

**CM - 618 Course Project**

**“CO<sub>2</sub>-TEMPERATURE  
RELATIONSHIP IN GLACIAL  
CYCLES: CAUSE OR EFFECT?”**

**Group 10**

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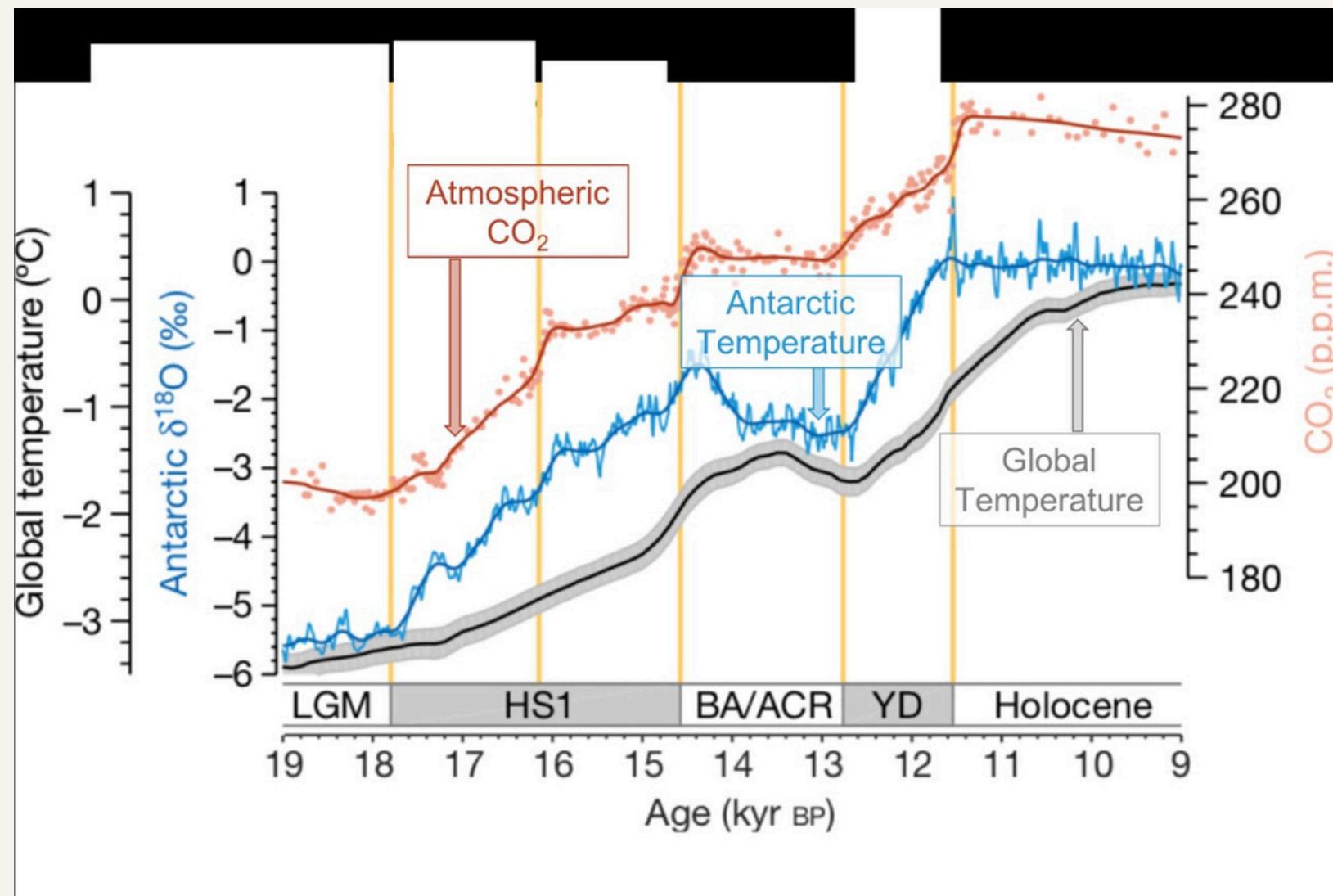
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# Glacial Cycles



*Vostok Ice-core graph*

- During glacial–interglacial transitions, temperature increases occurred first, due to orbital (Milankovitch) forcing.
- CO<sub>2</sub> lagged temperature by ~200–800 years, mainly because warming oceans released dissolved CO<sub>2</sub>.
- CO<sub>2</sub> did not initiate the warming, but acted as a positive feedback amplifier, increasing total warming magnitude.
- Without the CO<sub>2</sub> feedback, orbital forcing alone cannot account for the full ~5–6°C warming.

# Hypothesis ( $H_1$ ):

- During past glacial cycles, temperature rise occurred first and CO<sub>2</sub> increased later as a feedback amplifier.
- However, in the current era, human-driven CO<sub>2</sub> emissions are leading the temperature rise, making CO<sub>2</sub> the primary forcing today.

