RESPONSIVENESS OF ATMOSPHERIC CO2 TO ANTHROPOGENIC EMISSIONS: A NOTE

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ABSTRACT: A statistically significant correlation between annual anthropogenic CO2 emissions and the annual rate of accumulation of CO2 in the atmosphere over a 53-year sample period from 1959-2011 is likely to be spurious because it vanishes when the two series are detrended. The results do not indicate a measurable year to year effect of annual anthropogenic emissions on the annual rate of CO2 accumulation in the atmosphere.[1]

1. INTRODUCTION

The theory of anthropogenic global warming is that since 1750, human activity, involving the use of fossil fuels, the manufacture of cement, and changes in land use, has been injecting an artificial flow of carbon dioxide (CO2) into the atmosphere at such an accelerated rate that it has overwhelmed nature's delicate carbon balance and caused a steadily rising unnatural and unprecedented accumulation of CO2 in the atmosphere. The change in atmospheric composition has enhanced its greenhouse effect causing surface temperatures to rise unnaturally and dangerously and threaten catastrophic consequences in terms of climate change (Hansen, 2006) (IPCC, 2007) (IPCC, 2014) (Plass, 1956). An important policy implication is that since these changes were created by artificial means they can also be moderated by artificial means simply by making significant reductions in our emissions of CO2 (IPCC, 2014).

Since the recent accumulation of CO2 in the atmosphere is ascribed solely to human emissions, a testable implication of the theory of anthropogenic global warming is that there should be a close correlation between the rate of anthropogenic emissions and the rate at which CO2 accumulates in the atmosphere; and this correlation should be observable at the inter-annual frequency level (Patra, 2005) (Raupach, 2008) (Keeling, 2001) (Plass, 1956) (Lorius, 1990). This means that, net of long term trends, we should find that years of higher annual emissions should correspond with years of greater annual increase in atmospheric CO2 and years of lower emissions should correspond with years of lower rates of accumulation of atmospheric CO2. In this short note, we test this hypothesis by applying detrended correlation analysis, a tool that is often used by financial analysts to detect higher frequency changes net of long term trends (Prodobnik, 2008) (Granger, 1964) (Haan, 2002). The method tests the relationship between two variables that share a common direction in their long term drift in time by removing the drift component and comparing the detrended series in terms of correlation at shorter intervals. When applied to atmospheric CO2, this procedure shows that the correlation between the annual rate at which anthropogenic emissions are introduced into the atmosphere and the annual rate at which CO2 accumulates in the atmosphere, though significant, does not survive into the detrended series and is therefore likely to be spurious or an artifact of the common direction of their long term drift in time to which no anthropogenic cause can be ascribed.

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[1] Date: 8/8/2015, Revised 12/13/2015 mislabeled axes in some graphs corrected thanks to Joel O'Bryan, Revised 8/21/2015 to correct an error in Figure 2 with thanks to Anthony Watts.
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2. DATA AND METHODS

The CDIAC (Carbon Dioxide Information Analysis Center) maintained by the ORNL (Oak Ridge National Laboratories) plays an important role in gathering, archiving, and disseminating data that concern carbon dioxide (CDIAC, 2015). The CDIAC, in conjunction with the Mauna Loa CO2 measuring station, now a part of the USCRN (United States Climate Research Network) managed by the NOAA (National Oceanic and Atmospheric Administration) forms a central nexus of carbon dioxide data (NOAA, 2015). Our data on atmospheric CO2, annual emission of CO2 from the use of fossil fuels and the manufacture of cement, and the emission of CO2 from land use changes are drawn from these sources.

The atmospheric CO2 data were downloaded as monthly means from 1958 to 2014 and converted to annual means for each calendar year in the sample period. The values are denominated in ppmv (parts per million by volume) in the dataset and were multiplied by 7.81 to convert[2] ppmv CO2 to gigatons (GT) of CO2 (CDIAC, 2015) (Keeling, 2001).

