Atmospheric Carbon Dioxide
09/28/2025

The main contributor to the global climate change is the so-called global warming caused by the increase in atmospheric greenhouse gases, primarily the carbon dioxide. Carbon dioxide has an absorption band in the infrared wavelength that prevents the thermal emission of the globe (cooling) thus results in an increase in the global temperature. Therefore, the ability of forecasting atmospheric carbon dioxide concentration is an important subject in the climate science.

Figure 1 shows the monthly mean carbon dioxide concentration (parts per million, mole fraction) measured at the NOAA Mauna Loa Observatory, Hawaii (3400 m above the sea level). The measurements were first started by the Scripps Institution of Oceanography, UCSD, in 1958 also at Mauna Loa ("https://gml.noaa.gov/ccgg/about/co2_measurements.html"). This article attempts to forecast the atmospheric carbon diode concentration in the next decade using various available forecasting models.

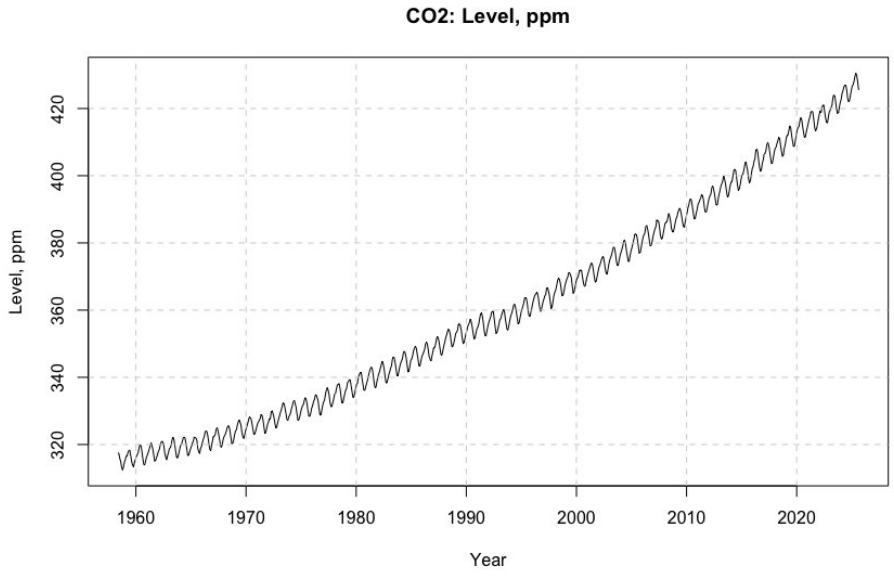

Figure 1, Carbon Dioxide Concentration Measurements at NOAA Mauna Loa Observatory, HI.

ARIMA Model

The carbon dioxide concentration shows a clear upward trend with annual (12 months) seasonality. The concentration variation over the year is attributed to the seasonal vegetation change with valleys situated during the summer on the northern hemisphere.

Figure 2 shows an ARIMA(0,1,0)(0,1,0)[12] model using the data from the beginning of 2022 to the end of 2024. The forecast concentrations in 2024 (blue line with the prediction intervals) are plotted against 2024 actuals (red line). The non-seasonal component, the first (0,1,0), is a random walk with no AR and MA terms, suggesting that the value at time t is a random step away from the value at the previous time. The seasonal component, the second (0,1,0), is also a random walk, with the value at time t being a random step away from the value from last year. The model has an accuracy of MAPE = 0.08%.

