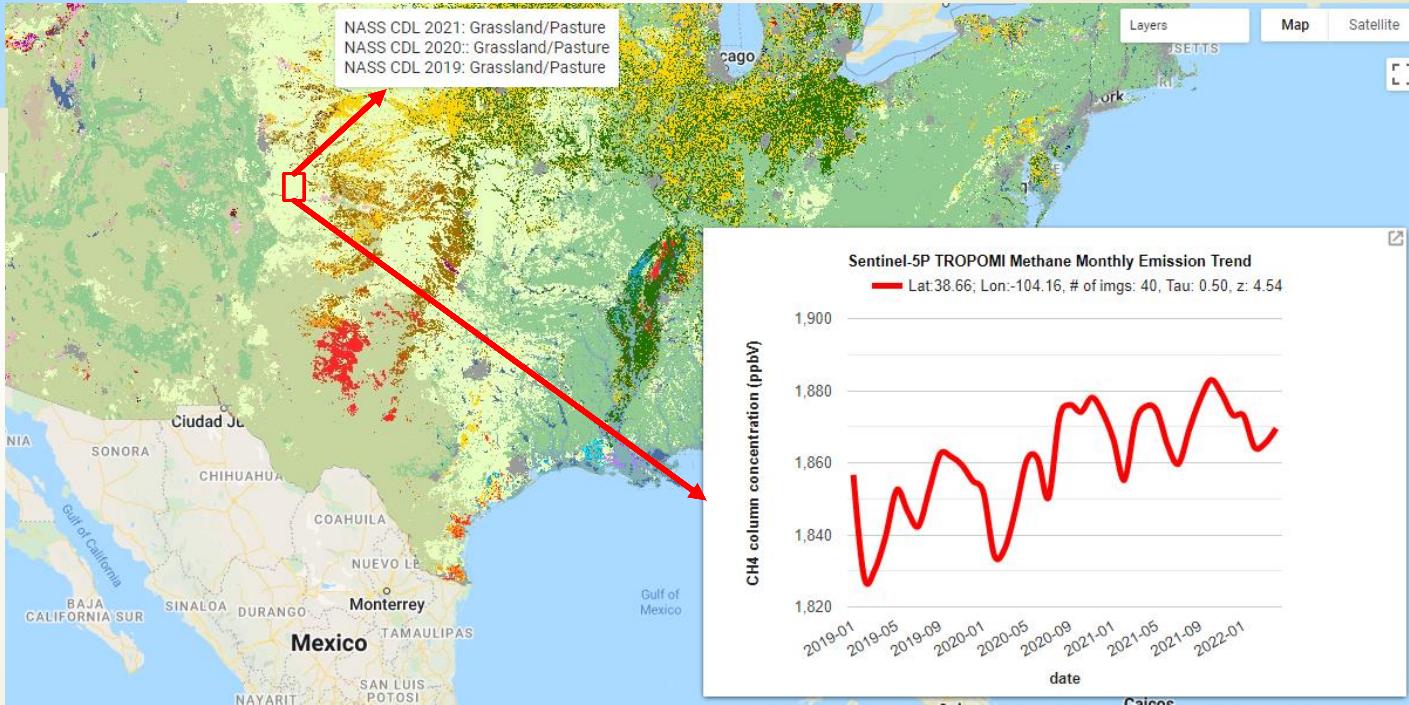




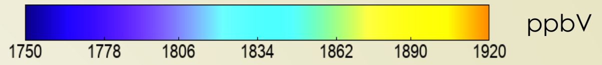
Mann-Kendall's Tau of monthly methane concentrations

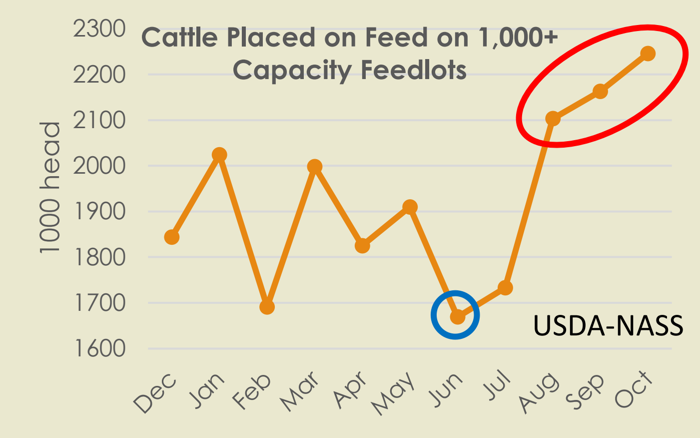
$$\tau = \frac{\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_i - x_j)}{C_2^n}$$