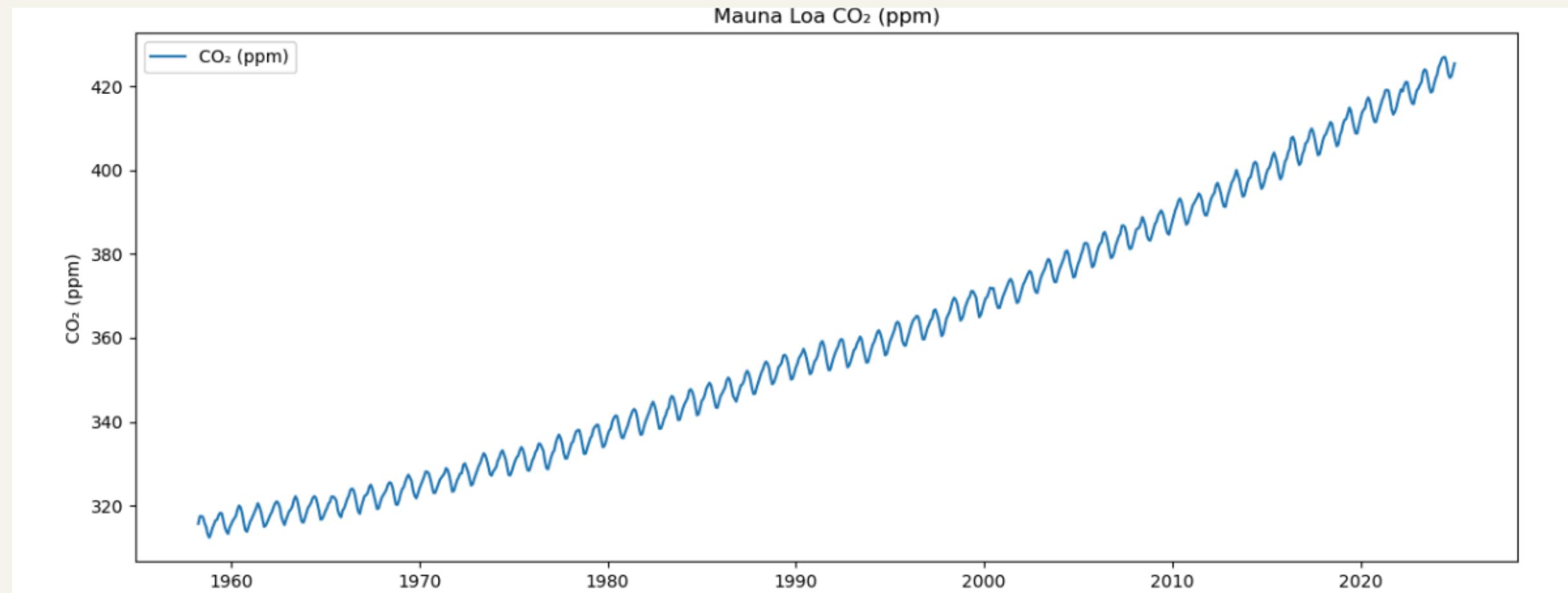
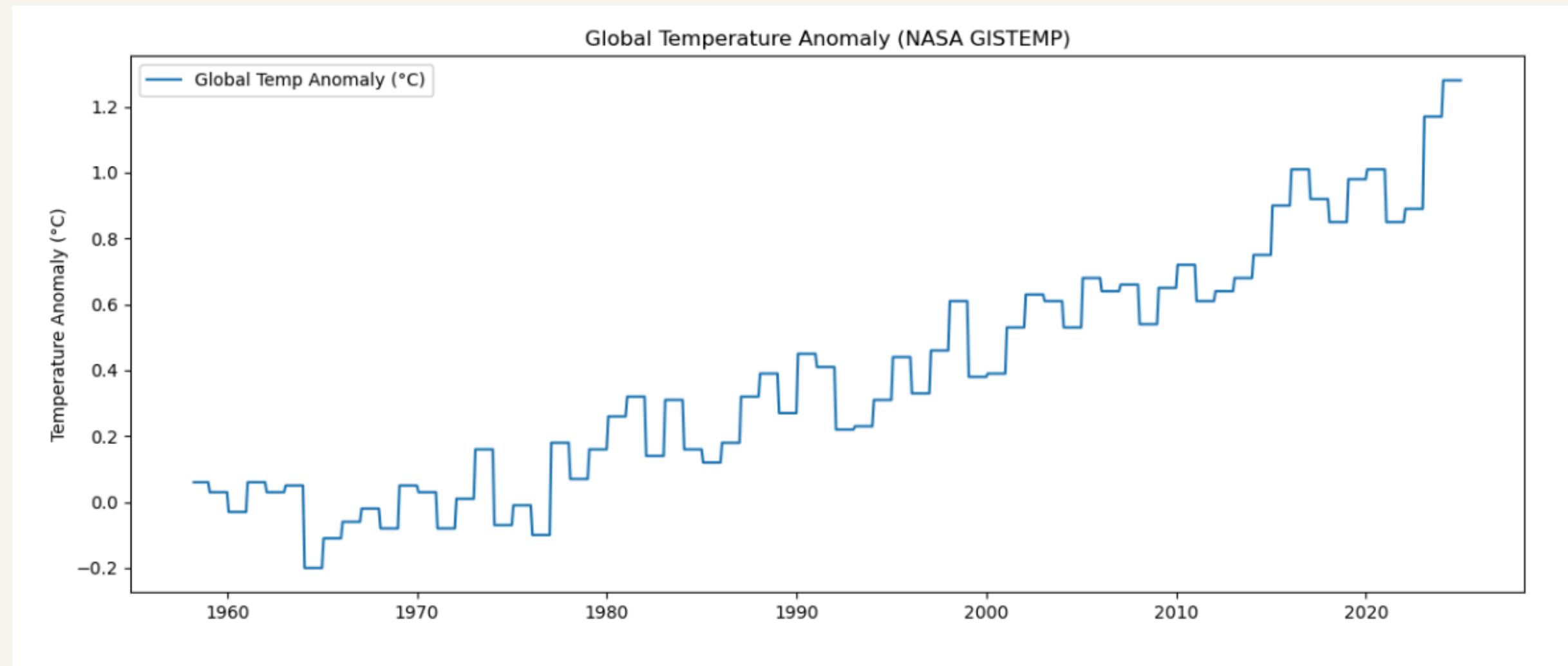
# Null Hypothesis ( $H_0$ ):

- Even in the present climate system, CO<sub>2</sub> still lags temperature as in glacial cycles.
- This implies temperature change is primarily initiated by other factors (e.g., methane, natural variability or ocean-atmosphere dynamics), and CO<sub>2</sub> only reacts afterward.