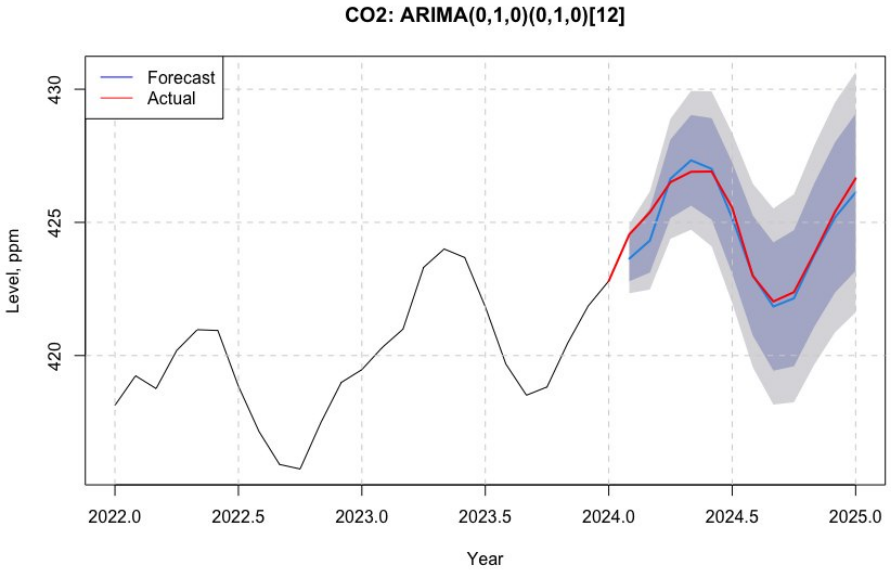

Figure 2, ARIMA Model of Atmospheric Carbon Dioxide Concentration.

The model shows that that the atmospheric carbon dioxide with 95% prediction interval will be between 428 and 433 ppm in January 2026. The average concentration increases 2 ppm from a year ago.

Holt-Winters Model

Figures 3 shows the seasonal Holt-Winters model using the same data from the beginning of 2022 to the end of 2024. The forecast concentrations in 2024 (blue line with the prediction intervals) are plotted against 2024 actuals (red line). The model has an accuracy of MAPE = 0.11 %.

The model shows that that the atmospheric carbon dioxide with 95% prediction interval will be between 428 and 432 ppm in January 2026. The average concentration increases 2 ppm from a year ago. These results are very similar to those of the ARIMA model.

Seasonality Removed

Figure 4 shows the average monthly atmospheric carbon dioxide concentration with seasonality removed. The red line is a linear regression model of the following:

$$CO_2 = 369.3 + 1.850(year - 2000) + 0.01449(year - 2000)^2 + 4.472 \times 10^{-5}(year - 2000)^3$$

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	3.693e+02	4.387e-02	8417.521	<2e-16	***
x	1.850e+00	2.897e-03	638.657	<2e-16	***
I(x^2)	1.449e-02	1.348e-04	107.478	<2e-16	***
I(x^3)	4.472e-05	4.576e-06	9.772	<2e-16	***

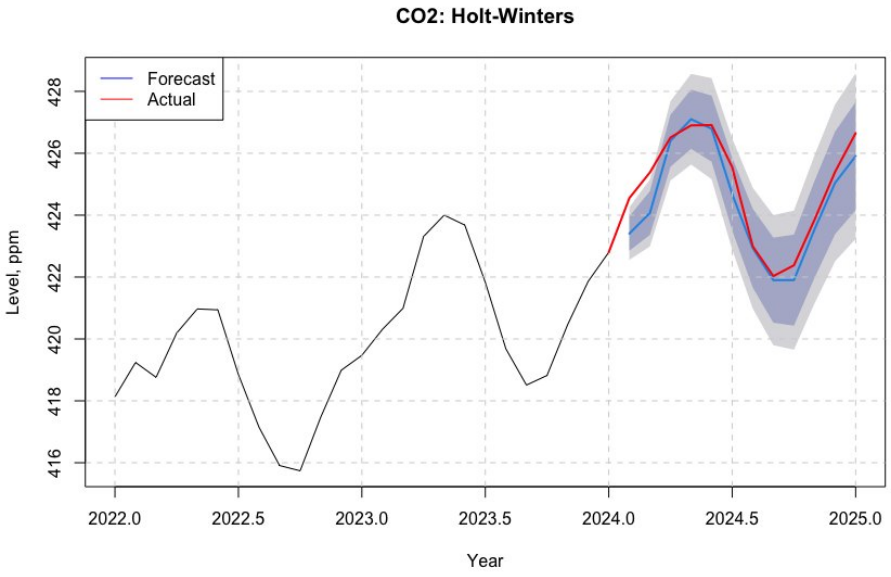

Figure 3, Holt-Winders Model of Atmospheric Carbon Dioxide Concentration.