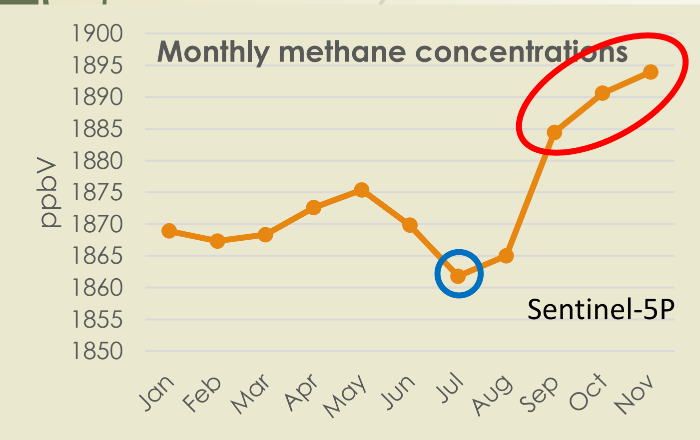
Mann-Kendall's Tau coefficients ranging from -1 to 1 show trends of monthly methane's concentrations between Feb 2019 and Mar 2022 (38 months). Positive numbers indicate increasing trends, and negative numbers decreasing trends. The map shows CH_4 emissions increased in most areas of the US in the specified period.

