Climate Change

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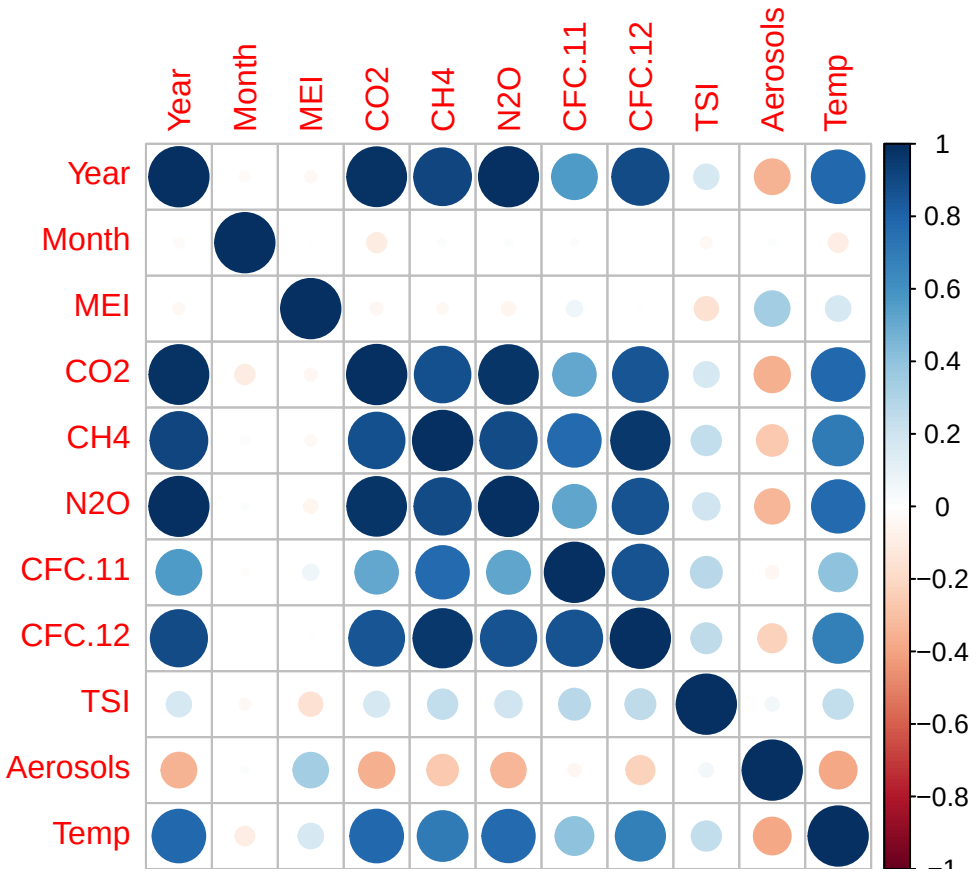
Average global temperature has been rising over the last century. The consequences of this continuous rise in global temperature include rising sea levels and an increased frequency of extreme weather events. In this report I will use linear regression models to study the relationship between average global temperature and several other factors.

We start by building a linear model with all viable predictors.

```
Call:
lm(formula = Temp ~ MEI + CO2 + CH4 + N2O + CFC.11 + CFC.12 +
    TSI + Aerosols, data = cc_train)

Residuals:
     Min       1Q   Median       3Q      Max
-0.25888 -0.05913 -0.00082  0.05649  0.32433

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.246e+02  1.989e+01  -6.265 1.43e-09 ***
MEI          6.421e-02  6.470e-03   9.923  < 2e-16 ***
CO2          6.457e-03  2.285e-03   2.826  0.00505 **
CH4          1.240e-04  5.158e-04   0.240  0.81015
N2O         -1.653e-02  8.565e-03  -1.930  0.05467 .
CFC.11      -6.631e-03  1.626e-03  -4.078 5.96e-05 ***
CFC.12       3.808e-03  1.014e-03   3.757  0.00021 ***
TSI          9.314e-02  1.475e-02   6.313 1.10e-09 ***
Aerosols    -1.538e+00  2.133e-01  -7.210 5.41e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.09171 on 275 degrees of freedom
Multiple R-squared:  0.7509,    Adjusted R-squared:  0.7436
F-statistic: 103.6 on 8 and 275 DF,  p-value: < 2.2e-16
```

This seems to be a fairly good model with many significant predictors and a fairly high r-squared. However, we notice something strange. N2O and CFC-11 variables are negative, indicating that increasing atmospheric concentrations of either of these two compounds is associated with lower global temperatures.However, we know that that nitrous oxide and CFC-11 are greenhouse gases: gases that are able to trap heat from the sun and contribute to the heating of the Earth.

