Scientific Proposal: Are humans the primary cause of modern-day climate change?

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Background

The Vostok station is a collaboration between Russian, US, and French scientists in East Antarctica where the Vostok core was drilled from an altitude of 3488 m. The core has a total length of 1930 m, and samples were taken at different depths, giving access to a record of atmospheric gas composition and local temperatures data dating as far back as 2310 BC. Scientists can measure air bubbles in ice cores to reconstruct the historical fluctuations in temperature and greenhouse gases, such as carbon dioxide (CO_2). This is accomplished by dating techniques such as flow and compression modeling and using proxy measurements such as deuterium for age. The shallowest data point is at 130 m, and the deepest is at 2,060 m.

The ice core is necessarily a history book, with the latest chapter on top - the deeper we drill, the older the compounds are.

Limitations and Sources of Error

The most significant limitation is that the data is based on Antarctic ice core records, which is not representative of global temperatures. Furthermore, the data does not show recent values of greenhouse gas emissions and temperature. CO_2 was lower during glacial times - the Earth was colder, and it was before the industrial revolution, which resulted in increases in CO_2 in the atmosphere due to rapid growth in factories and the burning of fossil fuels.

Additionally, there are errors in reconstructing climate history using ice core data. For instance, correcting for gas exchange and thermal diffusion in snow before the trapping of gas within bubbles enclosed in the compressed ice may lead to inaccuracies. Determining the age of ice is a potential source of error. (Figure 1)

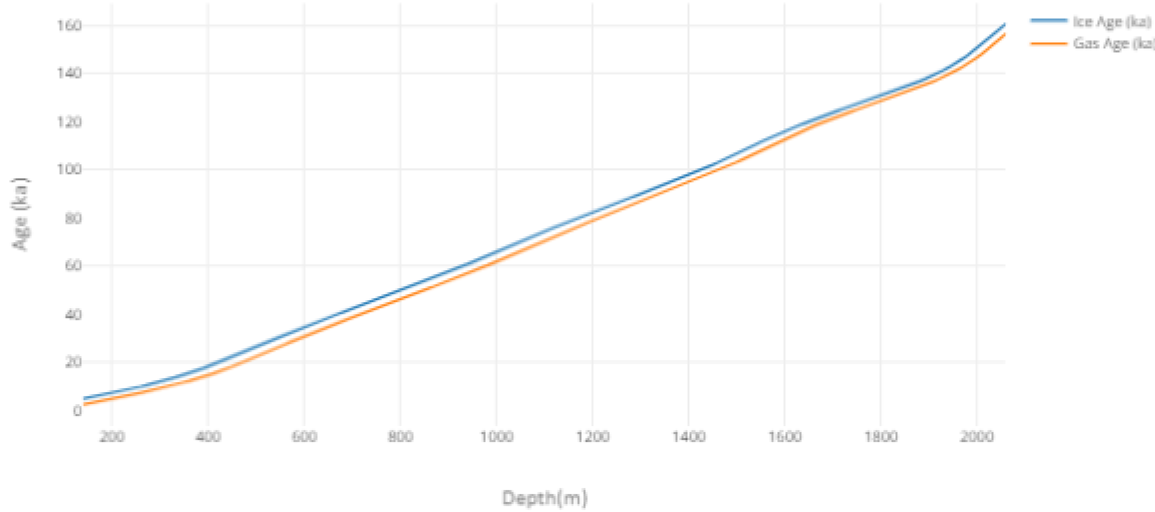

Figure 1. The age of ice and gas as a function of depth in the Vostok ice core data. Note that age increases down the core.The two age curves differ - for instance, at a depth of 300 m, a bubble of gas is 2.72 thousand years younger than the ice around it. (Petit et al., 1999)

This occurs because it takes time for the pores containing gas to become sealed off from the rest of the atmosphere. Until that happens, there is a continuous exchange between the ice-gas and the atmosphere. Thus, the carbon dioxide concentration in the air-filled spaces might be affected by interactions with the ice itself or with trapped impurities. On the other hand, the solid ice stops being modified once it is deposited. [1]

[1] **#observation:** This is a strong application of the HC because I have accurately interpreted the lag in ice and gas age in the Vostok ice core data. I have further engaged with the data and the underlying physics to explain likely reasons for this discrepancy and its implications for the reliability of the observational study.