The data for carbon emissions from fossil fuels and cement manufacture (Boden, 2013) are provided by the CDIAC on an annual basis from 1750 to 2010 (CDIAC, 2015). The value for 2011 was taken from the IPCC AR5 Chapter 6 (IPCC, 2014). Values provided as millions of metric tons of carbon equivalent were multiplied by 0.0036667 and converted to gigatons of CO2[3]. Carbon flux to the atmosphere from land use changes (Houghton, 2008) are provided by the CDIAC on an annual basis from 1850 to 2005. Values from 2006 to 2011 are estimated from the information in the IPCC AR5 Chapter 6 that these emissions had remained constant in the decade 2002-2011 at 0.9±0.8 gigatons of carbon equivalent (IPCC, 2014).

The earliest year for which an annual change in atmospheric CO2 can be calculated is 1959 and the latest year for which all fluxes are available or may be estimated is 2011. These constraints restrict our sample to fifty three years in the period 1959-2011. The two time series studied in this sample period are: CO2=the annual change in atmospheric carbon dioxide, and Emissions = total anthropogenic emissions from the use of fossil fuels, land use change, and the manufacture of cement.

The analysis is carried out in three steps. First we examine the trend in time for each of the two time series and compute the simple OLS linear regression trend for each time series. Secondly, we take the residuals of these linear trend models to represent the detrended series. And thirdly, we compare the correlation between the two series for both the raw data and the detrended series and interpret them in terms of the responsiveness of atmospheric CO2 to anthropogenic emissions in different time scales (Granger, 1964) (Haan, 2002).

A simple example from finance is used to demonstrate the procedure. The data are provided by Yahoo Finance[4]. The NASDAQ composite index and the DJIA stock market index are compared to evaluate the responsiveness of the NASDAQ to the DJIA in different time scales. The data are the monthly means of

[2] The factor 2.13 is used to convert ppmv to carbon and 3.667 to convert carbon to carbon dioxide.

[3] 0.001*44/12

[4] finance.yahoo.com

daily close prices from April 2009 to April 2014, a period that yields a sample size similar to the CO2 data under consideration. Figure 1 shows a steady upward trend for both markets in the sample period. The differences between the trend line and the data series are the residuals of the OLS linear regression equations shown. These residuals constitute the detrended series and they are shown in Figure 2. Evident in their near zero values of R^2 is that there is no trend in the detrended series.