# Data Sources and References

- **Global Atmospheric Methane Concentration Trends** - NOAA Global Monitoring Laboratory (1950–Present)
  - **Global Atmospheric CO<sub>2</sub> Concentration Trends** - NOAA Global Monitoring Laboratory (Mauna Loa, 1958–Present)
  - **Human-Induced Methane (CH<sub>4</sub>) Emissions by Sector & Year** - Climate Change Tracker
  - **ERA5 Reanalysis Climate Dataset** - Copernicus Climate Data Store (Hourly Global Gridded Fields)
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- Humlum, O., Stordahl, K., & Solheim, J.-E. (2013), Global and Planetary Change, 100, 51–69.
  - Mar et al. (2022), Environmental Science & Policy, 134, 127–136.

# Modern Era (Post 1950)



# Methodology and Results

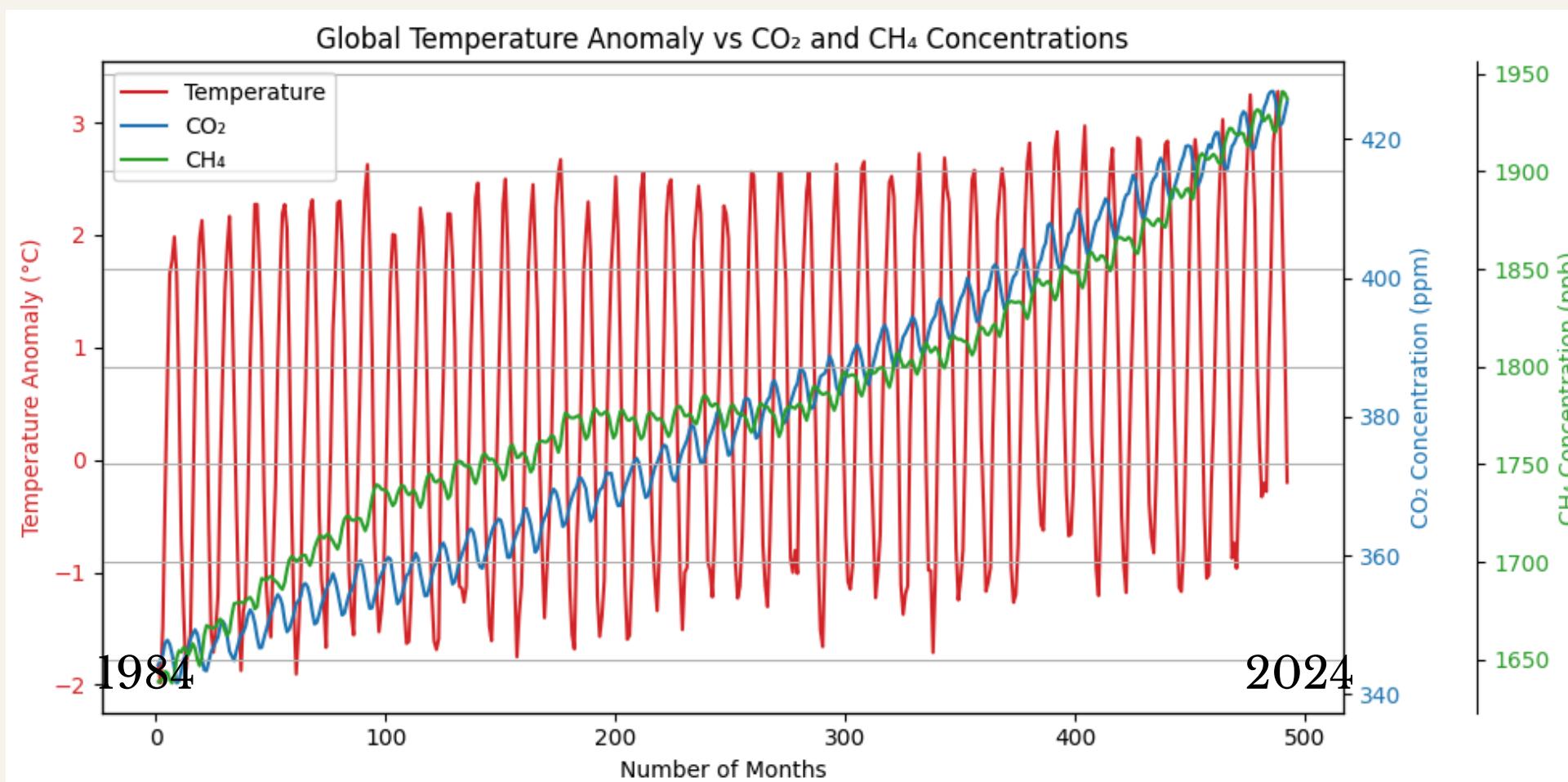
We specifically focus on **methane** in our analysis

In order to not reject our null hypothesis, we need to prove following things:

