Climate Change

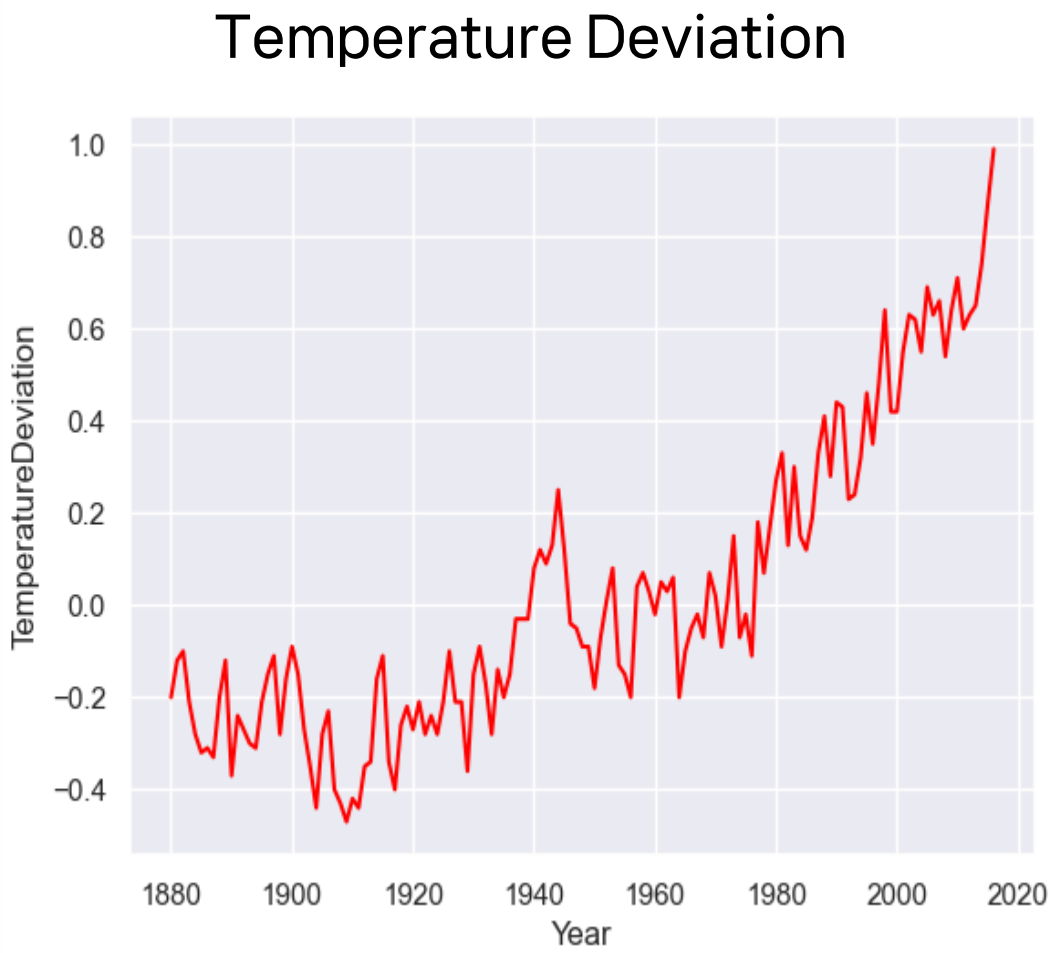
Yuchen Wei (201779381)
Apphia Aidoo (201802406)
Aman Bhattacharyya (201711295)
Sungyeon Lim (201764876)

Contents

01 Introduction

01 Introduction | Climate Change

- Climate change involves long-term shifts in temperatures and weather patterns.
- Can be caused by natural causes and human activities, particularly the burning of fossil fuels such as coal, oil, and gas.
- Burning fossil fuels releases greenhouse gases like carbon dioxide and methane, which act as a blanket around the Earth, trapping heat from the sun and causing temperatures to rise.
- Major sources of greenhouse gas emissions include transportation, energy production, agriculture, and industrial activities.



02 Natural Causes

02 Natural Causes | Natural Gases of Climate Change

Volcanoes:

Volcanoes can influence the climate in substantial ways, primarily through the emission of volcanic gases and ash particle into the atmosphere.

Sulfur Dioxide (SO2):

This is the most significant gas in terms of its impact on the climate. When erupted into the atmosphere, SO2 can form sulfate aerosols which reflect sunlight back into space, leading to a cooling of the Earth's surface.

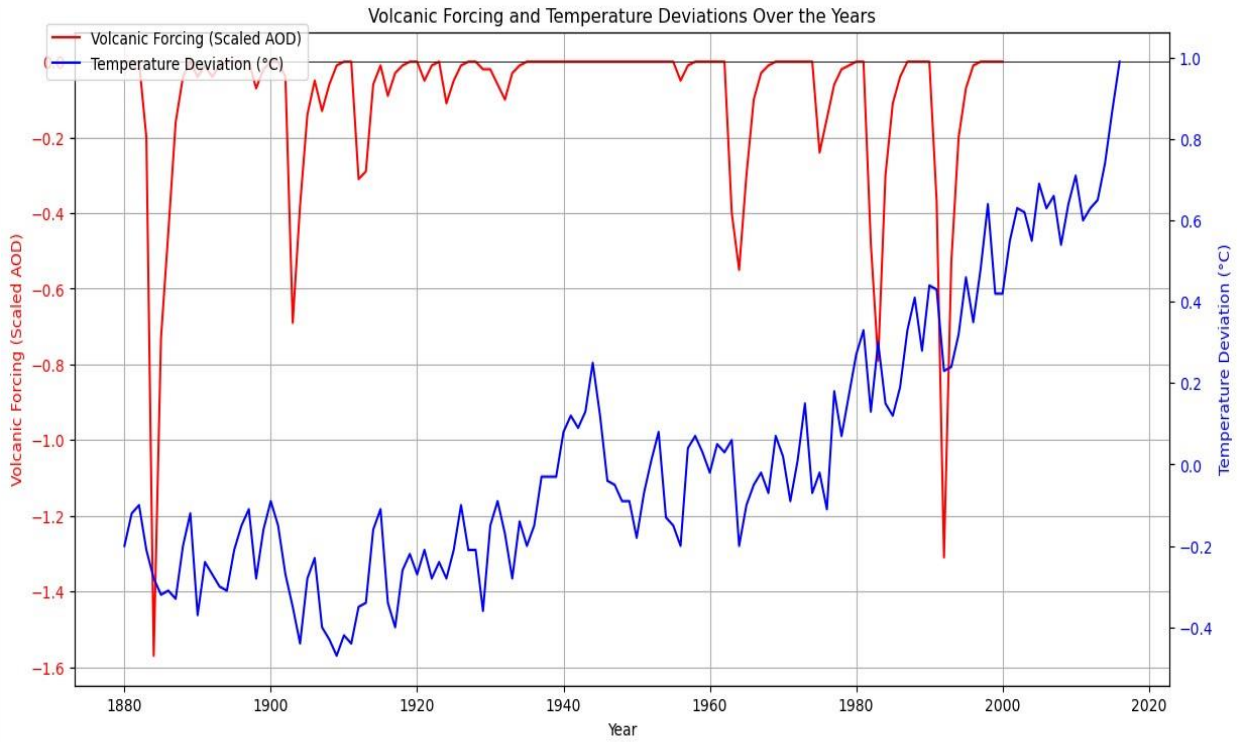
Ash Particles (Aerosol):

Volcanic ash can also block sunlight directly by creating a thick cloud in the atmosphere.

02 Natural Causes | Effect of Volcanic Eruption

Effect of Volcanic Eruption on the Climate

- The red line indicates volcanic activity
- The blue line indicates temperature deviation
- Major volcanic eruptions, corresponds to a noticeable temporary dip in global temperatures

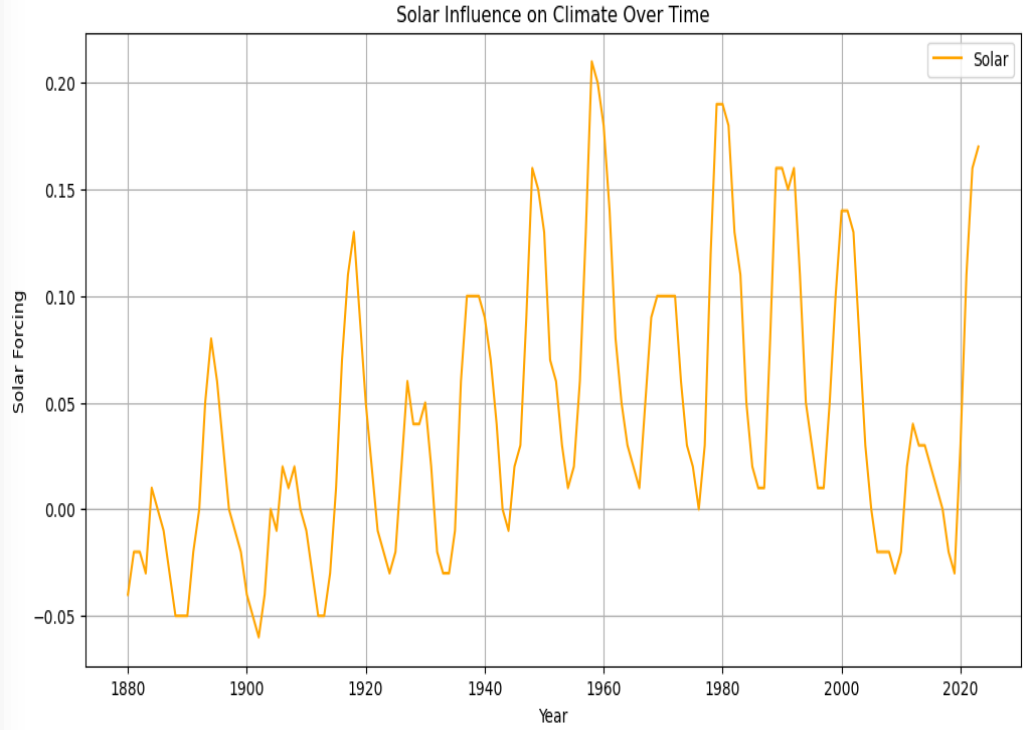


02 Natural Causes | Solar Activity

Sun Cycles and Energy Output: The Sun undergoes various cycles that influence its overall energy output.