Figure 1: Trends in the time series

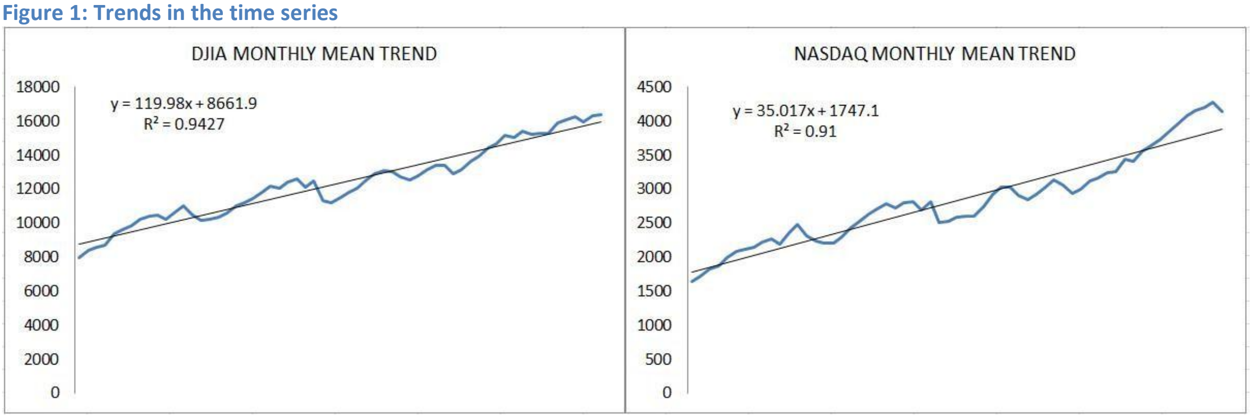


Figure 2: The detrended series

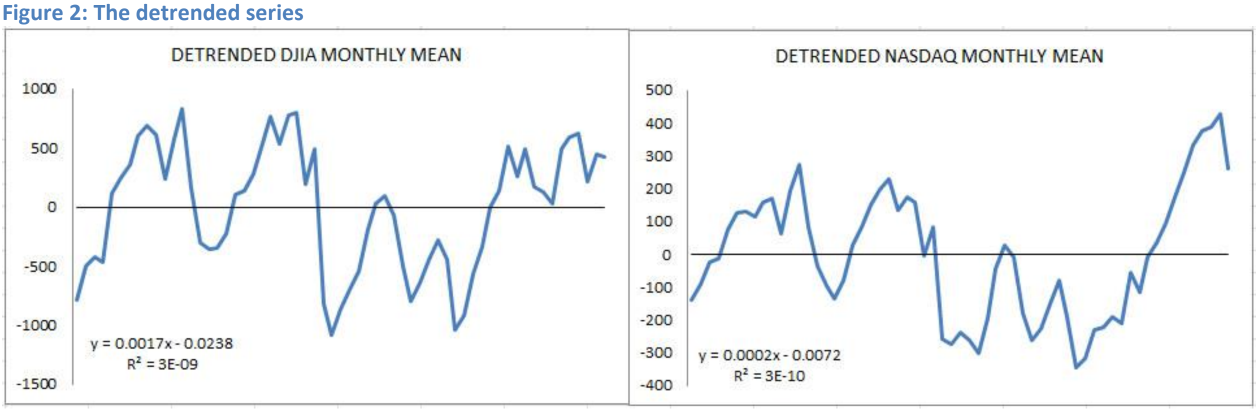


Figure 3: Correlations at different time scales: p-values: raw data p=3.63E-48, detrended series p=2.17E-17

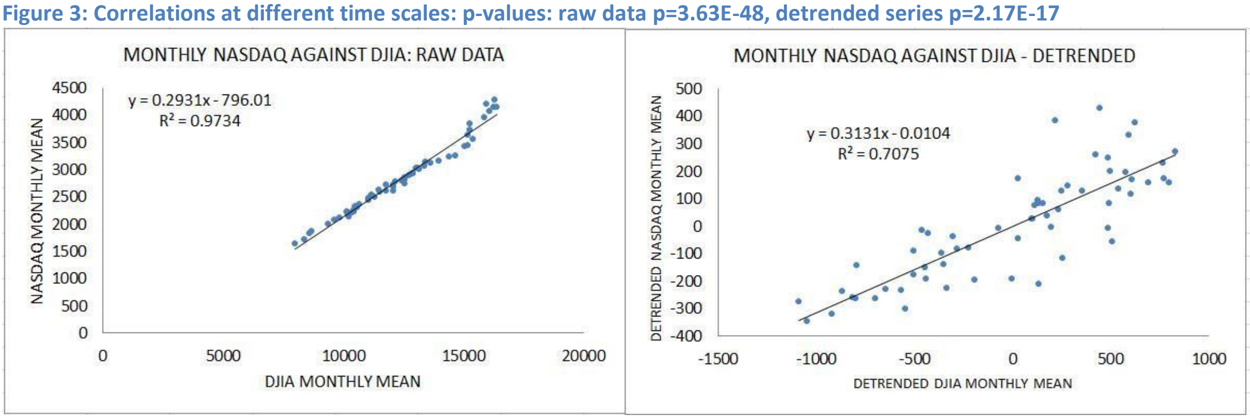


Figure 3 shows the relationship between the NASDAQ and the DJIA in the original time series and in the detrended time series. Setting our maximum false positive error rate at α=0001 in accordance with