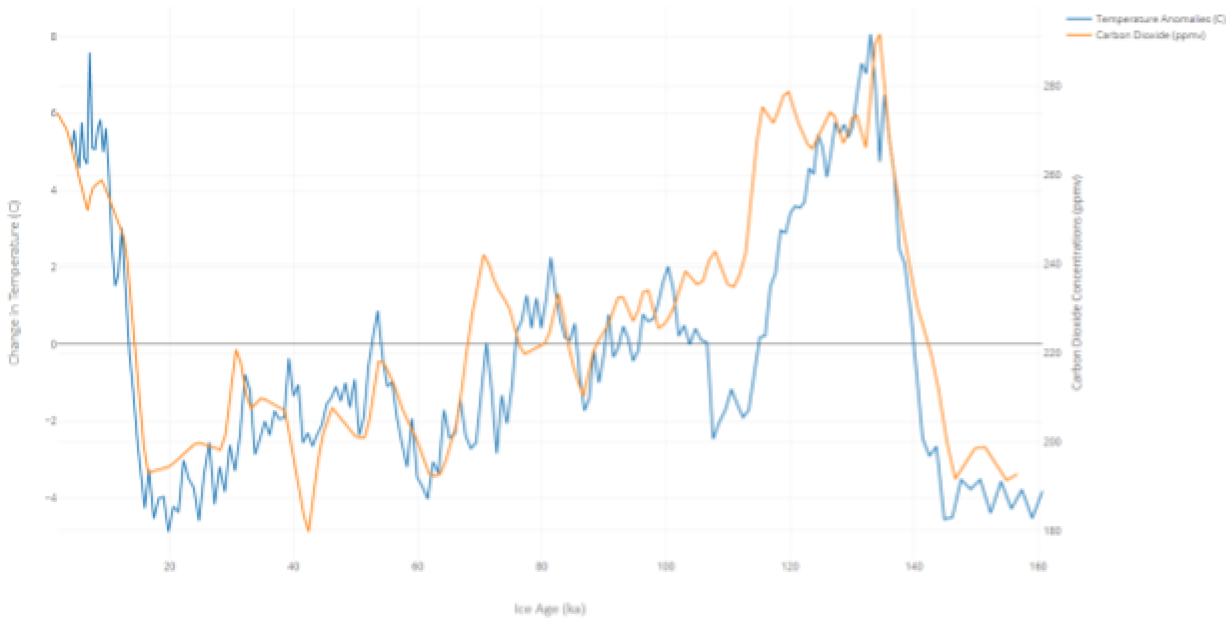

Figure 2. Temperature anomalies from timeseries mean and carbon dioxide concentrations as a function of ice age. (Petit et al., 1999). Plotting anomalies yields the advantage that values are not dependent on the particular locations and reporting periods of the actual weather stations, giving more meaningful information about our climate. According to this data, the climate has varied by about 12 degrees celsius. Furthermore, greenhouse gas composition changes first i.e. CO_2 peaks before temperature change.

According to Figure 2[2], our greenhouse gas composition changes first, i.e., CO2 peaks before temperature change, such as at 136.8 ka in ice age, when CO2 peaks, and temperature peaks at 131.47 ka. The difference in times between these is 5.33 ka. If carbon dioxide increase precedes temperature increase, then the rise in greenhouse gas concentrations may be attributed to causing the rise in temperature, providing substantial evidence for global warming. Another possibility states that greenhouse gas concentrations result from temperature increases caused by tilts in the Earth's axis around the sun, which in turn feedback to further increase temperature.