- Sunspot Variation: Among these cycles, changes in the number of sunspots are significant.
- Impact on Earth's Climate:
  - Periods with higher sunspot activity are associated with increased solar energy reaching Earth, resulting in warmer temperatures.
  - Conversely, periods with fewer sunspots correlate with less solar energy reaching Earth, leading to cooler temperatures.

Chart: Periods of increased solar forcing (peaks) can contribute to warmer global temperatures, while periods of lower solar forcing can contribute to cooler temperatures.



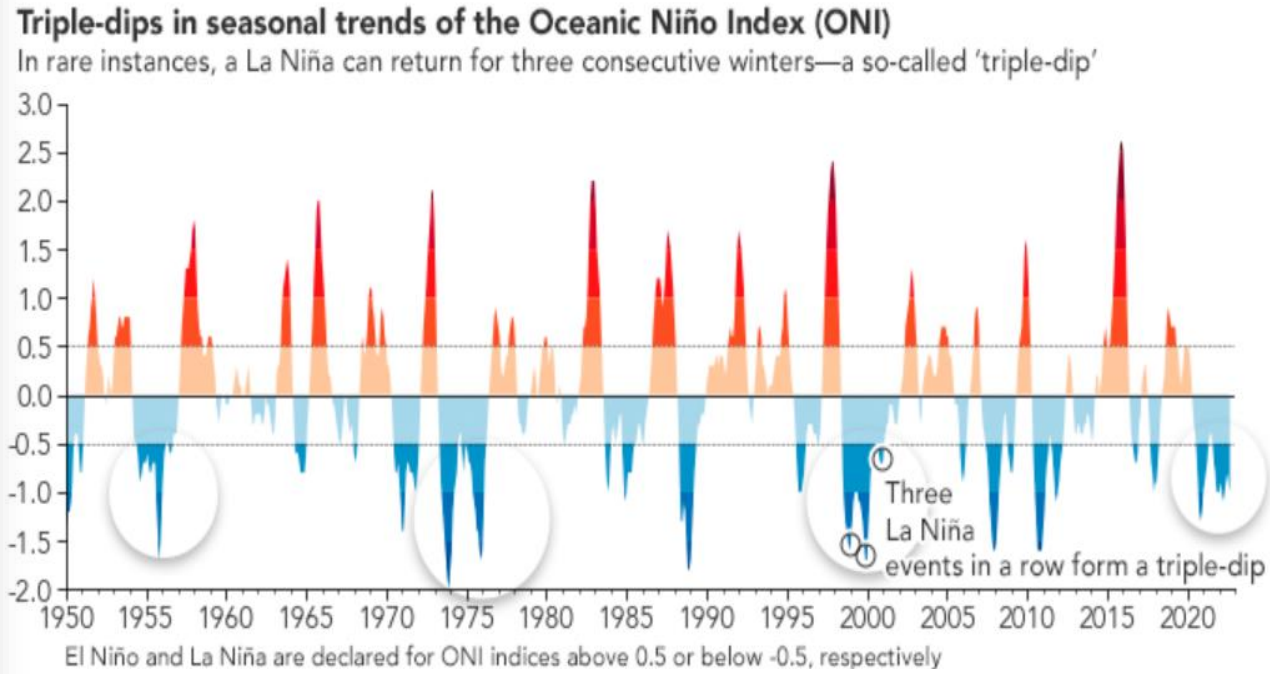
02 Natural Causes | Ocean Currents

Oceans are a major contributor of the climate change, as they store and transport heat and carbon.

Changes in ocean currents can influence climate patterns.

El Nino and La Nina are part of the El Nino-Southern Oscillation (ENSO) cycle, which describes temperature fluctuations between the ocean and atmosphere in the east-central Equatorial Pacific.

- El Nino is warm phase of the ENSO cycle, it leads to warmer than usual sea surface temperatures in the central and eastern Pacific Ocean.
- La Nina, opposite to El Nino, is characterised by usually cold ocean temperatures in the Equatorial Pacific.



02 Natural Causes | Summary

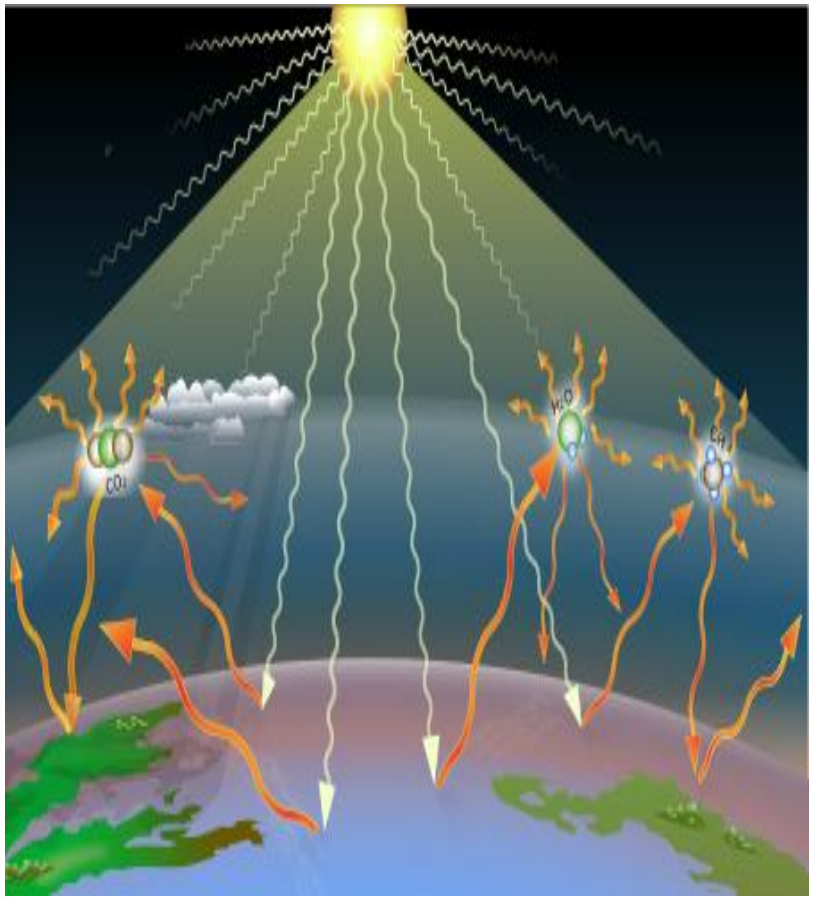
- As we have seen, natural phenomena such as volcanic eruptions, solar activities, El Nino, and La Nina somewhat impact global temperatures.
- There causes are crucial components of the Earth's climate system, leading to fluctuations and shifts in weather patterns across the globe.
- Keynote: While these natural factors do contribute to fluctuations in global temperatures, it is important to recognise that they are not the sole drivers of climate change.