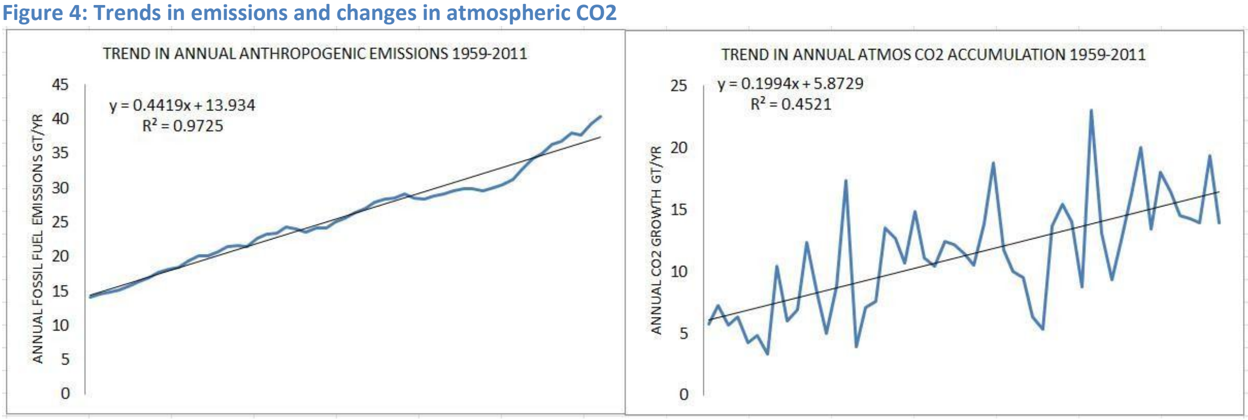
“New standards for statistical evidence” published by the National Academy of Sciences (Johnson, 2013) and correcting for multiple comparisons according to the Bonferroni procedure (Holm, 1979) we find that both the original series and the detrended series show statistically significant relationships in both time scales. We conclude from this comparison that not only does the NASDAQ share a common upward drift with the DJIA in its long term trend; it is also responsive in a monthly time scale. That is, the high correlation noted in the raw data can be decomposed into two components – one for a long term drift in time and one that represents the responsiveness of the NASDAQ to changes in the DJIA from month to month.

We use the same procedure to test the responsiveness of changes in atmospheric CO2 to the rate of anthropogenic CO2 emissions. In this case the time scale for long term linear trend is set to 53 years corresponding with our sample period of 1959-2011. The time scale for short term responsiveness is set to one year consistent with prior work in this area (Keeling, 2001) (Patra, 2005). We use the detrended series in these data to test whether, net of long term trends, a short term year to year effect of the rate of anthropogenic emissions per year can be detected on annual changes in atmospheric CO2.

3. DATA ANALYSIS

Figure 4 shows the trends in the original data series. Both trends are statistically significant although visual clues do not appear to indicate a correlations in short term fluctuations. This intuition is somewhat clearer in the shapes of the detrended series shown in Figure 5 where we see that short term fluctuations in these series do not appear to correspond.

Figure 4: Trends in emissions and changes in atmospheric CO2



We put this intuition to a statistical test by looking at the correlation between the original series and that between the detrended series. If both OLS linear regression coefficients are statistically significant then we can conclude that the two series are related not only in terms of their long term drift but also in terms of their short term annual fluctuations. Such a conclusion would be consistent with the fundamental assumptions of the theory of anthropogenic global warming. The relevant OLS regression results are depicted in Figure 6.