This is the basis for the argument of climate change skeptics, who posit that historically atmospheric CO2 levels have risen after temperature increases began caused by the Earth's orbital (Milankovitch) cycles and therefore anthropogenic emissions are not the major cause of climate change. (Martino, 2013)

[2] **#dataviz:** This presents effective data visualization techniques because I have manipulated the data to show anomalies and presented them on the same graph to identify underlying patterns in fluctuations and make easy comparisons. I have also critiqued on the limitation of this visualization by suggesting that ice core data from Vostok is not representative of global temperatures, which is a foundation for the hypothesis I propose later in the study.

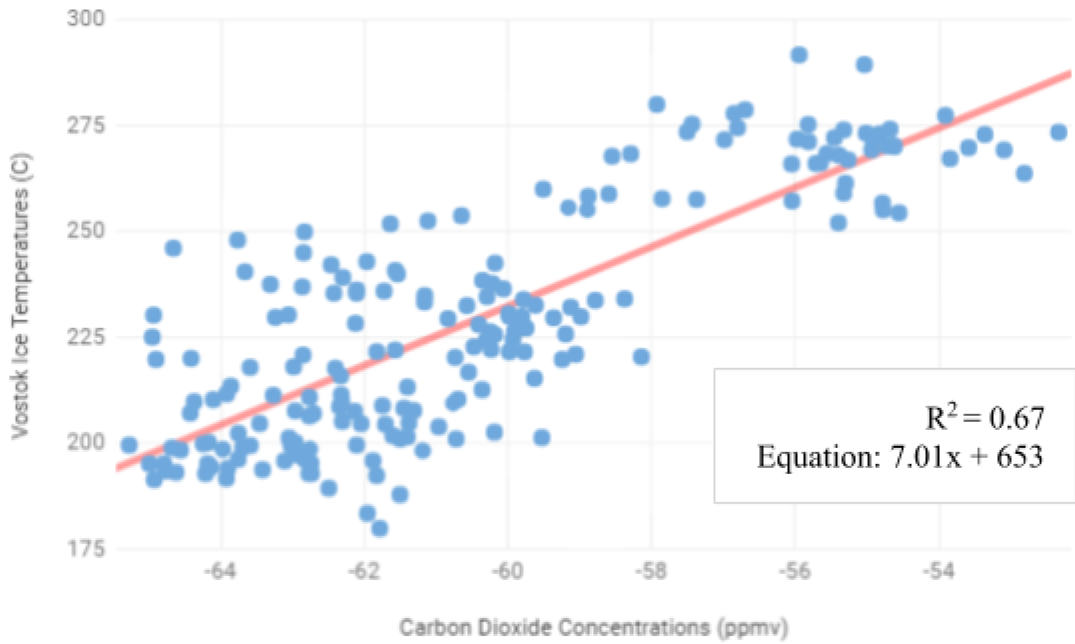

Figure 3. Scatterplot displaying the relationship between Vostok ice temperatures and carbon dioxide concentrations. Note that the best fit line is a linear regression. High r value indicated that carbon dioxide and temperatures have a strong positive correlation and high R^2 suggests that our linear regression line approximates the real data points well.

In Figure 3, the correlation coefficient r measures the strength of the relationship between carbon dioxide concentration and ice core temperatures. The correlation is not perfect since there are many confounding variables and neither of these things influences temperature solely on their own. Many factors contribute to temperature, including the concentrations of other greenhouse gases and orbital characteristics of the earth. Nevertheless, the high positive value indicates that increase in both temperature and carbon dioxide concentrations co-occur. We shall test the model by computing the expected temperature according to the Vostok ice core model and the actual surface temperature below:

Current CO2 concentration: 402.29 parts per million (ppm) (NOAA, 2017)

$y = 7.01x + 653$

$Y = 402.29$

$402.29 = 7.01x + 653$

$X = -35.8$ C

The past relationship between CO_2 and temperature predicts that today's Vostok temperature should be about -35.8C, while today's surface temperature is -38C. (AccuWeather, 2017) This is a mere 2.2C difference. Such close results further increases our confidence in the model.