03 Greenhouse Gases

03 Greenhouse Gases | Greenhouse Gas Emissions

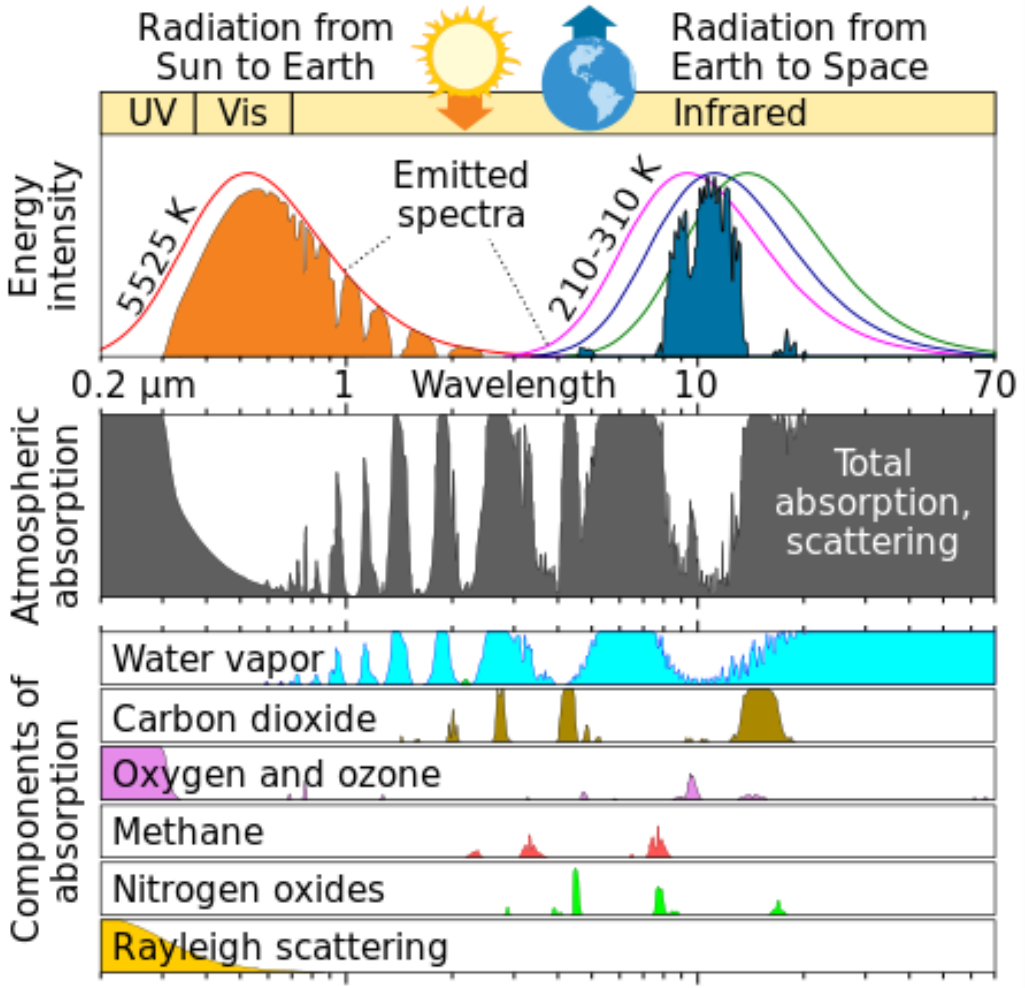
Greenhouse Gas Emissions and its Effect on Climate Change

- Emission of human influenced greenhouse gases is a primary driver of climate change
- Greenhouse gases help regulate the Earth's temperature to make it habitable for various organisms
- Greenhouse gases absorb and emit infrared radiation and they are known as infrared active
- Earth's atmosphere is made up of 78% Nitrogen, 21% Oxygen and 0.9% Argon, they have symmetry in the distribution of their electrical charges and are almost totally unaffected by infrared thermal radiation



03 Greenhouse Gases | Mechanism of Greenhouse Effect

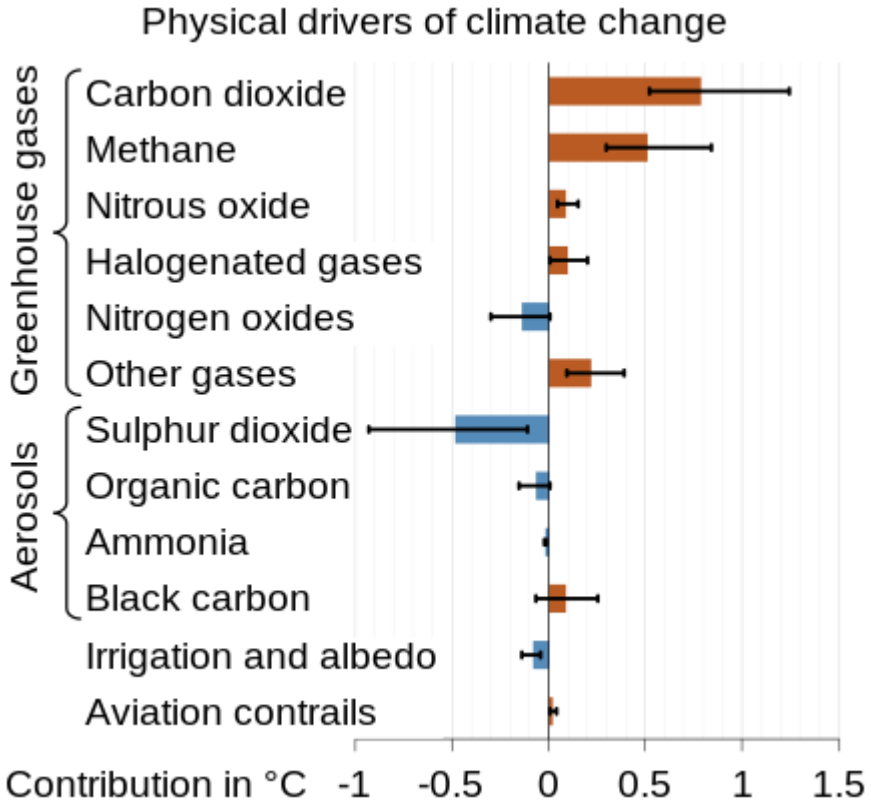
- Both the Earth and the Sun emit electromagnetic radiation
- For the Sun these emissions peak in the visible region whereas for the Earth it peaks at infrared
- In the present atmosphere, water vapour is the most significant of these greenhouse gases, followed by carbon dioxide and various other minor greenhouse gases.
- Greenhouse gases capture 70-85% of the energy in upgoing thermal radiation emitted from the Earth surface.



03 Greenhouse Gases | Effect of Greenhouse Gases

Greenhouse Gases and Effect on Climate Change

- Water vapours cause about 50% of the greenhouse effect, but humans do not directly influence the amount of water vapour in the environment hence it doesn't add to climate change unlike the emission of other greenhouse gases.
- It is observed that carbon dioxide has the most effect on global temperatures out of all greenhouse gases (other than water vapours which isn't compared here as it doesn't contribute to man made climate change)



03 Greenhouse Gases | Effect of Greenhouse Gases

The experiments were carried forward by quantifying the impact of each individual long wave (LW) absorbers which is done by examining the net amount of long-wave radiation absorbed in the atmosphere while holding the climate properties fixed

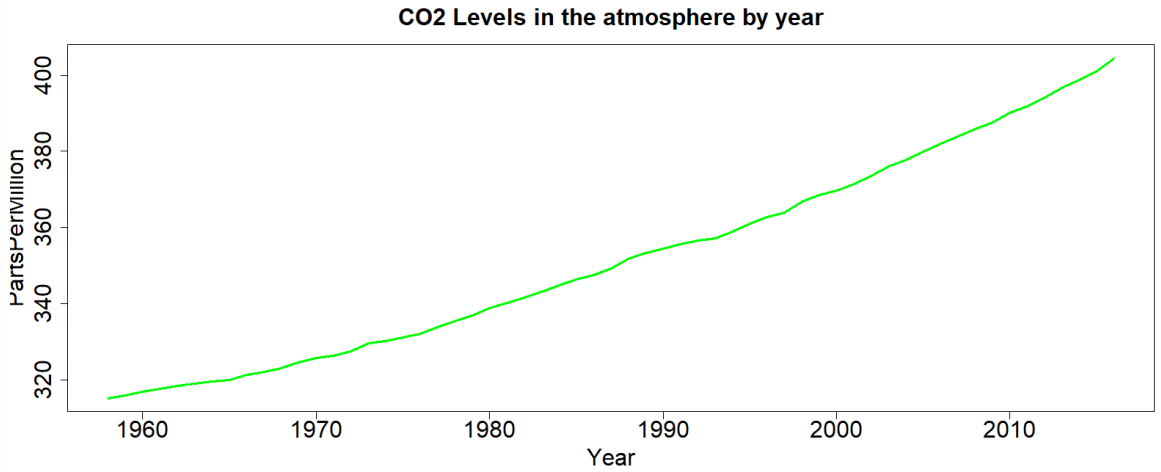
Contributor	K&T (1997)		Schmidt (2010)	
	Clear Sky	With Clouds	Clear Sky	With Clouds
Water vapor	60	41	67	50
Clouds		31		25
CO2	26	18	24	19
Tropospheric ozone (O3)	8			
N2O + CH4	6			
Other		9		7

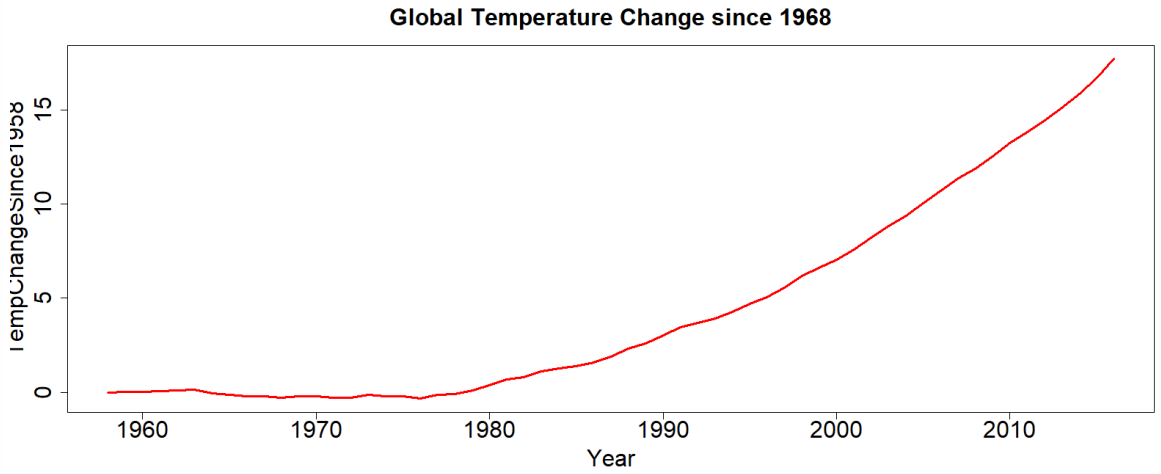
First 2 columns are from :Kiehl, J.T.; Kevin E. Trenberth (1997). "Earth's annual global mean energy budget". Bulletin of the American Meteorological Society.
Last 2 columns are from: Schmidt, G.A.; R. Ruedy; R.L. Miller; A.A. Lacis (2010), "The attribution of the present-day total greenhouse effect" (