Figure 5: The detrended series

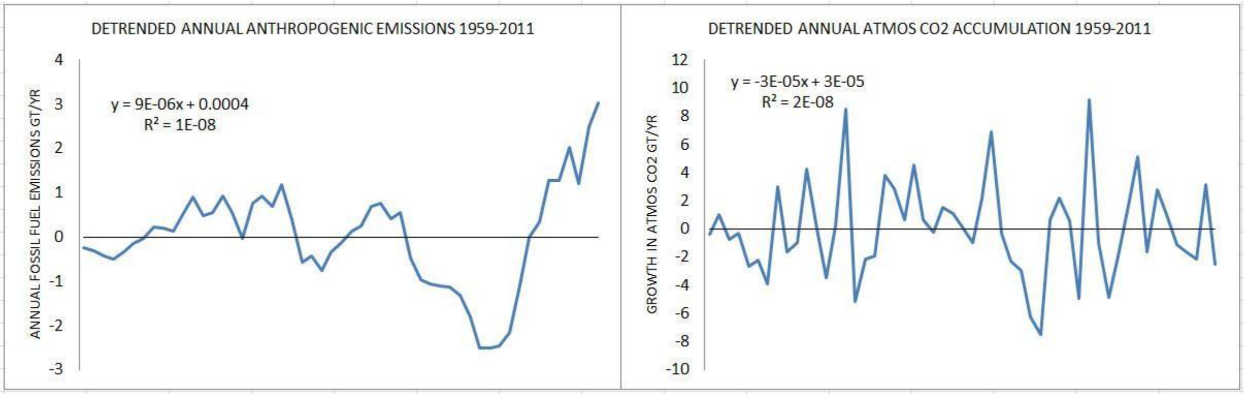


Figure 6 corroborates the visual intuition in Figure 5. Here we see that the statistical significance of the relationship between the two raw data series disappears when the data are detrended. We conclude that the observed correlation between annual anthropogenic emissions and the annual accumulation rate of CO_2 in the atmosphere derives from the common direction of their long term drift and not from any correspondence in annual fluctuations. The absence of a correlation in short term changes can be visualized in the direct comparison of the raw data in Figure 7.

Figure 6: Detrended correlation analysis: 1959-2011. p-values: raw data p = 3.34E-8, detrended series p = 0.558

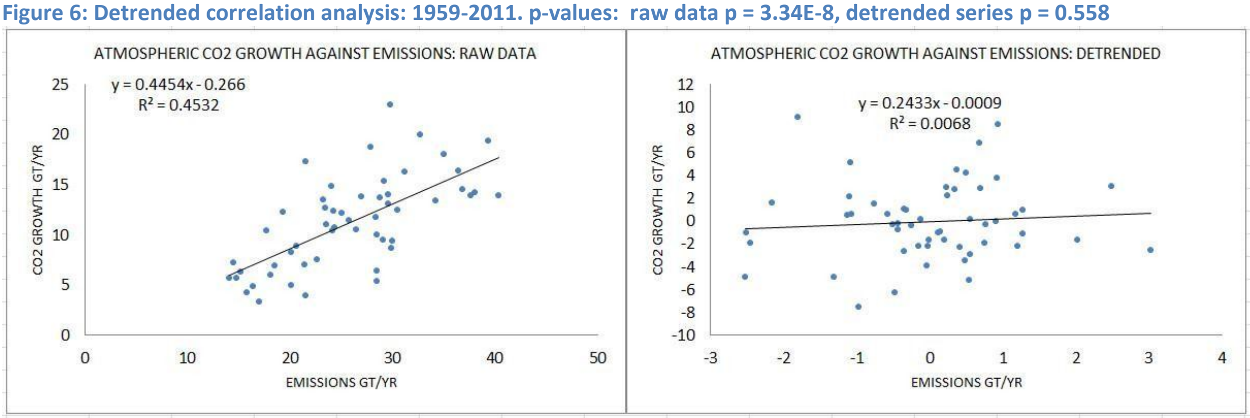
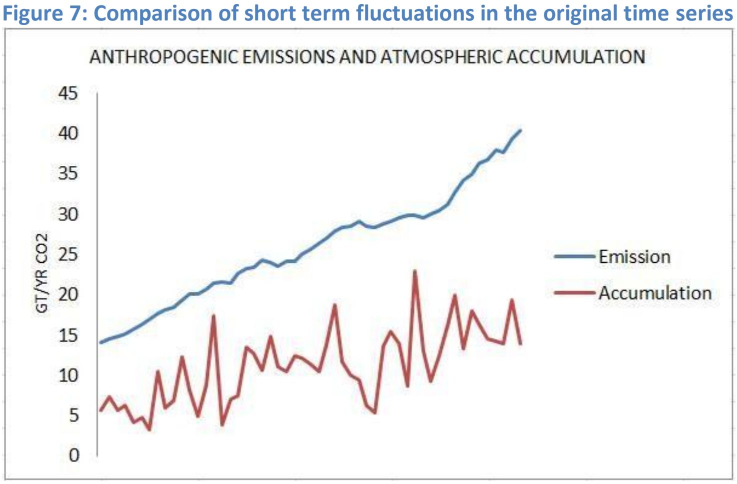


Figure 7: Comparison of short term fluctuations in the original time series



Detrended correlation analysis may also be used to investigate the relationship between surface temperature and the rate of change in atmospheric CO2. It is known that an increase in surface temperature correspondingly increases *net*[5] natural emissions from both land and oceans (IPCC, 2014). A theoretical basis for this relationship is the increase in the partial pressure of CO2 with temperature[6] in accordance with Henry's Law (Takahashi, 2002).