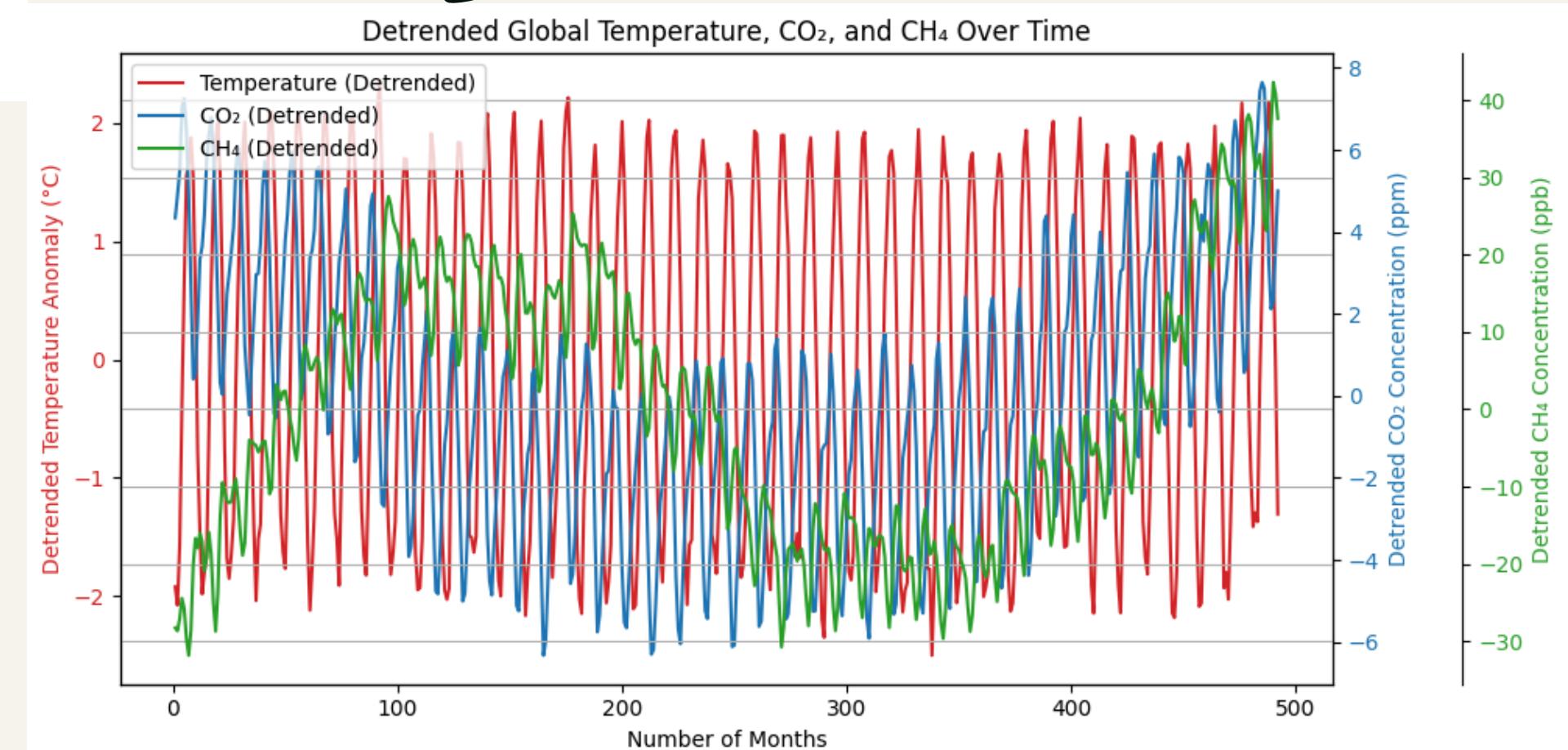
- CO<sub>2</sub> concentration significantly lags the increasing global temperature
- Methane emissions and/or concentration significantly leads the increasing global temperature

# 1. Cross Correlation

## 1.1 CO<sub>2</sub> and Methane Concentrations



De-Trending



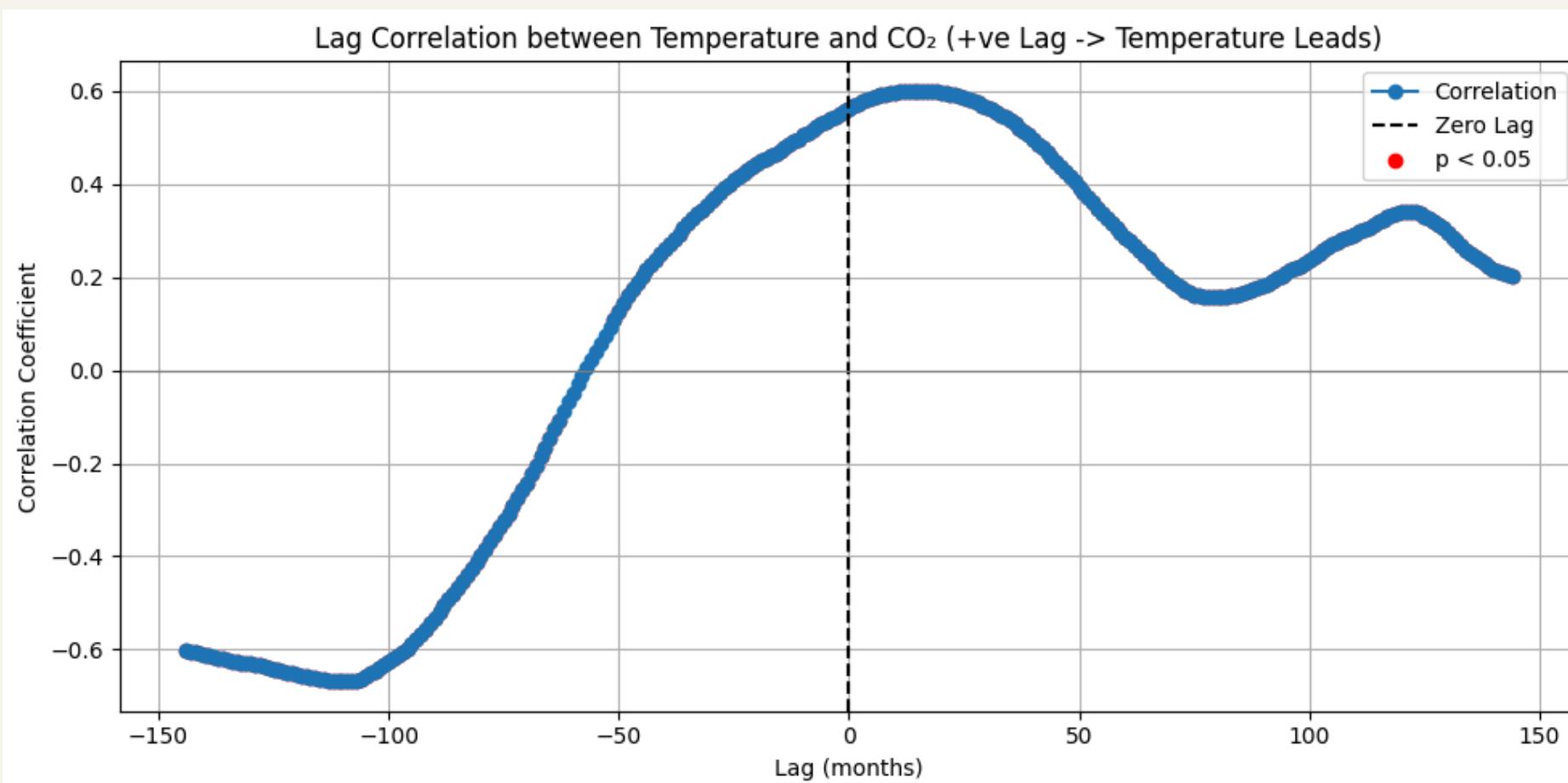
# 1. Cross Correlation

## 1.1 CO<sub>2</sub> and Methane Concentrations

Smoothed the de-trended data by applying rolling mean over 48 months (4 years) to remove periodicities in the data as well as correlations