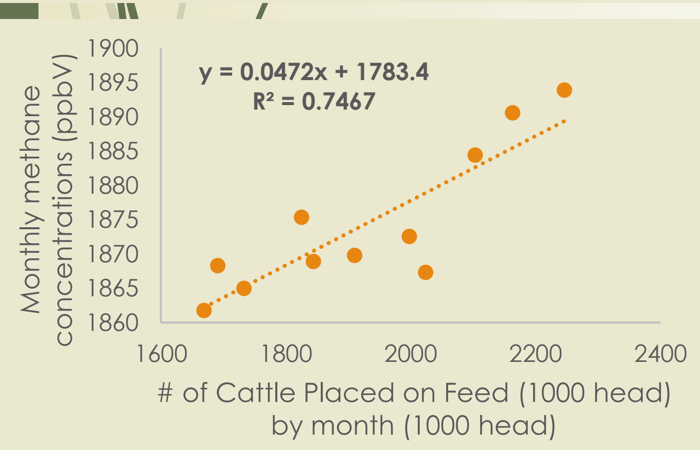


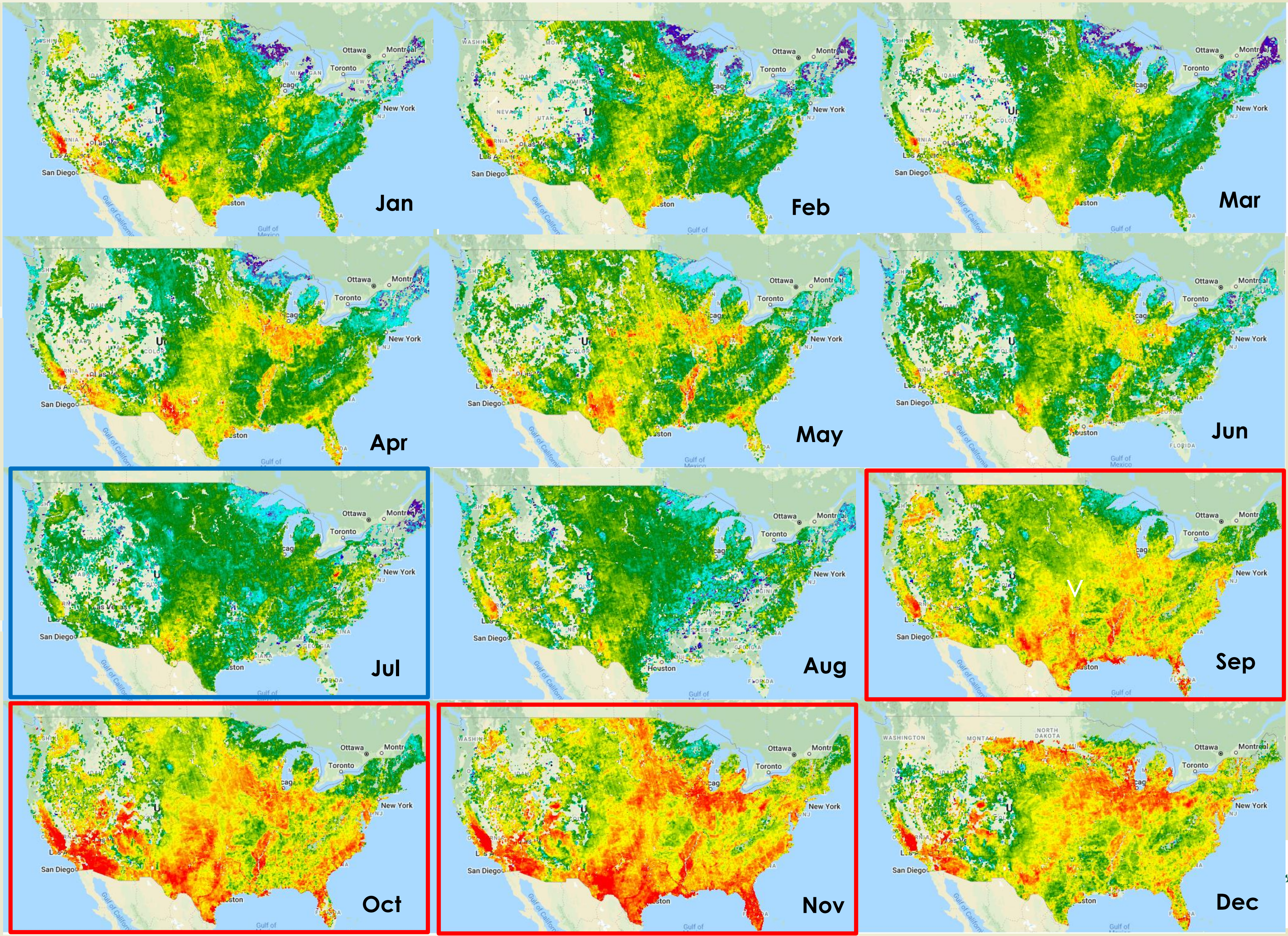
Monthly methane emissions in 2021





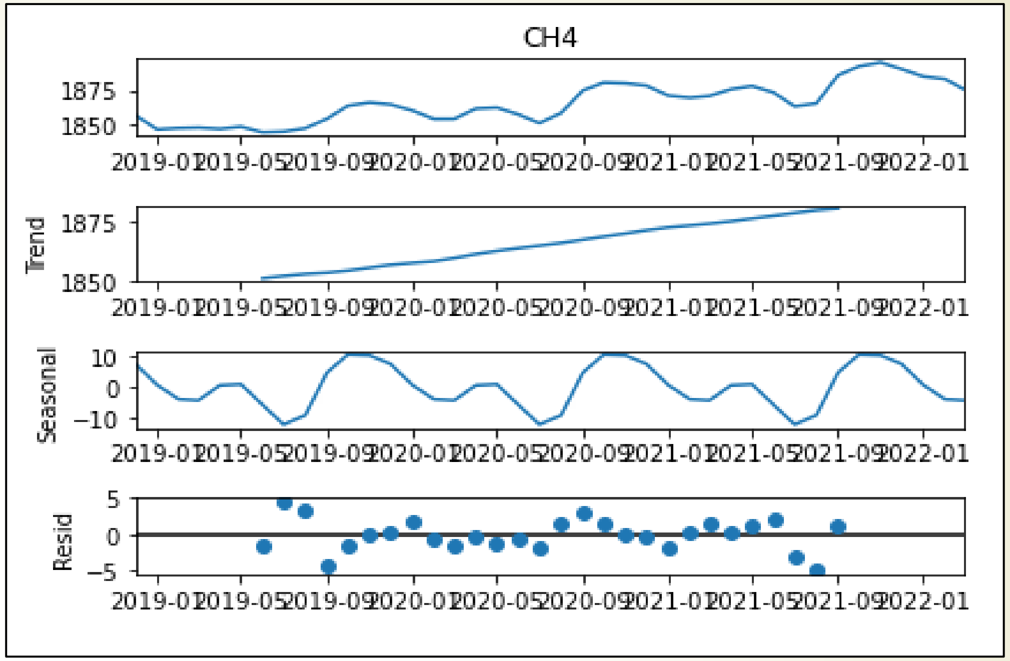


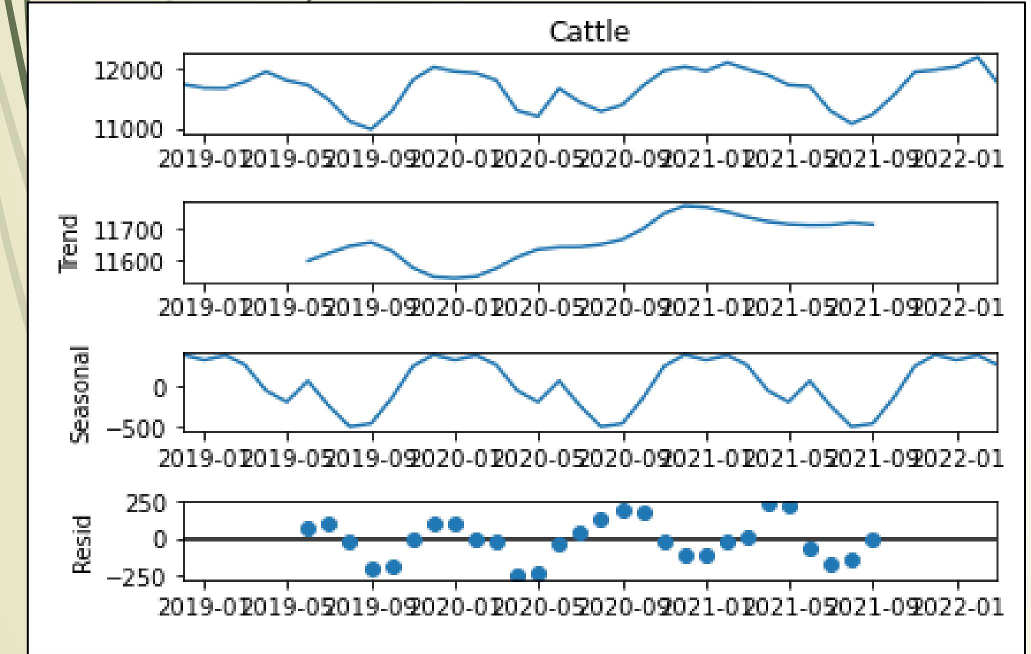


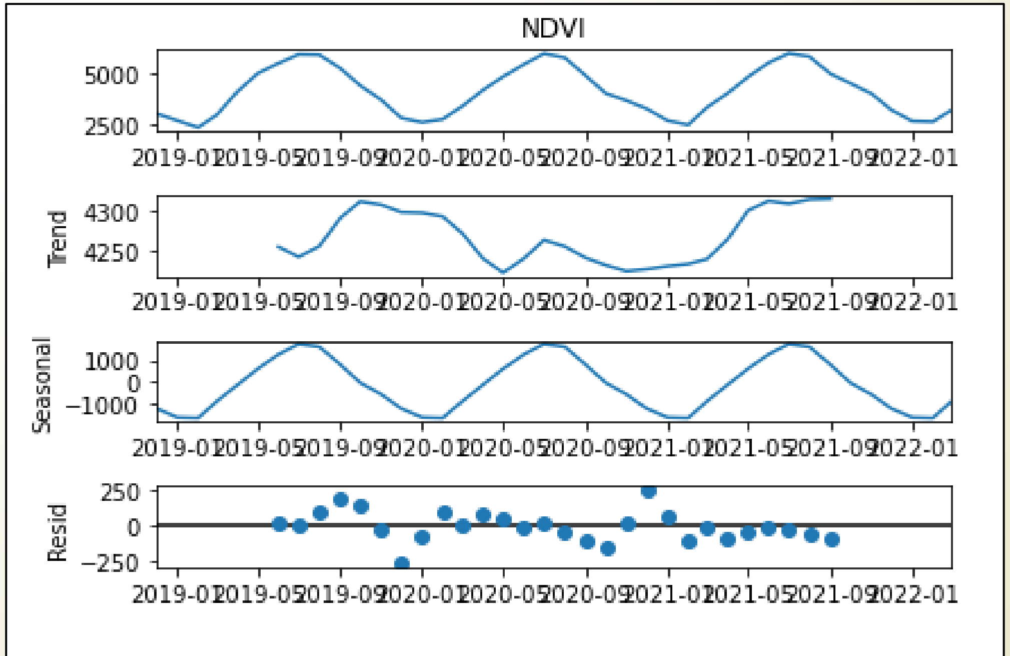


Fourier Transform for time series analysis - seasonal decomposition

- The Fourier Transform transforms a signal from the time domain to the frequency domain.
- A time series can be considered as a combination of level, trend, seasonality, and noise components.
- Decomposition of a time series gives us a better understanding of the frequencies inside a signal.