High quality satellite data for the lower troposphere are available for all regions of the globe – both ocean and land - since 1979. Here we use the University of Alabama Huntsville compilation of monthly mean temperature anomalies for the northern hemisphere (NH) for both land and ocean derived from gridded satellite data (UAH, 2015). The NH region conforms to the location of Mauna Loa, the selected CO2 measurement station, in the middle of the Pacific Ocean at latitude +19.5. The UAH temperature data are reported as temperature anomalies in Centigrade degrees.

We see in Figure 8 that both surface temperature and changes in atmospheric CO2 show a long term rising trend in the sample period 1979-2014. The detrended series are shown in Figure 9.

Figure 8: Trends in lower troposphere temperature[7] and change in atmospheric CO2: 1979-2014

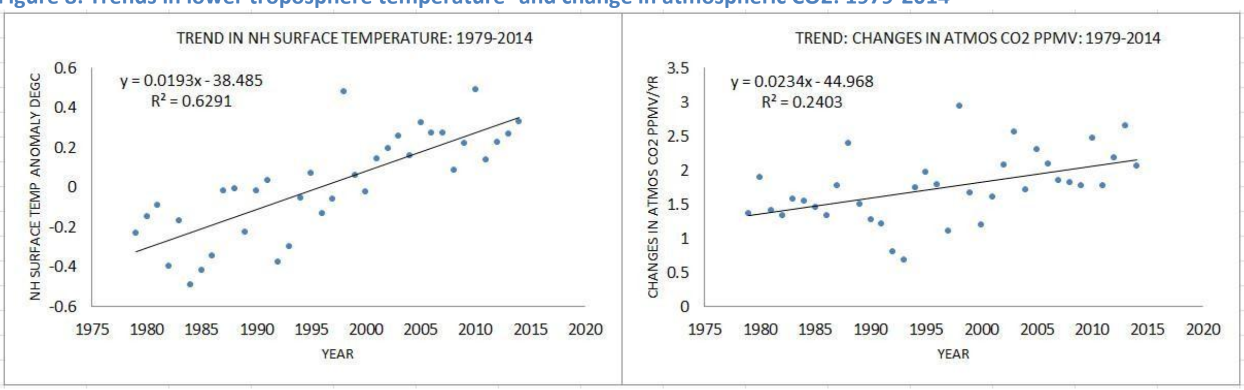
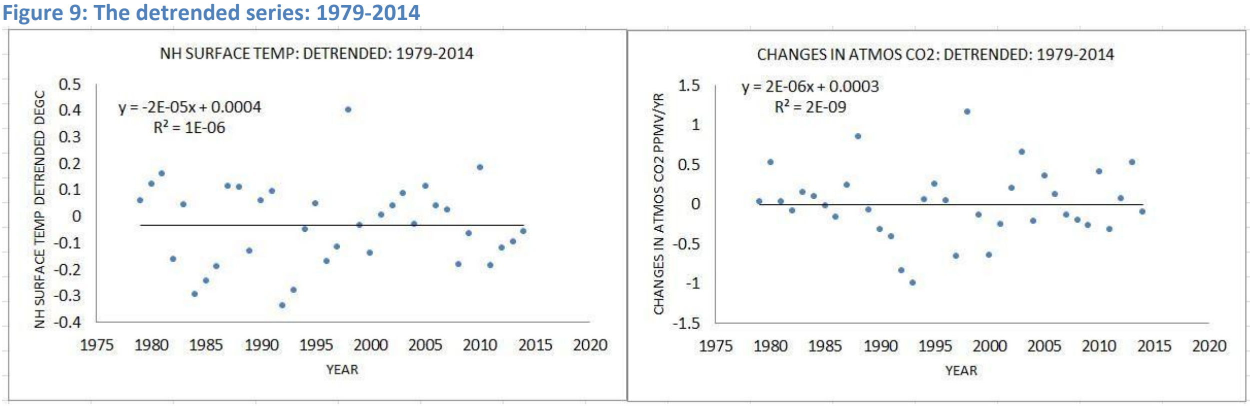