03 Greenhouse Gases | Concentration of CO2

Concentration of CO2 and Global Temperature Deviations Analysis

- Emissions of CO2 is the major human influenced factor affecting global climate change
- Datasets used for analysis: IMF data of carbon dioxide level in part per million and global temperature deviation data given for assignment 4
- Similar upward trend, correlation between the variables found to be 0.957





03 Greenhouse Gases | Concentration of CO2

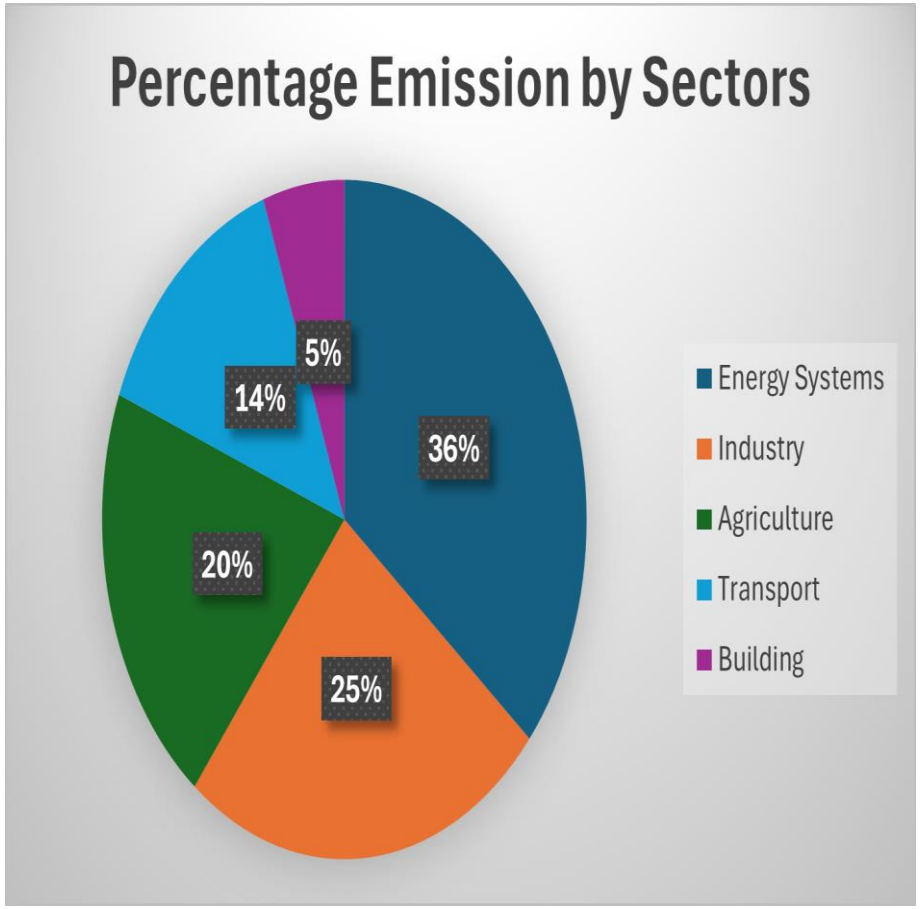
```
Call:
lm(formula = TempChangeSince1958 ~ PartsPerMillion, data = merged_df)

Residuals:
    Min      1Q  Median      3Q     Max
-2.0838 -1.4854 -0.3441  1.3424  2.9517

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     -64.9433     2.7889  -23.29   <2e-16 ***
PartsPerMillion   0.1971     0.0079   24.95   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.592 on 57 degrees of freedom
Multiple R-squared:  0.9161,    Adjusted R-squared:  0.9147
F-statistic: 622.6 on 1 and 57 DF,  p-value: < 2.2e-16
```

- A general linear model used due to high correlation and visible linear relationship between variables
- For increase in 1 PPM of CO2 concentration in the atmosphere it's predicted that the temperature will increase by 0.1971°C in global temperature (there is standard error of 0.008 °C)

03 Greenhouse Gases | Human Activities

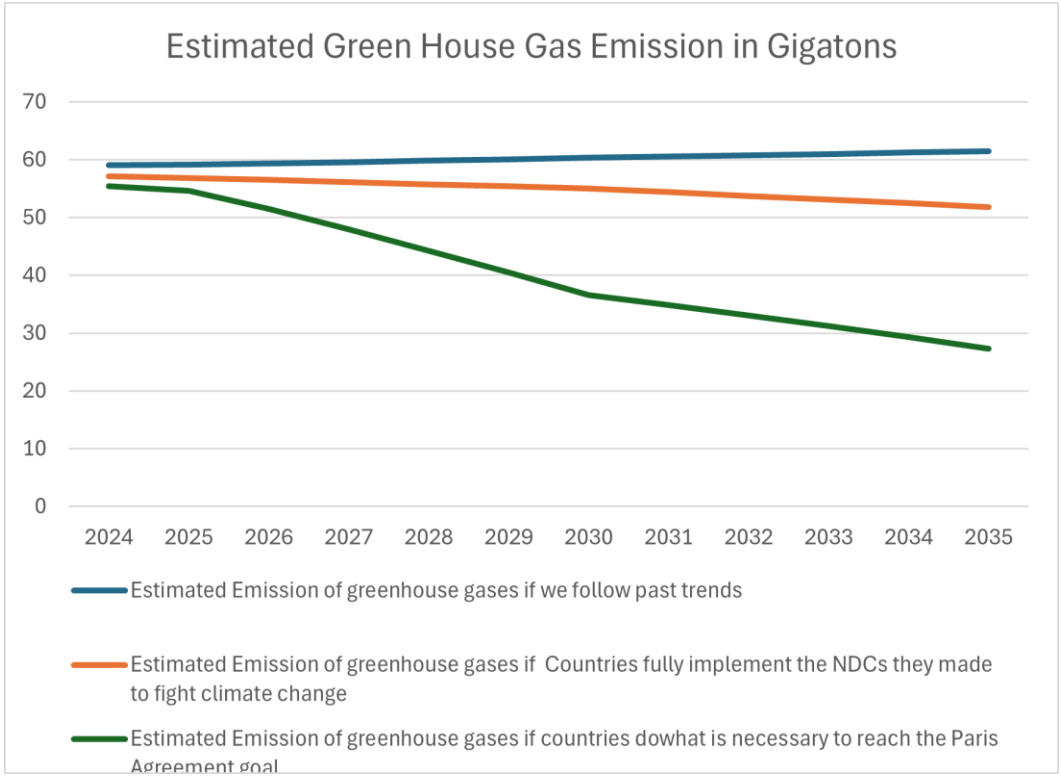
data collected from https://worldemissions.io/

Sector	Sub Sector	Emission (GT)	Total Emission Sector (GT)
Energy Systems	Electricity Production: Coal	10.9	21.3
	Fossil Fuels Production	5	
	Electricity Production: Gas	3.5	
	Other Energy Use/Combustion	0.93	
	Heating	0.53	
	Electricity Production: Oil	0.44	
Industry	Metal	3.6	14.4
	Chemicals	2.7	
	Waste	1.9	
	Cement	1.8	
	Others	4.4	
Agriculture	Land Use Change	5.5	12
	Live Stock	3.7	
	Crops	2.8	
Transport	Cars/Buses/Trucks	6.2	8
	Rail & Others	0.7	
	Ships & International Shipping	0.7	
	Air Travel	0.4	
Building	Heating & Cooking	2.65	3.2
	Cooling	0.55	