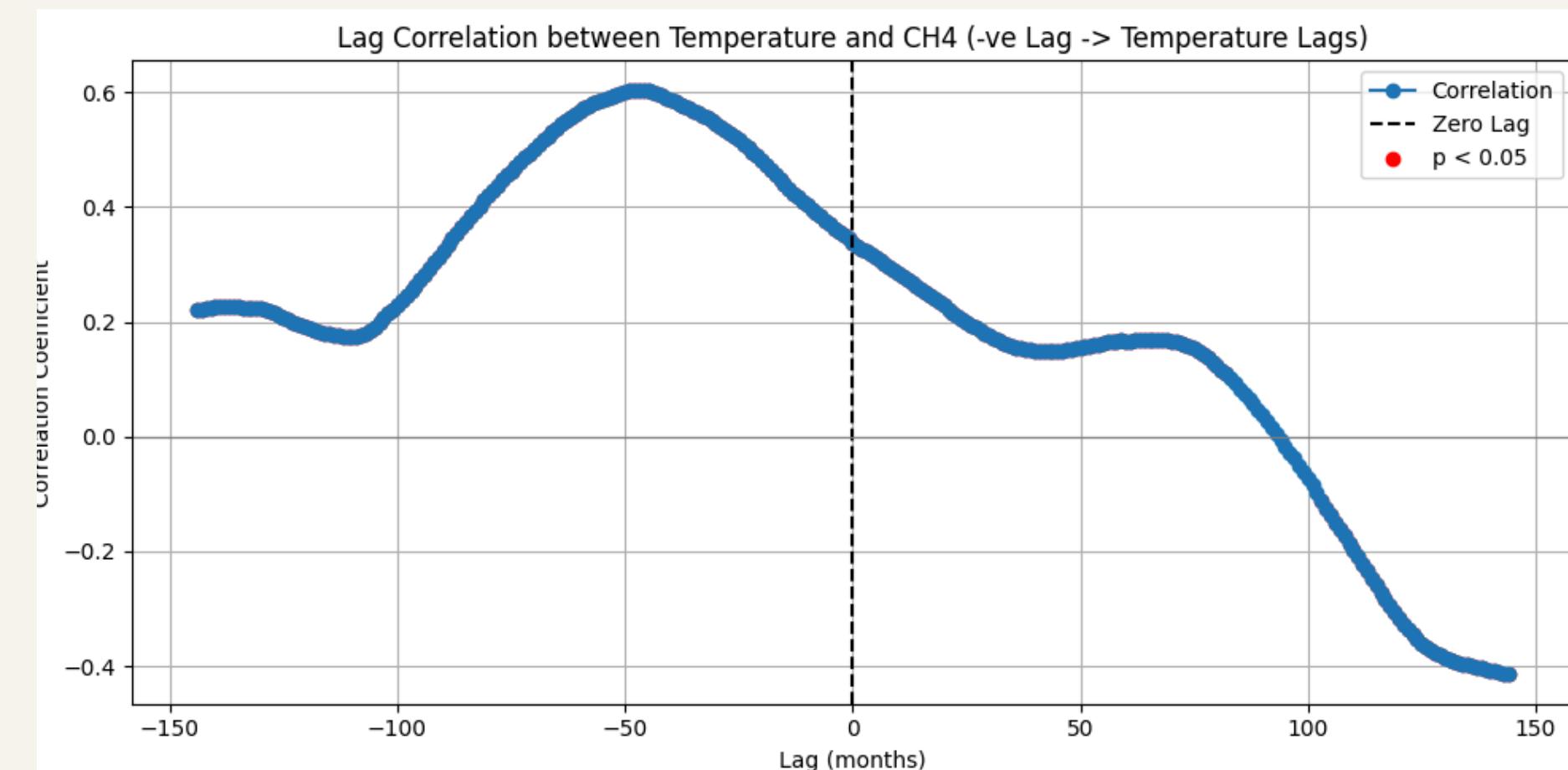
### CO<sub>2</sub> conc. and Temperature Correlation

Peak correlation at lag = 15.0 months ( $r = 0.600$ ,  $p = 1.7843e-43$ )



### Methane conc. and Temperature Correlation

Peak correlation at lag = -47.0 months ( $r = 0.604$ ,  $p = 5.3206e-41$ )