Figure 9: The detrended series: 1979-2014



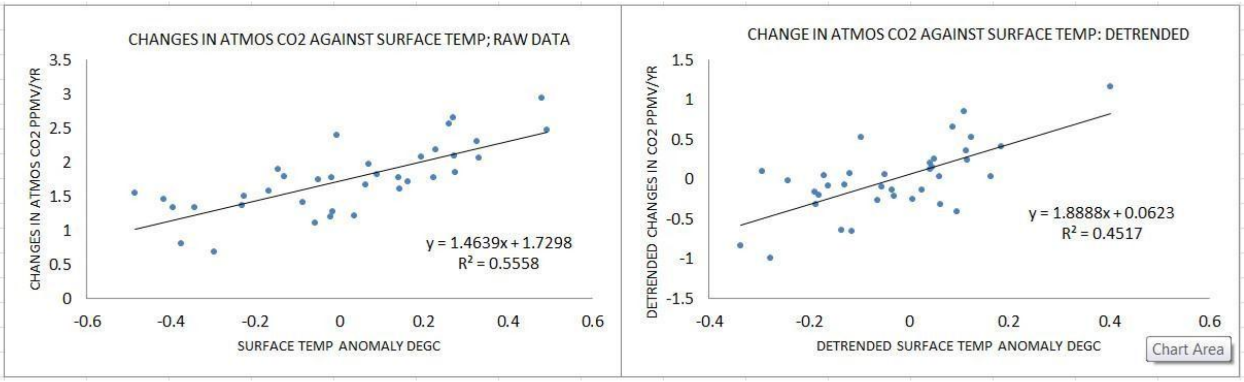
5 Net natural emissions = total emissions from all natural sources – total absorption by all natural sinks.

6 At constant liquid phase concentration

7 Lower troposphere temperature is used as a proxy for surface temperature.

The positive and statistically significant correlation between changes in atmospheric CO2 and surface temperature, both in the raw data and in the detrended series, is evident in Figure 10. Detrended analysis shows that changes in atmospheric CO2 are related to surface temperature both in the long term and in the short term over a wide range of time scales. In comparing these results with the similar detrended analysis of the responsiveness of changes in atmospheric CO2 to the rate of anthropogenic emissions, it is noteworthy that Figure 10 represents a more credible relationship than Figure 6 which shows no responsiveness of annual changes in atmospheric CO2 to the annual rate of anthropogenic emissions in the detrended series.

Figure 10: Detrended correlation analysis: 1979-2014. p-values: raw data p = 1.82E-7, detrended series p = 7.18E-6



4. SUMMARY AND CONCLUSIONS

A necessary condition for the theory of anthropogenic global warming is that there should be a close correlation between annual fluctuations of atmospheric CO2 and the annual rate of anthropogenic CO2 emissions. Data on atmospheric CO2 and anthropogenic emissions provided by the Mauna Loa measuring station and the CDIAC in the period 1959-2011 were studied using detrended correlation analysis to determine whether, net of their common long term upward trends, the rate of change in atmospheric CO2 is responsive to the rate of anthropogenic emissions in a shorter time scale from year to year. It was found that the observed correlation between these variables derives solely from a common direction in their long term trends and not from a correspondence in their annual fluctuations. As a corollary to this finding, a further study reveals that change in atmospheric CO2 is responsive to surface temperature both in long term trends and in short term annual fluctuations. The results have significant implications for interpreting the observed increase in atmospheric CO2 in terms of the climate system and the theory of anthropogenic global warming.

All data and computational details used in this note may be downloaded from its online data archive (Munshi, 2015).

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