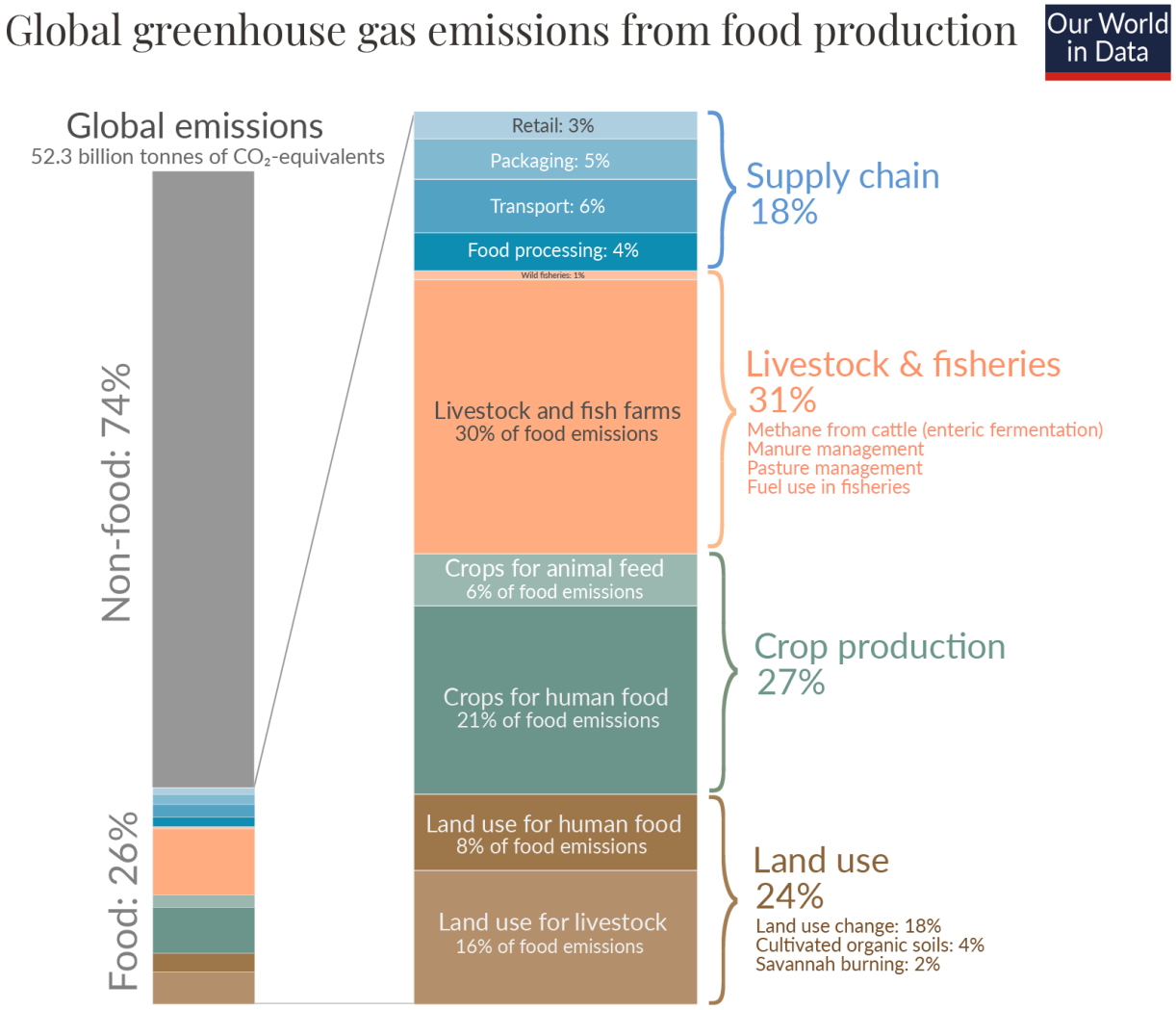
03 Greenhouse Gases | Efforts to Mitigate Climate Change

- Ban of CFCs and other Ozone depleting substances after the formulation of Montreal Protocol in 1987 to curb the usage by half
- In 1990, the Montral Protocol underwent substantial reinforcement, mandating the complete cessation of CFC usage in industrialised nations by 2000 and and in developing nations by 2010
- Presently, the Montral Protocol has been embraced by 197 nations worldwide
- In recent years, 196 countries got tougher to sign the Paris Agreement it is an international treaty on climate change that was adopted in 2015
- To limit the increase in global surface temperature to well below 2 °C and to stay within the 1.5 °C limit, greenhouse emissions must be slashed by approximately 50% by 2030



04 Agricultural Food Production

04 Agricultural Food Production | Background

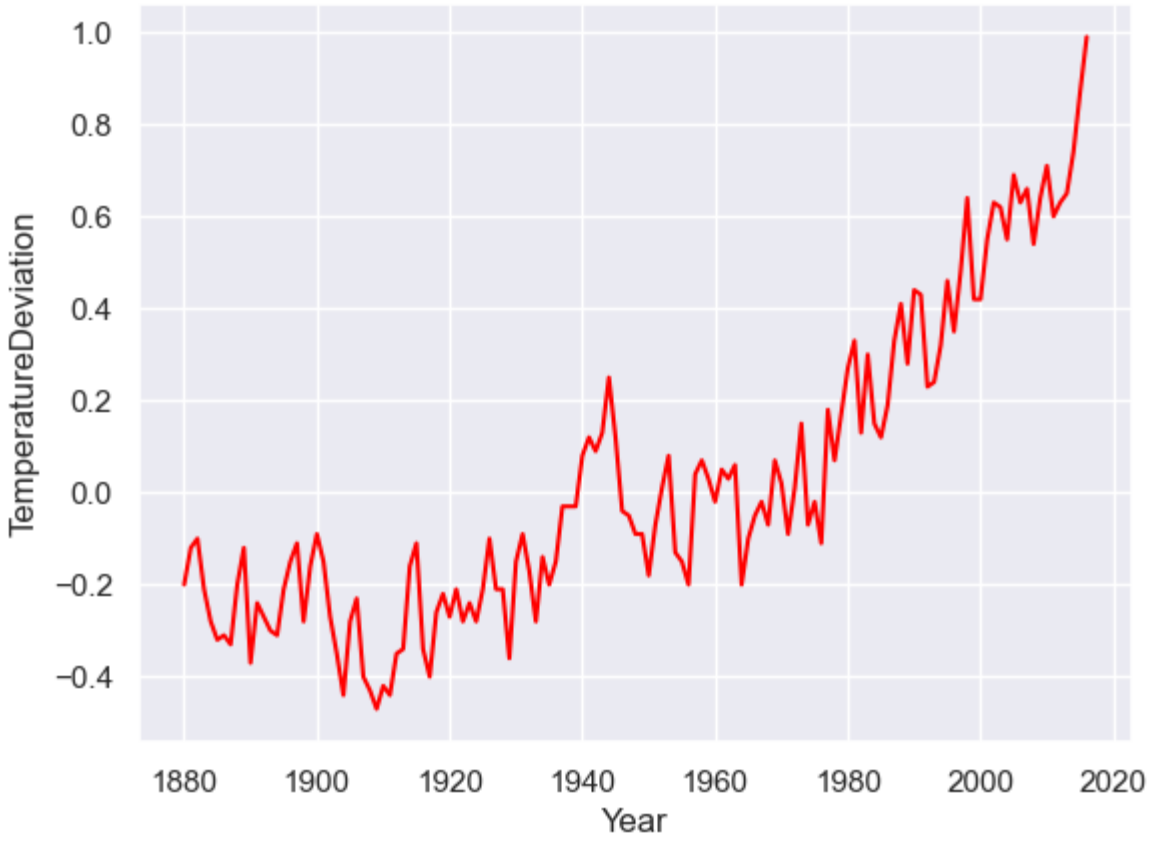


Data source: Joseph Poore & Thomas Nemecek (2018). Reducing food's environmental impacts through producers and consumers. Published in *Science*.

"Food production is responsible for one-quarter of the world's greenhouse gas emissions"

04 Agricultural Food Production | Data

Temperature Deviation Data



Agri-food CO2 Emission Data

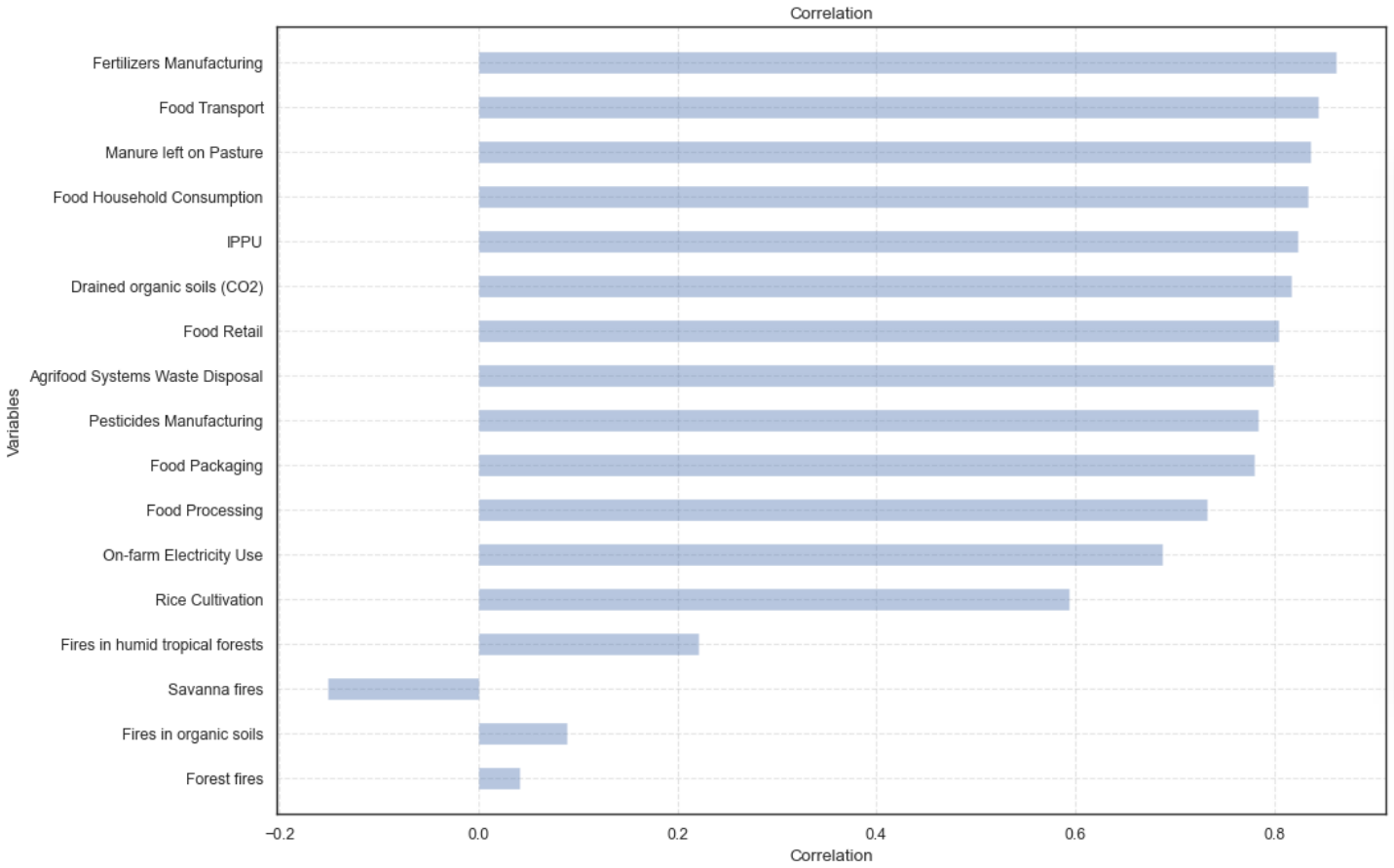
```
agrifood = pd.read_csv('agrifood.csv')
agrifood.head()
```