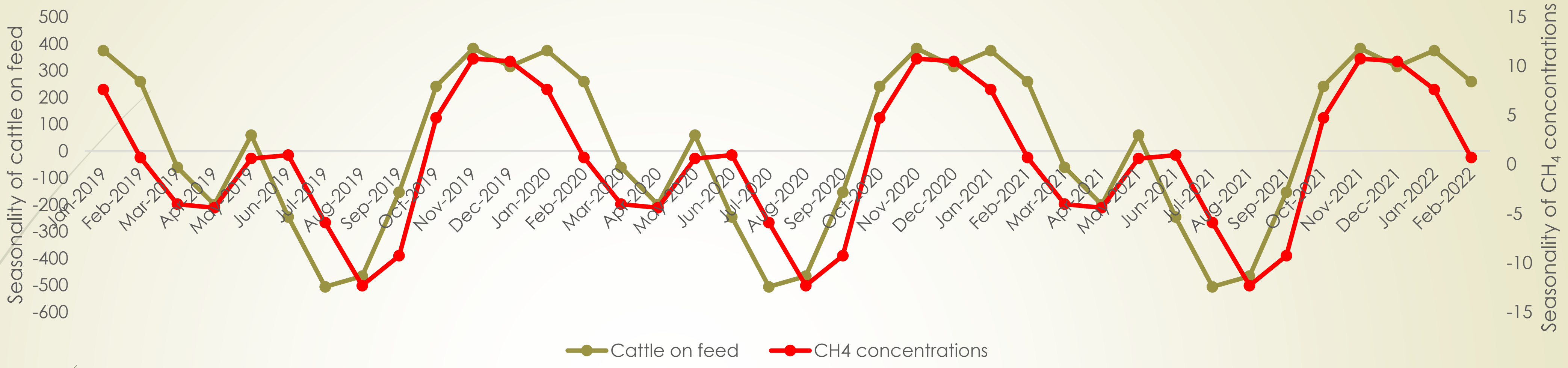






Fourier Transform derived seasonality from cattle on feed and methane concentrations

Seasonality patterns of monthly cattle on feed and CH_4 concentrations



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.863447421
R Square	0.745541449
Adjusted R Square	0.738473156
Standard Error	3.669473334
Observations	38

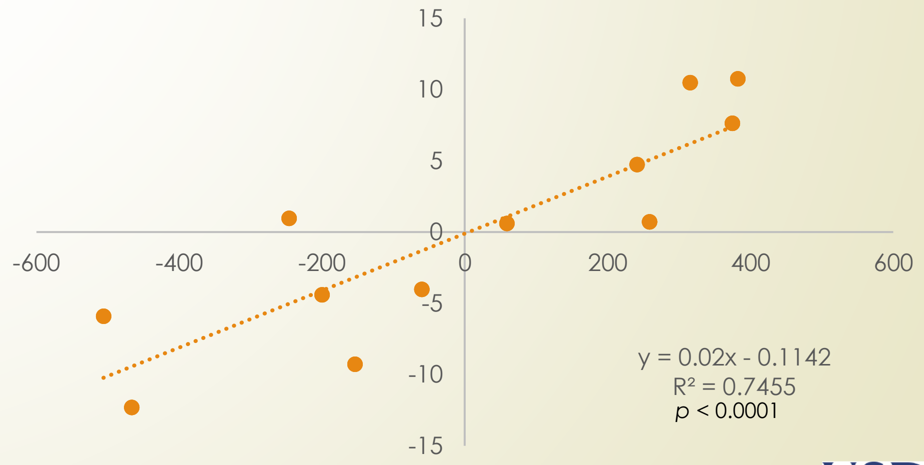
ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	1420.25	1420.25	105.4768728	3.03E-12
Residual	36	484.7412	13.46503		
Total	37	1904.991			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.114188949	0.596154	-0.19154	0.849176628	-1.32324	1.094867	-1.32324	1.094867
X Variable 1	0.020017003	0.001949	10.27019	3.03265E-12	0.016064	0.02397	0.016064	0.02397