Motivation

The implications of determining the rate of the causal relationship between greenhouse gases and temperature changes are that policies which regulate greenhouse gas emissions are dependant on this knowledge. To assess the benefits of a policy, we need a shared consensus that anthropogenic changes in carbon emissions accelerate temperature changes when compared to glacial/interglacial transitions. International organizations and national governments must be able to weigh the benefits and potential losses, such as economic troubles and accurately predict future temperatures.

Study Objective

The Vostok ice core data suggest CO_2 was a key mechanism of global warming during the last deglaciation. This is a synthesis of the effects of the observed subtle change in Earth's orbit Milankovitch cycles around the sun and our current understanding of the greenhouse effect, whereby increases in the amount of light reaching the earth, upsetting ocean circulation and resulting in the release of CO_2. (Shakun et al., 2012) The rise in CO_2 sets in motion global temperature increases by trapping radiant heat that pulls the whole Earth out of its glaciated state.

I hypothesize that increases in CO_2 emissions past normal levels accelerate the positive feedback loop of temperature increase as a result of the excess energy initially trapped in our climate through the greenhouse effect.[3] [4]

[3] **#hypothesisdriven:** By presenting the Vostok ice core data to identify underlying patterns of regularity, I have reconciled with accepted knowledge of the effects of Milankovitch cycles and greenhouse effects to suggest a well-formed hypothesis inductively (going from specific to general). My hypothesis is both explanatory in terms of the effects of anthropogenic emissions on global warming and predictive in terms of the likely trends in carbon dioxide emissions and temperature increases in the past.

[4] **#plausability:** My hypothesis is consistent with substantiated scientific knowledge, its assumptions and premises are coherent with observational data, it is testable in principle (generates specific predictions about the trends in carbon dioxide emissions and temperature increase) and it is parsimonious since it takes into account the effects of both Milankovitch cycles and suggest that carbon dioxide is driver in climate sensitivity.

Study methods:

The primary data for this study is instrumental measurements of the temperature change and CO_2 during the last deglaciation from multiple geographic regions. Ice core data was previously collected in Greenland (NEEM community members, 2013). Although most of the planet's glacial ice is located near the poles, there are many mountain glaciers near the equator and ice core data from these regions can provide additional insight into Earth's climate history. Furthermore, proxy data from sediments drilled from the ocean floor and continental lakes can also yield meaningful data. Proxy data include radiocarbon from the ocean's surface, magnesium content of plankton seashells, pollen assemblages and ice core data from Greenland (which is snowier and the gas bubbles aren't as younger from the surrounding ice). The use of widely distributed points, using appropriate proxy calibrations can provide a more representative picture of global mean temperatures. We will also incorporate in our study the official global temperature figures published by GISTEMP series via the NASA Goddard Institute for Space Sciences (GISS), showing data since the 1880's.

<u>Positive outcome</u>**:** The closer the modeled changes match those seen in the globally, the higher the confidence we have in the realism of our models. In specific, we will observe that carbon dioxide concentrations preceded global warming globally during the last glaciation. Preceding here means that the upward trends were first observed in CO_2 emissions before temperature.[5]

In retrospect, future analysis of ice cores (10,000 years from now) will show a very much larger rate of temperature increase (assuming anthropogenic emissions as usual), corresponding to a disruption in the natural patterns of the past 180,000 years and an accelerated greenhouse effect. Unfortunately, there would most likely be less samples of ice cores to study due to the melting of glaciers from global warming.

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[5] **#theorytesting:** This is a successful use of the HC because I have drawn on data collected from different sources to enable increasing predictive power of accepted knowledge about Earth's climate cycles. Through the use of sound deductive steps, I have generated a testable hypothesis which makes specific predictions by reconciling the greenhouse effect, Milankovitch cycle and observation data from the Vostok ice core study and designed the study with a strong theoretical basis. Furthermore, I have evaluated the likely effectiveness of the study design by identifying caveats and limitations, and how we shall correct for them to achieve reliability.