	Year	Savanna fires	Forest fires	Rice Cultivation	Drained organic soils (CO2)	Pesticides Manufacturing
0	1990	265533.1965	203871.7269	929823.919130	752445.9744	55011.031460
1	1991	265533.1965	203871.7269	930480.142397	752445.9744	54433.936841
2	1992	265533.1965	203871.7267	939513.173286	752445.9743	57481.699902
3	1993	265533.1964	203871.7267	924193.393558	752878.5072	57749.542893
4	1994	265533.1964	203871.7267	927782.202763	752547.1299	62186.034696

18 variables

27 instances (1990-2016)

04 Agricultural Food Production | Correlation Analysis



Fertilizers Manufacturing: 0.8621

Food Transport: 0.8443

Manure left on Pasture: 0.8370

Food Household Consumption: 0.8338

IPPU: 0.8230

- Mostly, positively correlated

Vector Autoregressive (VAR) Model

1. A multivariate time series model used for analysing the dynamic relationships among multiple variables over time

2. It offers a flexible way to capture complicated real-world behaviours

3. An assumption made on stationary data
   Stationary: properties of a time series do not depend on the time

04 Agricultural Food Production | Time Series Analysis

VAR Order Selection (* highlights the minimums)

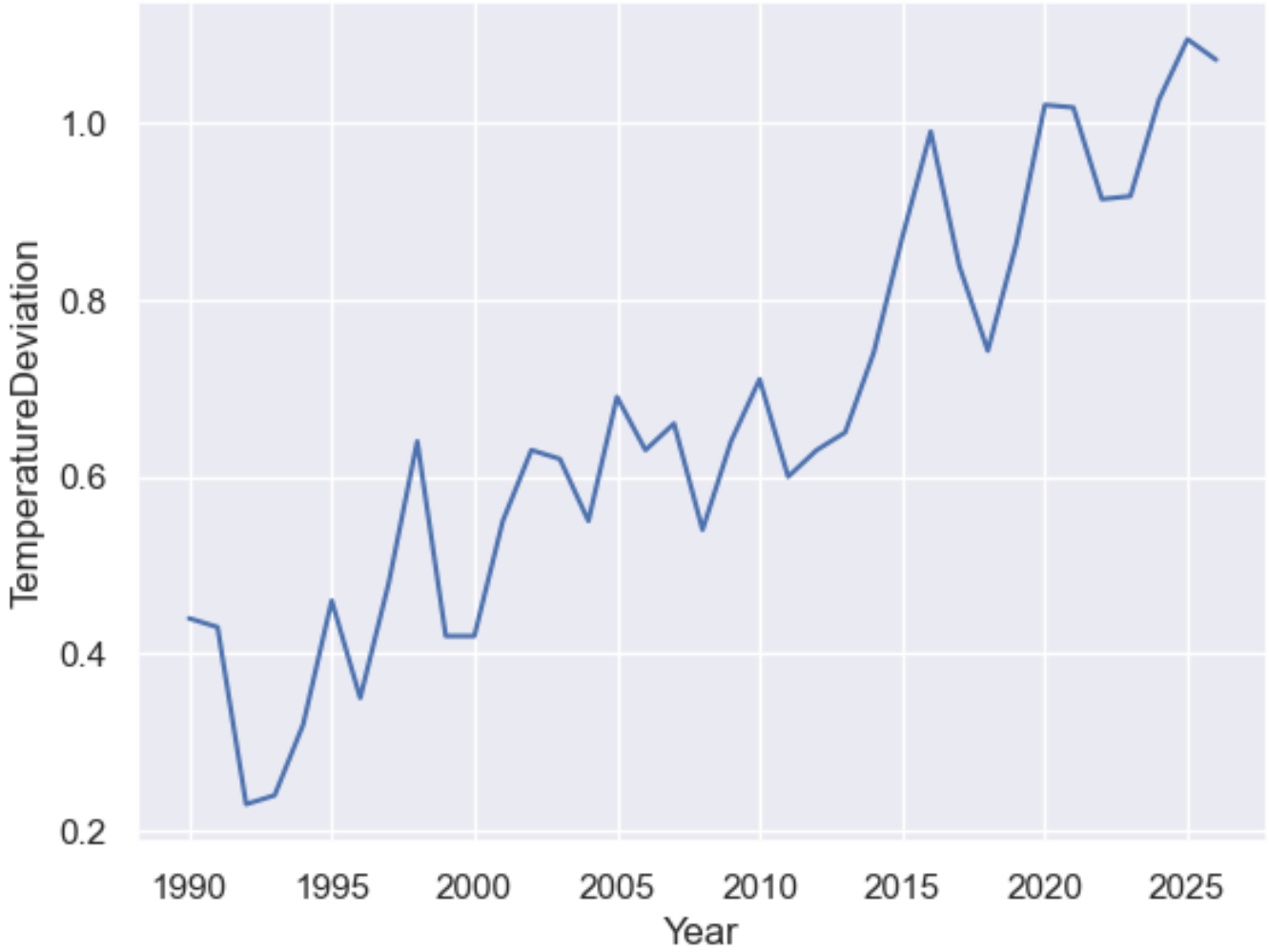
	AIC	BIC	FPE	HQIC
0	-13.97	-13.83*	8.543e-07*	-13.98
1	-13.87	-13.30	9.849e-07	-13.88
2	-14.06	-13.07	9.915e-07	-14.07
3	-14.23*	-12.82	1.506e-06	-14.25*

```
Results for equation TemperatureDeviation
=====================================================
                                        coefficient
-----------------------------------------------------
const                                      0.094591
L1.Agrifood Systems Waste Disposal        -0.443538
L1.IPPU                                    0.100636
L1.TemperatureDeviation                   -0.599433
L2.Agrifood Systems Waste Disposal         0.181634
L2.IPPU                                    0.020895
L2.TemperatureDeviation                   -0.528061
L3.Agrifood Systems Waste Disposal         0.121606
L3.IPPU                                   -0.414678
L3.TemperatureDeviation                   -0.384541
=====================================================
```

$$x_{TD}(t) = 0.095 - 0.44 \times x_{ASWD}(t-1) + 0.10 \times x_{IPPU}(t-1) - 0.60 \times x_{TD}(t-1)$$
$$+0.18 \times x_{ASWD}(t-2) + 0.021 x_{IPPU}(t-2) - 0.53 \times x_{TD}(t-2)$$
$$+0.12 \times x_{ASWD}(t-3) - 0.41 \times x_{IPPU}(t-3) - 0.39 \times x_{TD}(t-3)$$

04 Agricultural Food Production | Time Series Analysis

Forecasting temperature deviation



04 Agricultural Food Production | Summary

Correlation Analysis

The agricultural food production is one of the causes of the climate change

Time Series Analysis

Based on two main CO2 emission factors of agricultural food production process , it is forecasted that the temperature deviation will increase rapidly in the future

Decreasing the amount of CO2 emissions from the agricultural food production process will help to slow down the climate change