Because all of the gas concentrations reflect human development, it is likely that there is multicolinearity in our data set. Let's check for this



As predicted, we can see some high correlations. N2O, CFC-11, CFC-12, and CH4 are high correlated. Let's create a model without 3 of these 4 correlated variables.

```
Call:
lm(formula = Temp ~ MEI + N2O + TSI + Aerosols, data = cc_train)

Residuals:
     Min       1Q   Median       3Q      Max
-0.27916 -0.05975 -0.00595  0.05672  0.34195

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.162e+02  2.022e+01  -5.747 2.37e-08 ***
MEI          6.419e-02  6.652e-03   9.649  < 2e-16 ***
N2O          2.532e-02  1.311e-03  19.307  < 2e-16 ***
TSI          7.949e-02  1.487e-02   5.344 1.89e-07 ***
Aerosols    -1.702e+00  2.180e-01  -7.806 1.19e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.09547 on 279 degrees of freedom
Multiple R-squared:  0.7261,    Adjusted R-squared:  0.7222
F-statistic: 184.9 on 4 and 279 DF,  p-value: < 2.2e-16
```

Interestingly, getting rid of CH4, CFC-11 and CFC-12 has increased the N2O coeeficient from 0.016 to 0.024. However it has reduced theadjusted r-squared value significantly.

Let us now look at the model which minimises the AIC. AIC can be informally thought of as the quality of the model with a penalty for the number of variables in the model.

```
Start:  AIC=-1348.16
Temp ~ MEI + CO2 + CH4 + N2O + CFC.11 + CFC.12 + TSI + Aerosols

           Df Sum of Sq    RSS     AIC
- CH4       1   0.00049 2.3135 -1350.1
<none>                 2.3130 -1348.2
- N2O       1   0.03132 2.3443 -1346.3
- CO2       1   0.06719 2.3802 -1342.0
- CFC.12    1   0.11874 2.4318 -1335.9
- CFC.11    1   0.13986 2.4529 -1333.5
- TSI       1   0.33516 2.6482 -1311.7
- Aerosols  1   0.43727 2.7503 -1301.0
- MEI       1   0.82823 3.1412 -1263.2

Step:  AIC=-1350.1
Temp ~ MEI + CO2 + N2O + CFC.11 + CFC.12 + TSI + Aerosols

           Df Sum of Sq    RSS     AIC
<none>                 2.3135 -1350.1
- N2O       1   0.03133 2.3448 -1348.3
- CO2       1   0.06672 2.3802 -1344.0
- CFC.12    1   0.13023 2.4437 -1336.5
- CFC.11    1   0.13938 2.4529 -1335.5
- TSI       1   0.33500 2.6485 -1313.7
- Aerosols  1   0.43987 2.7534 -1302.7
- MEI       1   0.83118 3.1447 -1264.9


Call:
lm(formula = Temp ~ MEI + CO2 + N2O + CFC.11 + CFC.12 + TSI +
    Aerosols, data = cc_train)

Residuals:
     Min       1Q   Median       3Q      Max
-0.25770 -0.05994 -0.00104  0.05588  0.32203

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.245e+02  1.985e+01  -6.273 1.37e-09 ***
MEI          6.407e-02  6.434e-03   9.958  < 2e-16 ***
CO2          6.402e-03  2.269e-03   2.821 0.005129 **
N2O         -1.602e-02  8.287e-03  -1.933 0.054234 .
CFC.11      -6.609e-03  1.621e-03  -4.078 5.95e-05 ***
CFC.12       3.868e-03  9.812e-04   3.942 0.000103 ***
TSI          9.312e-02  1.473e-02   6.322 1.04e-09 ***
Aerosols    -1.540e+00  2.126e-01  -7.244 4.36e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.09155 on 276 degrees of freedom
Multiple R-squared:  0.7508,    Adjusted R-squared:  0.7445
F-statistic: 118.8 on 7 and 276 DF,  p-value: < 2.2e-16
```

The model with the lowest AIC omits CH4. Let us compare how our last two models do on test data

```
The test r-squared for the AIC minimizing model is 0.63
```

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The test r-squared for the 4 variable model is 0.5
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On the basis of current evidence, the AIC minimizing model seems to be most appropriate

Data Appendix:

Year: the observation year.

Month: the observation month.

Temp: the difference in degrees Celsius between the average global temperature in that period and a reference value. This data comes from the Climatic Research Unit at the University of East Anglia.

CO2, N2O, CH4, CFC.11, CFC.12: atmospheric concentrations of carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), trichlorofluoromethane (CCl3F; commonly referred to as CFC-11) and dichlorodifluoromethane (CCl2F2; commonly referred to as CFC-12), respectively. This data comes from the ESRL/NOAA Global Monitoring Division.

CO2, N2O and CH4 are expressed in ppmv (parts per million by volume – i.e., 397 ppmv of CO2 means that CO2 constitutes 397 millionths of the total volume of the atmosphere)

CFC.11 and CFC.12 are expressed in ppbv (parts per billion by volume).

Aerosols: the mean stratospheric aerosol optical depth at 550 nm. This variable is linked to volcanoes, as volcanic eruptions result in new particles being added to the atmosphere, which affect how much of the sun's energy is reflected back into space. This data is from the Godard Institute for Space Studies at NASA.

TSI: the total solar irradiance (TSI) in W/m2 (the rate at which the sun's energy is deposited per unit area). Due to sunspots and other solar phenomena, the amount of energy that is given off by the sun varies substantially with time. This data is from the SOLARIS-HEPPA project website.

MEI: multivariate El Nino Southern Oscillation index (MEI), a measure of the strength of the El Nino/La Nina-Southern Oscillation (a weather effect in the Pacific Ocean that affects global temperatures). This data comes from the ESRL/NOAA Physical Sciences Division.