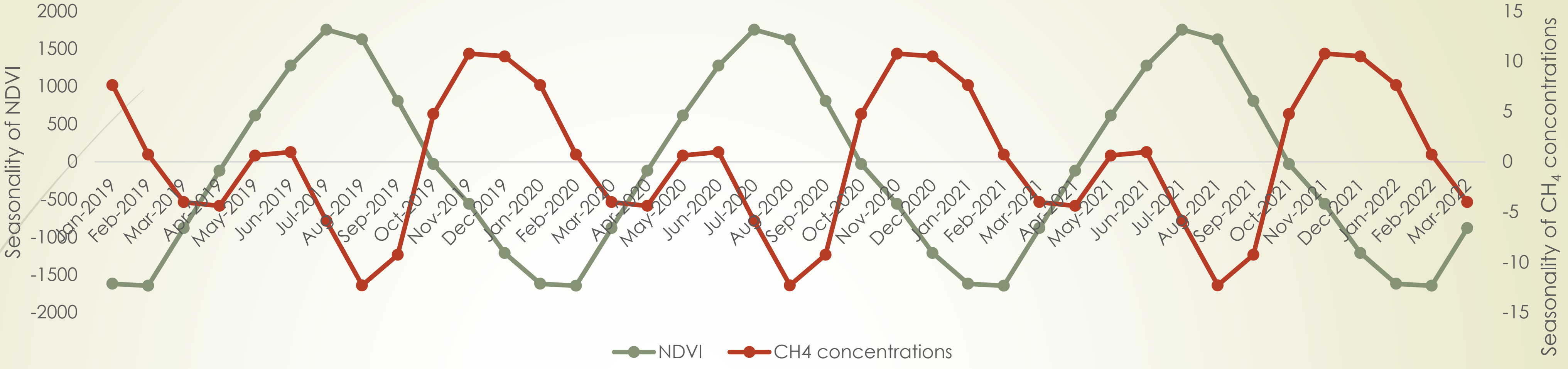
- Fourier Transform-derived seasonality of monthly cattle on feed and that of methane concentrations were highly consistent during the time period from Dec 2018 through Feb 2022.
- A significant positive correlation ($R^2 = 0.75$) existed between the two seasonality components.

Relationship between seasonalities of monthly cattle on feed and CH_4 concentrations



Fourier Transform derived seasonality from NDVI and methane concentrations

Seasonality patterns of monthly NDVI and CH_4 concentrations



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.627982
R Square	0.394361
Adjusted R Square	0.377993
Standard Error	944.1843
Observations	39

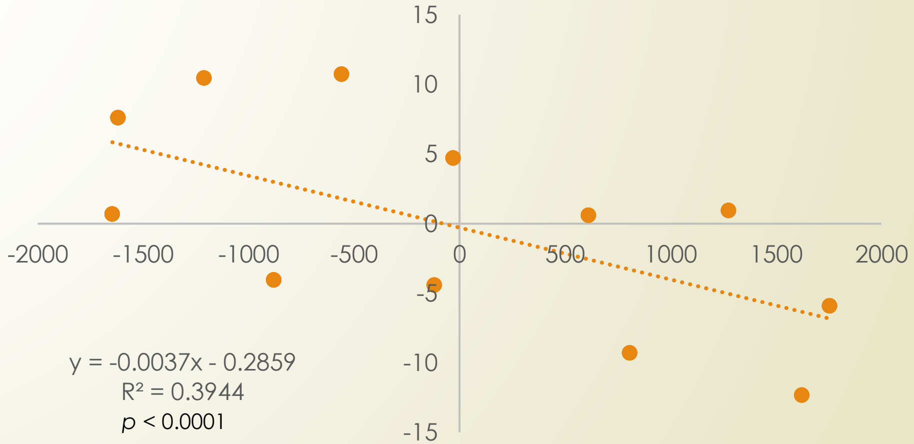
ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	21478097	21478097	24.09252222	1.87E-05
Residual	37	32984906	891483.9		
Total	38	54463002			

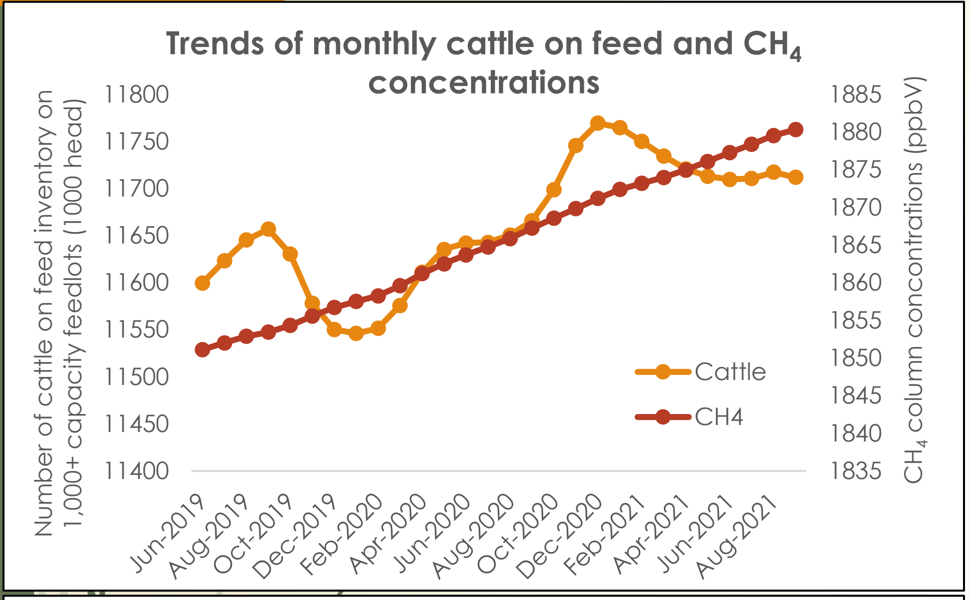
	Coefficient	*andard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-94.6083	151.2093	-0.62568	0.535366833	-400.988	211.7708	-400.988	211.7708
X Variable 1	-105.697	21.53382	-4.90841	1.87141E-05	-149.329	-62.0652	-149.329	-62.0652