05 Extreme Weather

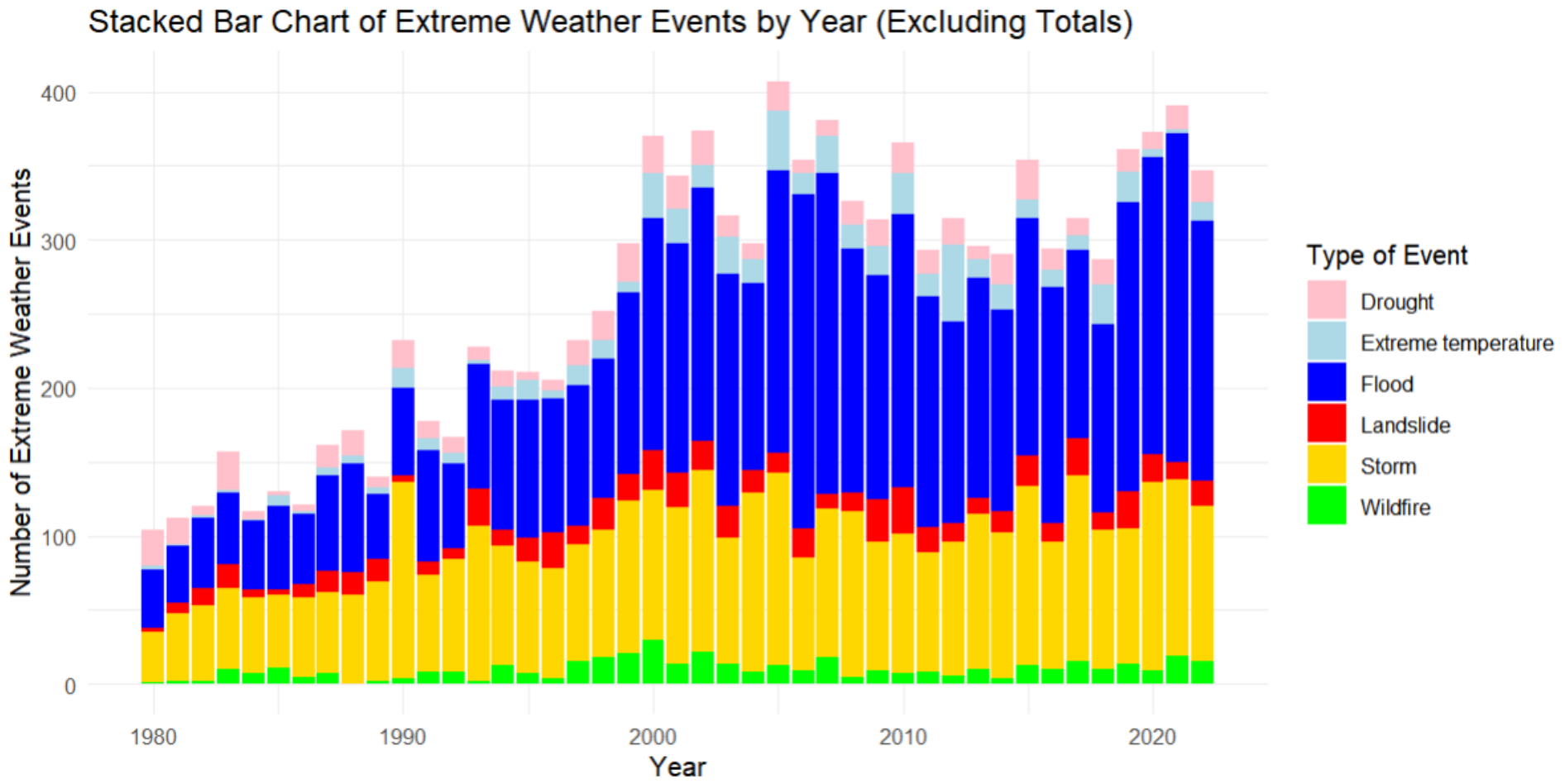
05 Extreme Weather | Overview

Global climate change is caused by a number of factors, one of the most notable consequences is a significant increase in the frequency of extreme weather.

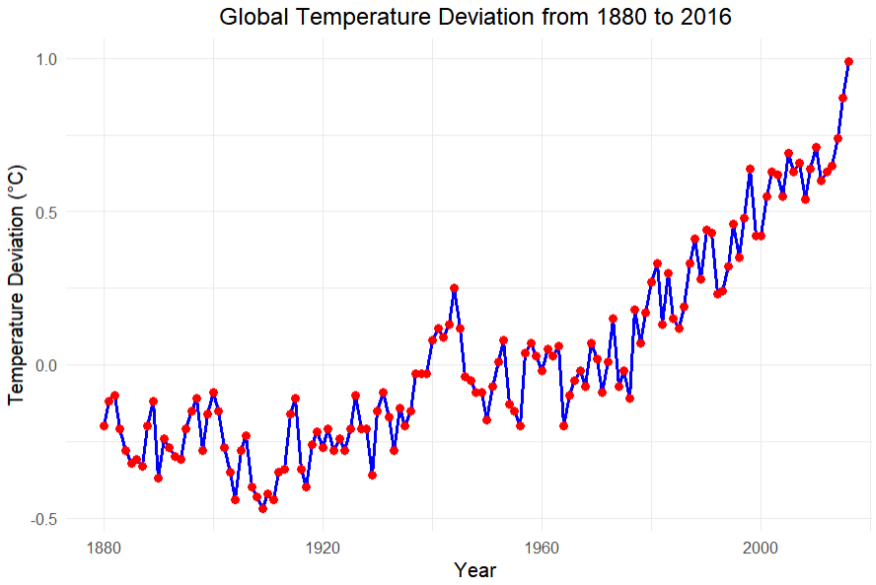
05 Extreme Weather | Basic Visualisation

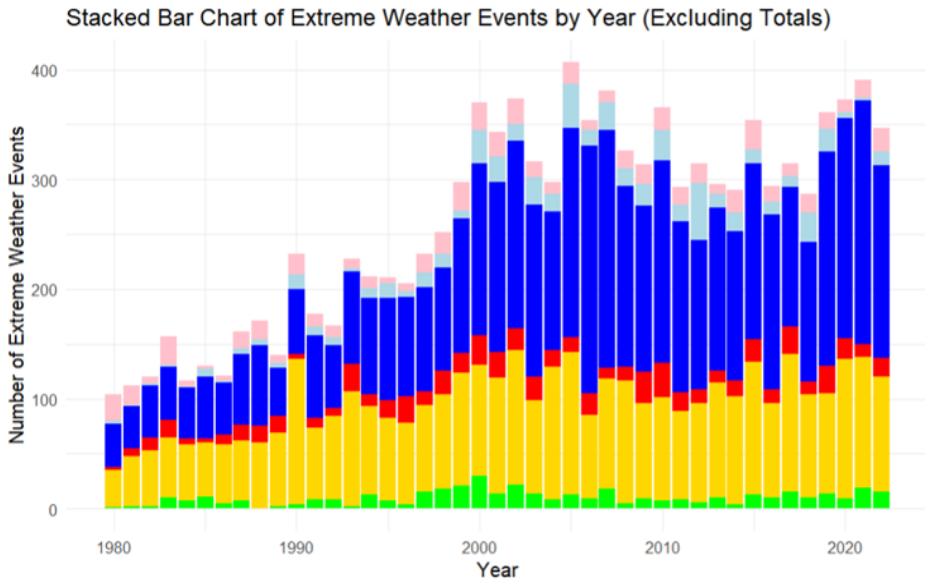
On the IMF website there is data on the frequency of extreme weather over nearly last 40 years.

All of analyses were based on RStudio.



05 Extreme Weather | Correlation Analysis





Same trend

Correlation analysis

```
> print(correlation_result)

        Pearson's product-moment correlation

data:  data_merged$Frequency and data_merged$TemperatureDeviation
t = 7.9954, df = 35, p-value = 2.083e-09
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.6488535 0.8948150
sample estimates:
      cor
0.8038668
```

low p-value:
reject hypothesis
some correlation exists

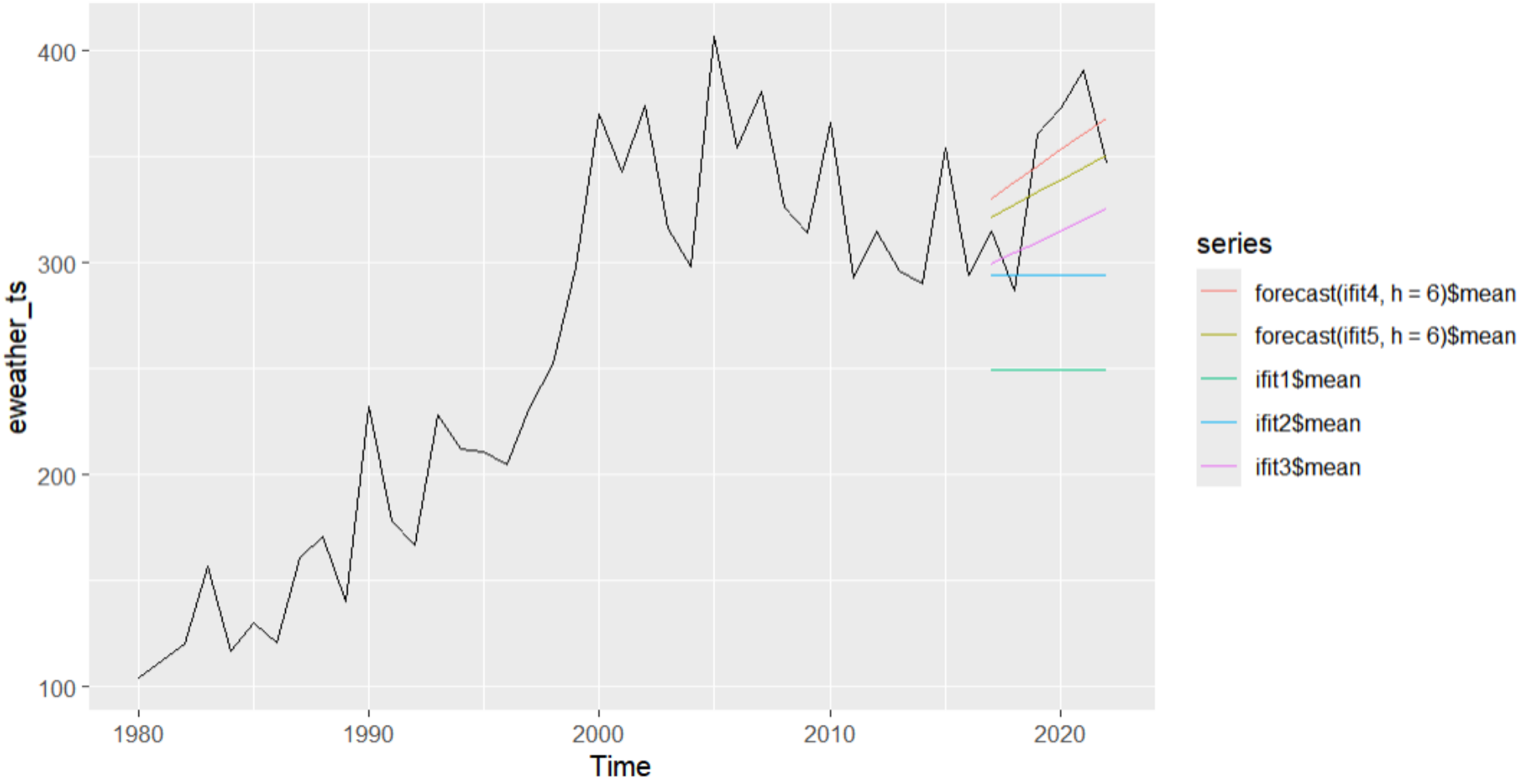
cor = 0.8038668:
there is a strong positive correlation between the two variables