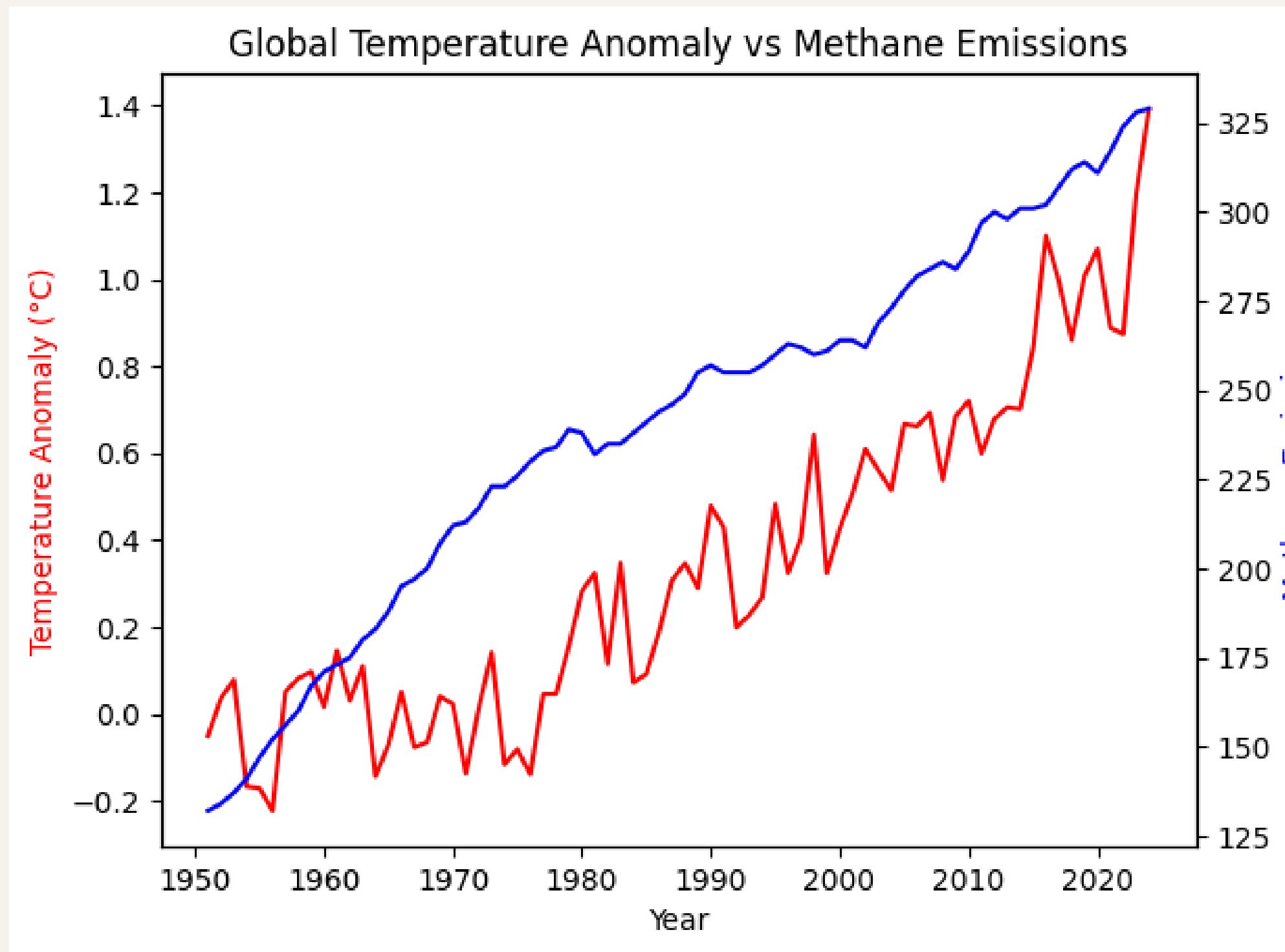


CO<sub>2</sub> conc. significantly ( $p < 0.05$ ) lags the increasing temperature

Methane conc. significantly ( $p < 0.05$ ) lead the increasing temperature

# 1. Cross Correlation

## 1.2 Human Activities based Methane Emissions



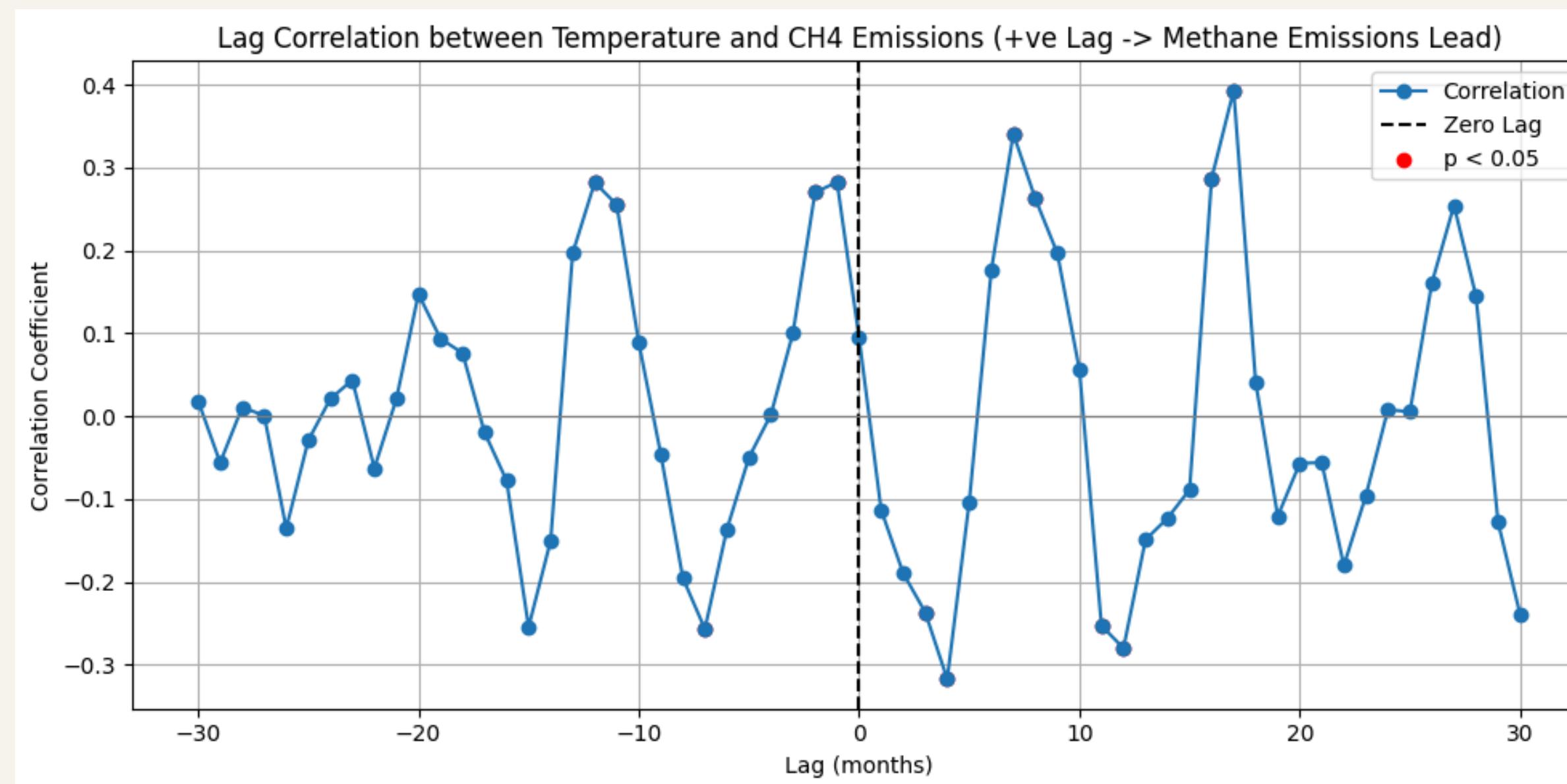
Visually, we can see that  
Methane Emissions lead  
Temperature