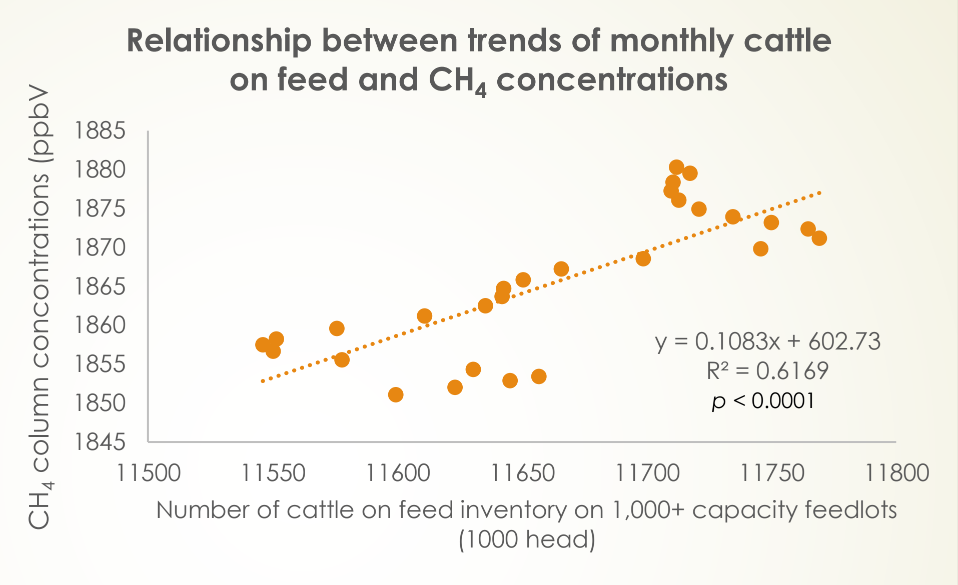
- Fourier Transform-derived seasonality of NDVI and that of methane concentrations showed opposite patterns during the time period from Dec 2018 through Feb 2022.
- A significant negative correlation (R^2 = 0.39) existed between the two seasonality components.
- The results explained lower CH_4 concentrations detected during summertime than wintertime as shown in TROPOMI images.

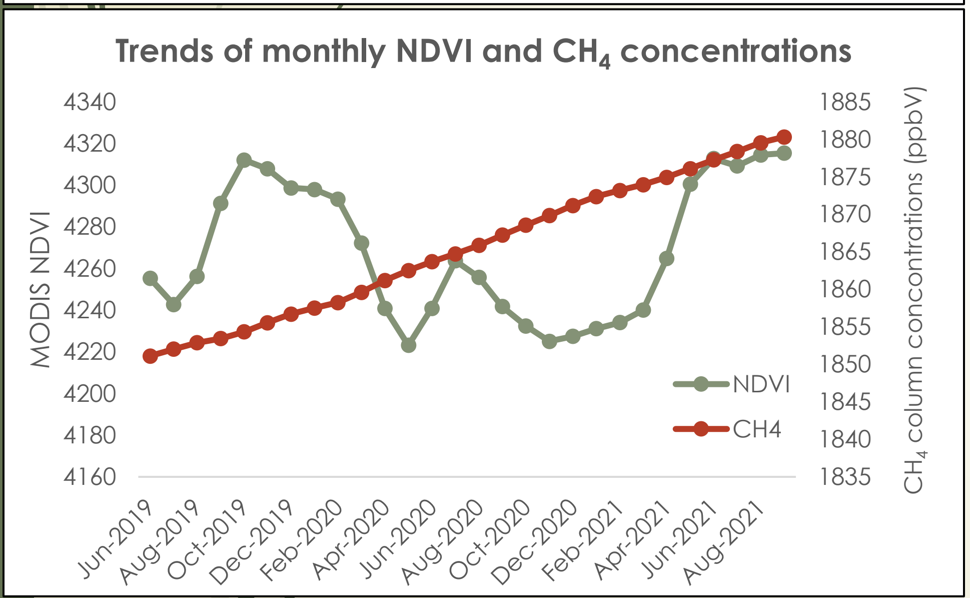
Relationship between seasonalities of monthly NDVI and CH_4 concentrations