Negative outcome**:** Increasing carbon dioxide preceded by global warming during the last glaciation across global data. [6]

Since other non-temperature effects also influence each proxy, there are numerous confounding factors for each variable. Therefore, amalgamating the proxy data into a global reconstruction can help uncover at least the general pattern that emerges dominated by temperature and carbon dioxide concentrations. In other words, the signal-to-noise ratio increases so that we have a more meaningful metric that couldn't be obtained from a single record due to the existence of confounding variables. However, discrepancies are likely to be caused by filling in missing values. For instance, NASA's GISTEMP uses statistical methods to fill in gaps surrounding their measurements, and a similar method would be required for the gap in our proxy data as well. We would likely use a quadratic fit because even for the Vostok data, the residuals are not normally distributed around the regression line, especially at high values, and a linear model might not be appropriate.

Furthermore, there are risks to using past behavior as an analog for the present. We do not account for analytical uncertainties or uncertainties related to lack of global coverage and spatial bias in the data set.

All the previous data points in the Vostok data represent responses of the system interpreted to have been initiated by subtle changes in incoming solar radiation, related to Milankovitch cycles, which set off a complex sequence of feedbacks, partially involving CO2. In the present circumstance, the running hypothesis is that increasing CO2 is accelerating warming, so it's not evident that the same feedback mechanism will prevail.

[6] **#testability:** I have clearly identified a prediction that follows directly from the hypothesis and is supported by multiple lines of evidence regarding Milankovitch cycles and the greenhouse effect (testability in practice). This outcome is falsifiable and can be tested experimentally since it produces measurable, analyzable results about the trends in carbon dioxide emissions and temperature increases globally. (testability in principle)

Summary:

The correlation of carbon dioxide (CO2) concentration and temperature in Antarctic ice-core records suggests a close link between CO2 and climate. Nevertheless, the role and relative importance of CO2 in producing these climate changes remain unclear. The feedback effects of carbon dioxide concentrations and temperature rises from the Vostok ice core data are "mixed in" with the Milankovitch-induced changes and simple inspection of graphs doesn't really allow these to be deconvoluted visually. This is why my proposed study is essential in providing a theoretical framework of the relationship between CO2 emissions and global temperature. In this study, we will construct a record of global surface temperature from numerous proxy records and possibly show that CO2 emissions are correlated with and generally precedes temperature increases during the last (that is, the most recent) deglaciation. Future directions include construction of global climate model simulations to compute the effects of possible reductions in anthropogenic emissions and how that will influence future temperatures. This has particular relevance in driving research about the optimal design of infrastructure and human societies to develop resistance to climate change.

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Additional Notes

In [11]:
```
import matplotlib.pyplot as plt
import numpy as np
from matplotlib import style
import pandas as pd
import plotly
import plotly.graph_objs as go
import plotly.plotly as py

plotly.tools.set_credentials_file(username='tanhakat3', api_key='153s3FQUU07OuweDealN')
```

```
Populating the interactive namespace from numpy and matplotlib
```

In [12]:
```
import csv

with open('vostok.csv.csv') as csvdf:
    depth = []
    iceage = []
    gasage = []
    co2 = []
    temp = []
    csvReader = csv.reader(csvdf)
    for row in csvReader:
            depth.append(row[0])
            iceage.append(row[1])
            gasage.append(row[2])
            co2.append(row[3])
            temp.append(row[4])



depth = depth[3:]
iceage = np.array(list(map(float, iceage[3:])))
#iceage = [1950-(i*1000) for i in iceage]
gasage = np.array(list(map(float, gasage[3:])))
#gasage = [1950-(j*1000) for j in gasage]


trace1 = go.Scatter(x=depth,y=iceage,mode = 'lines',name = 'Ice Age (ka)')

trace2 = go.Scatter(x=depth,y=gasage, mode = 'lines', name = 'Gas Age (ka)')

layout = go.Layout(
    title='',
    xaxis=dict(
        title='Depth(m)',
        titlefont=dict(
            family='Calibri',
            size=18,
            color='#7f7f7f'
        )
    ),
    yaxis=dict(
        title='Age (ka)',
        titlefont=dict(
            family='Calibri',
            size=18,
            color='#7f7f7f'
        )
    )
)

data = [trace1, trace2]
fig = go.Figure(data=data, layout=layout)
py.iplot(fig, filename='age',layout=layout)
```

```
temp = np.array(list(map(float, temp[3:])))
tempvar = [i+60.3937543 for i in temp]


trace1 = go.Scatter(x=iceage,y=tempvar,mode = 'lines',name = 'Temperature Variation (C)')

layout = go.Layout(
    title='',
    xaxis=dict(
        title='Ice Age (ka)',
        titlefont=dict(
            family='Calibri',
            size=18,
            color='#7f7f7f'
        )
    ),
    yaxis=dict(
        title='Change in Temperature (C)',
        titlefont=dict(
            family='Calibri',
            size=18,
            color='#7f7f7f'
        )
    ),
)

data = [trace1]
fig = go.Figure(data=data, layout=layout)

py.iplot(fig, filename='tempa',layout=layout)
```