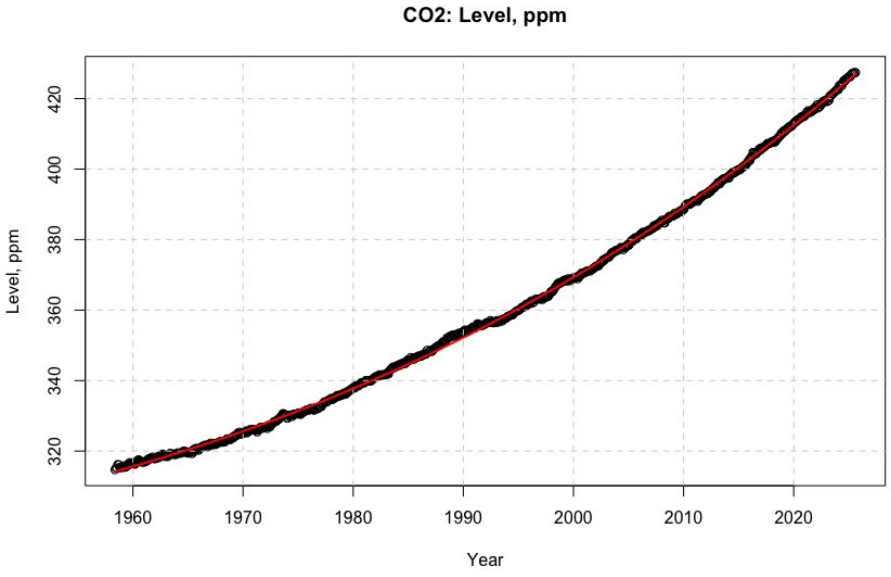

Figure 4, Atmospheric Carbon Dioxide Concentration after Removal of Annual Seasonality.

These coefficients are all statistically significant based on the p-values. Therefore, the atmospheric carbon dioxide increases the concentration at approximately 1.85 ppm per year. The most worrisome is that the rate of the concentration increase is not decelerating, but accelerating at 0.029 ppm/year^2:

$$\frac{dCO_2}{dt} = 1.85 + 0.029 \cdot (year - 2000)$$

During the next decade, if the humanity expects a slowdown in global warming, the accelerating term must show a reversal. The world should pay a close attention to this important term.

Appendix Perl Script

The measurement data from "https://gml.noaa.gov/ccgg/about/co2_measurements.html" are not immediately amenable for forecasting. The following Perl script is used to reformat the data into a .csv file.

```
#!/perl/bin/perl -w

######### Start ###################################
load_data("co2.txt");
exit();

######### make Data for csv ######################
sub load_data{
open(INFILE,"<$_[0]") or die "Could not open $_[0].\n";
local $/ = undef; my $raw=<INFILE>; close(INFILE);
my @df0=split(/\R/,$raw); my @df= grep { !/^#/ } @df0;
my @t0=map{my @tmp=split(/\s+/);$tmp[3]} @df; shift(@t0);
my @x0=map{my @tmp=split(/\s+/);$tmp[4]} @df; shift(@x0);
my @y0=map{my @tmp=split(/\s+/);$tmp[5]} @df; shift(@y0);
my @merged;
push @merged, map {$t0[$_],",", $x0[$_],",", $y0[$_],"\n"} 0 .. $#t0;
open(OUTFILE,">co2.csv") or die "Could not open co2.csv.\n";
       print OUTFILE @merged;
close(OUTFILE);
};
```

Figure 5. Perl Script Used for Preparing the .csv File from the Measurements (co2.txt)