# 1. Cross Correlation

## 1.2 Human Activities based Methane Emissions

Methane Emissions significantly ( $p < 0.05$ ) lead the increasing temperature

Peak correlation at lag = 17.0 months ( $r = 0.393$ ,  $p = 2.5063e-03$ )



# 2. Granger Causality Test for CO<sub>2</sub> conc. and Temperature

Granger Causality Test is a statistical test used to determine if one time series is useful for forecasting another

## Our Results

Granger test: Does CO<sub>2</sub> → Temp?

Best lag up to 24 months = 24; p-value = 0.026

Granger test: Does Temp → CO<sub>2</sub>?

Best lag up to 24 months = 20; p-value = 5.45e-11

Monthly data captures carbon cycle feedbacks, so temp predicts short-term CO<sub>2</sub> fluctuations strongly

# 3. Transfer Entropy based Analysis

Transfer Entropy quantifies how much knowing the past of X improves the prediction of Y's future, capturing nonlinear and directional dependencies that correlation or Granger Causality Test might miss

## Thumb Rule

If  $TE(X \rightarrow Y) > TE(Y \rightarrow X)$ ,  
then the information flow from X to Y is greater than from Y to X,  
implying that X has a stronger causal (predictive) influence on Y

## Our Results

Transfer Entropy (Temperature  $\rightarrow$  CO<sub>2</sub>): 0.8498  
Transfer Entropy (CO<sub>2</sub>  $\rightarrow$  Temperature): 0.6058

Transfer Entropy (Methane  $\rightarrow$  Temp): 0.6384594482692192  
Transfer Entropy (Temp  $\rightarrow$  Methane): 0.20624450076430245