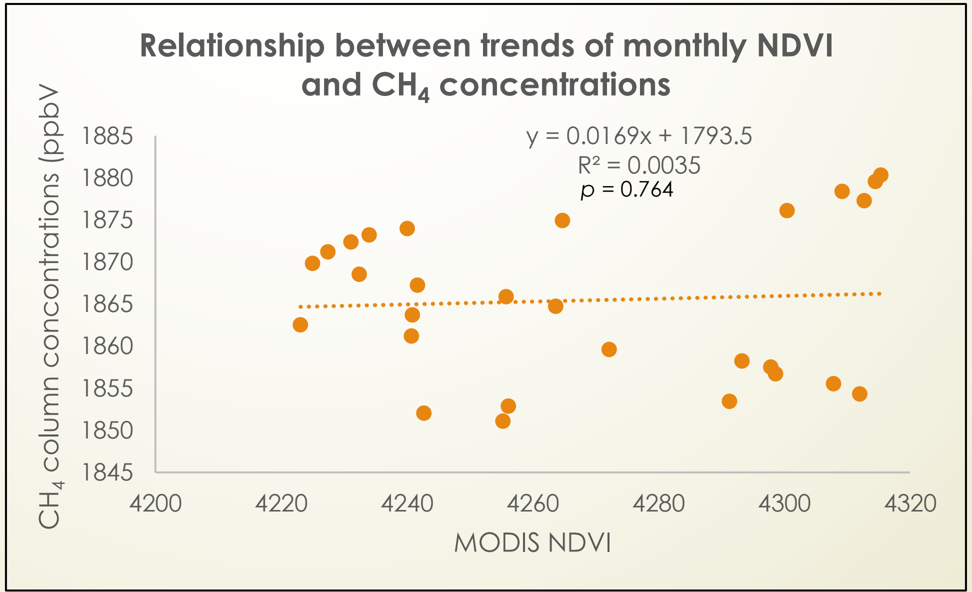


Fourier Transform derived trends from cattle on feed, NDVI and methane concentrations









- Results show that methane concentrations significantly increased in the atmosphere over the counties having CAFOs during the time period from Jun 2019 to Aug 2021.
- The trend of cattle on feed had a significant positive correlation with the trend of methane concentrations for the time period, and the former accounted for 62% of methane's increasing trend.
- The monthly NDVI did not show a significantly increasing or decreasing trend for the same time period.
- There was no correlation between the trend of NDVI and that of methane concentrations.

Summary and Conclusions

- TROPOMI measured CH_4 concentrations increased across most parts of the contiguous US during the study period.
- Higher CH_4 concentrations were detected from rice paddy fields than from CAFOs areas.
- Spatially, the distribution pattern of CH_4 concentrations from agricultural activities is highly consistent with those of CAFOs and rice cultivation.
- Temporally, both the FT derived seasonality and trend of monthly cattle on feed on 1000+ capacity feedlots were highly correlated with those of CH_4 concentrations for the study period.
- NDVI seasonality was negatively correlated with CH_4 seasonality, and no correlation existed between the trends of the two during the same period.
    - This suggests seasonal fluctuation of CH_4 was associated with both the number of cattle on feed (COF) and NDVI.
    - However, increasing trends of CH_4 were partially associated with COF (62%) but not NDVI.
- Future work will be extended to estimate the number of livestock on feed at any given time using Sentinel-5P TROPOMI data through building RNN (e.g., LSTM) deep learning models.

References

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Jones, E., Datil, A., Delfino, A., 2021, Yes, cattle are the top source of methane emissions in the US. Retrieved October 20, 2022, from https://www.verifythis.com/article/news/verify/environment-verify/cattle-cows-the-top-source-of-methane-emissions-in-united-states/536-8d5bf326-6955-4a9c-8ea5-761d73ba464c

Thank you and Questions

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