05 Extreme Weather | Modelling

Five different time series forecasting methods :

(1) Averaging (2) Naive (3) Drift (4) Exponential smoothing (5) ARIMA

Finally, use "accuracy" to evaluate.



05 Extreme Weather | Modelling

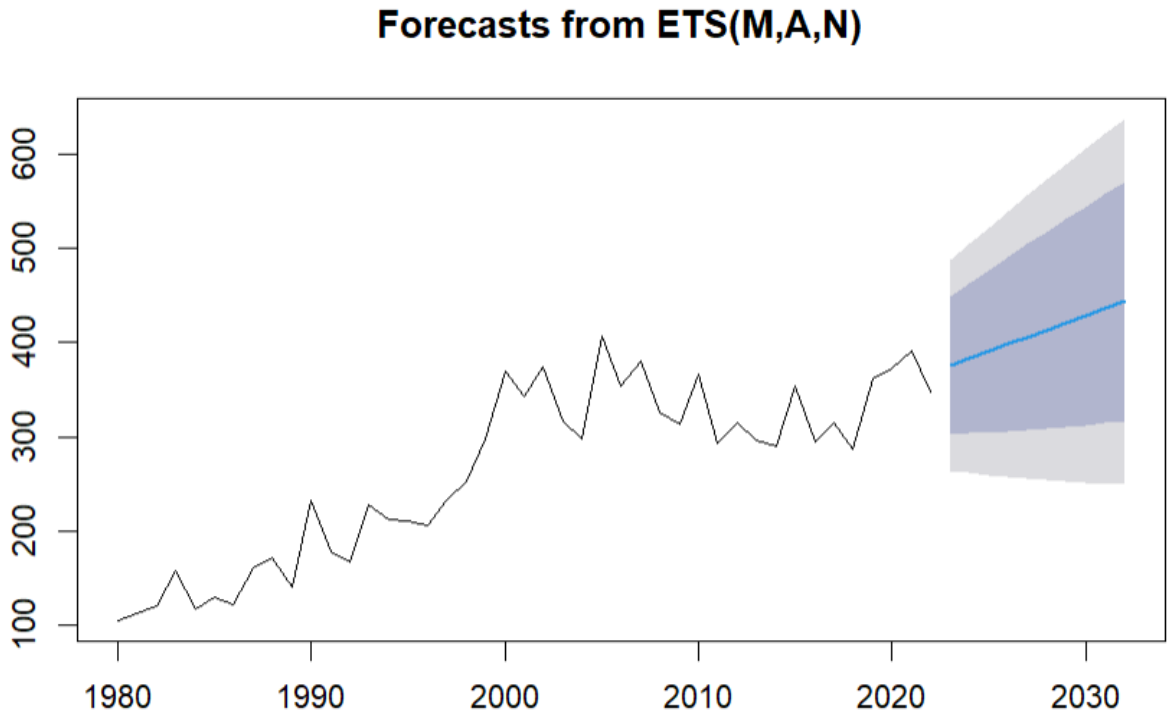
```
> accuracy(ifit1, test1)
                      ME      RMSE      MAE       MPE     MAPE     MASE      ACF1
Training set -6.155455e-15  90.78959 80.89993 -17.81048 41.32693 2.261178 0.8463522
Test set      9.596396e+01 102.20553 95.96396  26.96462 26.96462 2.682223 0.3527967
             Theil's U
Training set        NA
Test set      2.318763
> accuracy(ifit2, test1)
                    ME     RMSE      MAE       MPE     MAPE     MASE       ACF1
Training set  5.277778 44.26185 35.77778  1.305386 14.27108 1.000000 -0.4553323
Test set     51.666667 62.50067 54.00000 14.008131 14.82114 1.509317  0.3527967
             Theil's U
Training set        NA
Test set      1.444846
> accuracy(ifit3, test1)
                      ME     RMSE      MAE       MPE     MAPE     MASE       ACF1
Training set 6.317092e-15 43.94606 35.77778 -1.112888 14.25855 1.000000 -0.4553323
Test set     3.319444e+01 44.65717 39.04630  8.795784 10.83476 1.091356  0.1678298
             Theil's U
Training set        NA
Test set      1.048232
> accuracy(forecast(ifit4), test1)
                    ME     RMSE      MAE       MPE     MAPE     MASE       ACF1
Training set -4.276338 38.33662 31.61479 -3.040578 12.724269 0.8836432 0.04249808
Test set     -3.801901 28.40921 25.53800 -1.941734  7.690618 0.7137951 0.06279851
             Theil's U
Training set        NA
Test set     0.6787064
> accuracy(forecast(ifit5), test1)
                    ME     RMSE     MAE       MPE      MAPE      MASE       ACF1
Training set 0.1256925 37.81524 30.7579 -0.893327 12.168092 0.8596929 -0.07405552
Test set     9.4590446 30.92593 26.4312  1.872444  7.642277 0.7387604  0.14491986
             Theil's U
Training set        NA
Test set     0.7434717
```

With low "MAPE" and "MASE " on both training set and test set, and the lowest Theil's U value, **ifit4** (Exponential smoothing) is the best model.

05 Extreme Weather | Prediction

Select ifit4 model: exponential smoothing.

The forecast will base on available historical data from 1980 to 2022, predict the trend of extreme weather from 2023 to 2032.




```
> print(forecast_ifit4)
     Point Forecast    Lo 80    Hi 80    Lo 95    Hi 95
2023       375.7332 302.7418 448.7246 264.1025 487.3639
2024       383.2785 303.4906 463.0664 261.2535 505.3036
2025       390.8238 304.5371 477.1106 258.8596 522.7880
2026       398.3691 305.8141 490.9241 256.8185 539.9198
2027       405.9144 307.2737 504.5552 255.0564 556.7725
2028       413.4597 308.8799 518.0396 253.5187 573.4008
2029       421.0050 310.6055 531.4046 252.1635 589.8466
2030       428.5503 312.4289 544.6717 250.9580 606.1427
2031       436.0956 314.3330 557.8582 249.8758 622.3155
2032       443.6409 316.3038 570.9780 248.8957 638.3862
```

In 2023, the forecast begins with a total frequency 375, already higher than 347 in 2022.

From about 383 in 2024 to 444 in 2032, the frequency of extreme weather will continue to increase. There is a trend of increasing extreme weather year on year.

05 Extreme Weather | Summary

Conclusion:

According to the data analysis of extreme weather, there is an increasing trend from the stacked bar chart, especially the flood. By correlation analysis, the increase in the frequency of extreme weather is closely related to the temperature deviation. By using the exponential smoothing method to predict the frequency of extreme weather, it can be found it will continue to increase.

Future:

Because there is a strong link between extreme weather and global climate change, and according the prediction of future, it is imperative to take some practical measures to face this challenge:

1) Strengthen international community cooperation.
2) Governments should establish and improve the emergency management system to deal with extreme weather.
3) Strengthening public education and raise the awareness of the seriousness of climate change.

06 Conclusion

06 Conclusion

- Natural causes play a crucial role in shaping global climate patterns, with three main natural influences: volcanic eruptions, solar variability, and El Nino and La Nino
- The emission of human-influenced greenhouse gases is the primary factor causing climate change
- The CO2 emissions from agricultural food production have a significant impact on the climate change
- One of the most notable consequences of climate change is a significant increase in the frequency of extreme weather
- Based on various data analyses, it can be concluded that the climate is significantly changing, and the causes and effects of climate change have been discovered

Thank you for listening