# Conclusion

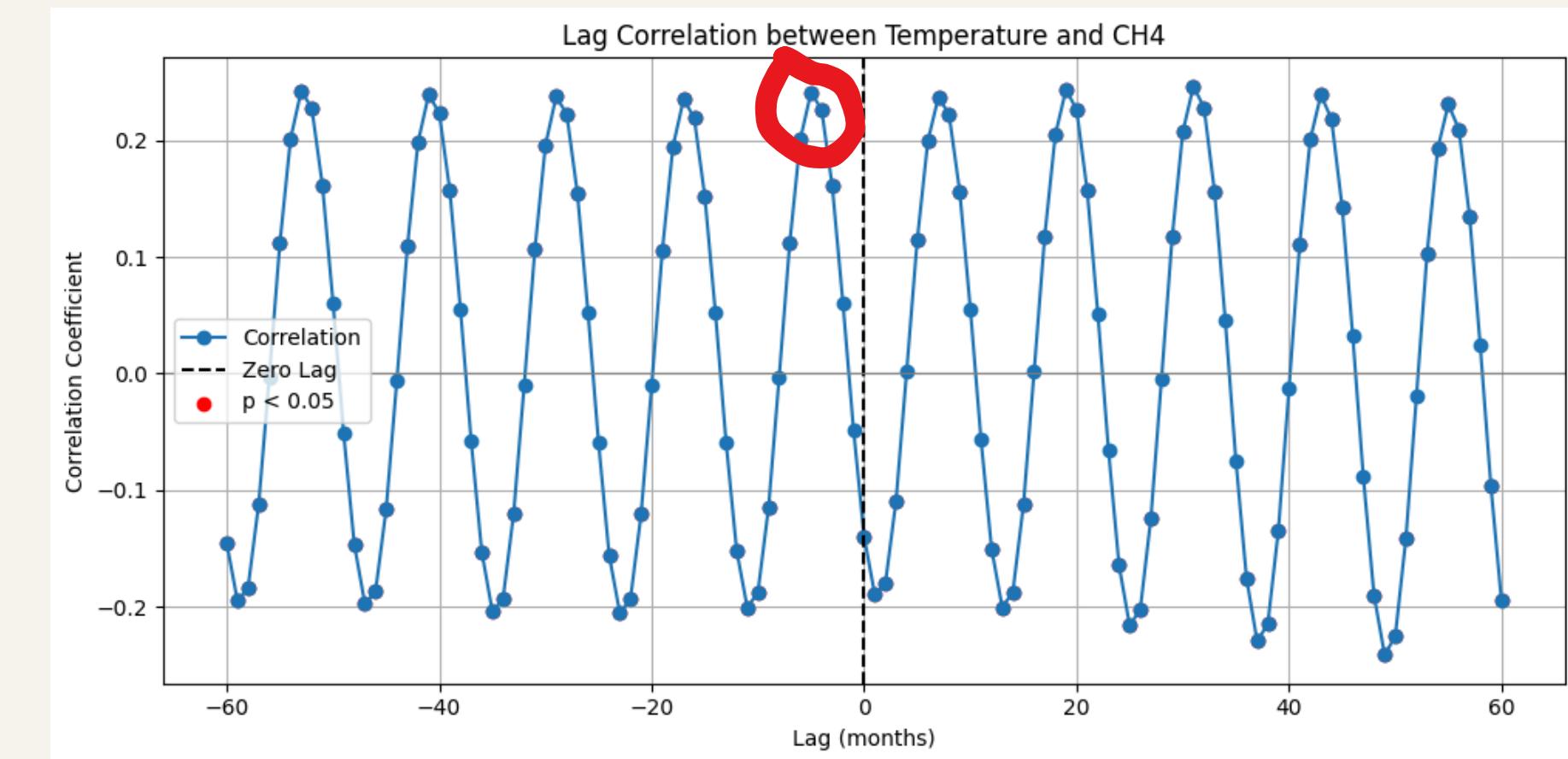
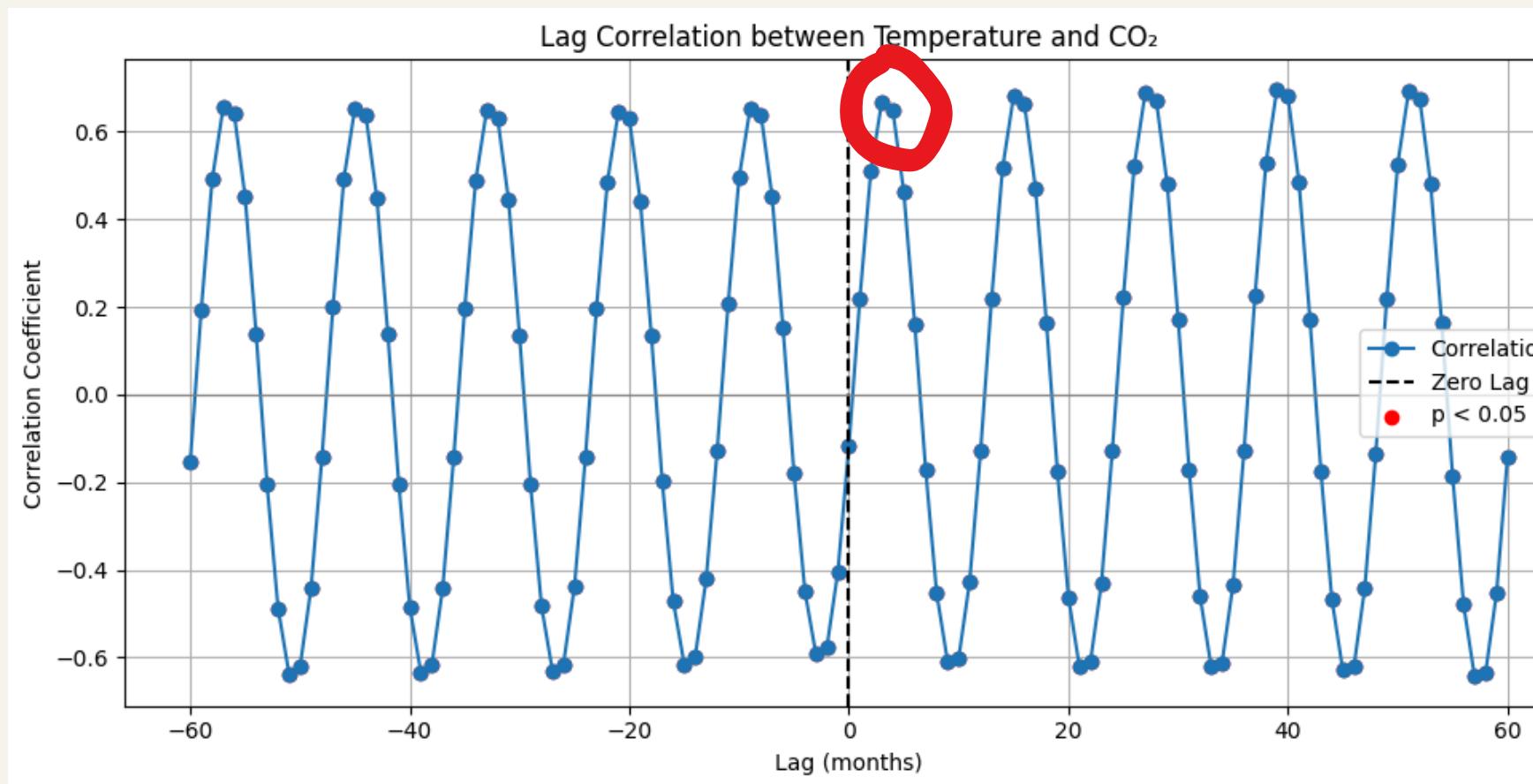
The evidence from our analysis provides a clear direction for further exploration and indicates a tendency towards **not rejecting the null hypothesis**. To be more specific, we cannot directly conclude/believe that the current trend has reversed with respect to the glacial trend. There are a lot of interdependencies involved in current scenario. Clearly, the lag (as clear from our analysis) has come down to months in the current scenario, from 100s of years in ice ages. Hence, **there is surely an impact of human activities in the current trend.**

Nevertheless, a more detailed study incorporating advanced statistical techniques and additional factors - such as **radiative forcing** and **other greenhouse gases** - would allow us to confirm this conclusion with greater confidence.

# Individual Contribution

Roll No.	Name	Contribution
22B1502	Rohit Jangir	Literature Review & Slide Preparation
22B1504	Yash Mehta	Model Formulation and Analysis
22B0452	Manthan Sawsakde	Model Formulation and Analysis
22B2247	Kuldeep Pujari	Literature Review & Slide Preparation
22B2246	Akshar Goyal	Model Formulation and Analysis

# Appendix



Cross Correlation Analysis without Smoothening