In [22]:
```
#Gives a new shape to an array without changing its data so that they can be used for a scatter plot
np.reshape(co2, (1, len(co2)))
np.reshape(temp, (1, len(temp)))

#creating a scatter plot of the two variables
fig, ax = plt.subplots()
#creates least squares polynomial fit. Returns the slope and intercept of a line that minimises the squared error.
fit = np.polyfit(temp,co2,deg=1)
#uses the slope and intercepts from fit to plot the regression line values of y
ax.plot(temp, fit[0] * temp + fit[1], color='red')
ax.scatter(temp,co2,alpha=0.2)

#labelling the axis
plt.xlabel("Vostok Temperature (C)", size = 12)
plt.ylabel("Carbon Dioxide Concentration (ppmv)", size =12)

fig.show()

#function to calculate pearson's correlation coefficient
def pearson(x,y):
    '''
    This function creates two empty lists.
    It takes two list objects as an input and standardizes each element in the list.
    It then multiplies the standardized score of each variable for individual blocks and adds them together.

    '''
    scorex = []
    scorey = []

    for i in x:
        scorex.append((i - mean(x))/StandardDeviation(x))

    for j in y:
        scorey.append((j - mean(y))/StandardDeviation(y))

    return sum([i*j for i,j in zip(scorex,scorey)])/(len(x))

def r_squared(x,y,degree):

    '''
    This function calculates the R^2 value for our lists of each variable.
    It first performs a least squares polynomial fit.
    Afterwards, it takes the y coordinates of the regression line
    and calculates the regression sum of squares and the total sum of squares.

    '''
    results = {}
    coeffs = np.polyfit(x,y,degree)
    results['polynomial'] = coeffs.tolist()

    p = np.poly1d(coeffs)
    yhat = p(x)

    ybar= mean(y)
    ssreg = sum([(coor-ybar)**2 for coor in yhat])
    sstot = sum([(coory - ybar)**2 for coory in y])
    results['determination'] = ssreg/sstot

    return results
```

```
#calculates the mean
def mean(x):
    '''
    This function takes a list object as an input and computes the mean by adding
    all the list elements together and dividing them by the total number of elements
    '''
    sum = 0.0
    for i in x:
        sum += i
    return sum / len(x)

def StandardDeviation(x):
    '''
    This function calculates the standard deviation of a set of data
    It first adds the squared deviation from the mean for each data point and
    returns the square root of that number'''
    sumv = 0.0
    for i in x:
        sumv += (i - mean(x))**2
    return math.sqrt(sumv/(len(x)))


r = 'r =' + str(round(pearson(temp,co2),2))

r2 = 'R^2 = ' + str(round(r_squared(temp,co2,1)['determination'],4))
m = r_squared(temp,co2,1)['polynomial'][0]
b = r_squared(temp,co2,1)['polynomial'][1]

equation = 'y =' + str(round(m, 2)) + 'x' + '+' + str(round(b,2))


plt.show()
plt.text(90,22,r)
plt.text(90,20,r2)
plt.text(90,18,equation)
print(equation)
```