Physics of Climate Exercise 1

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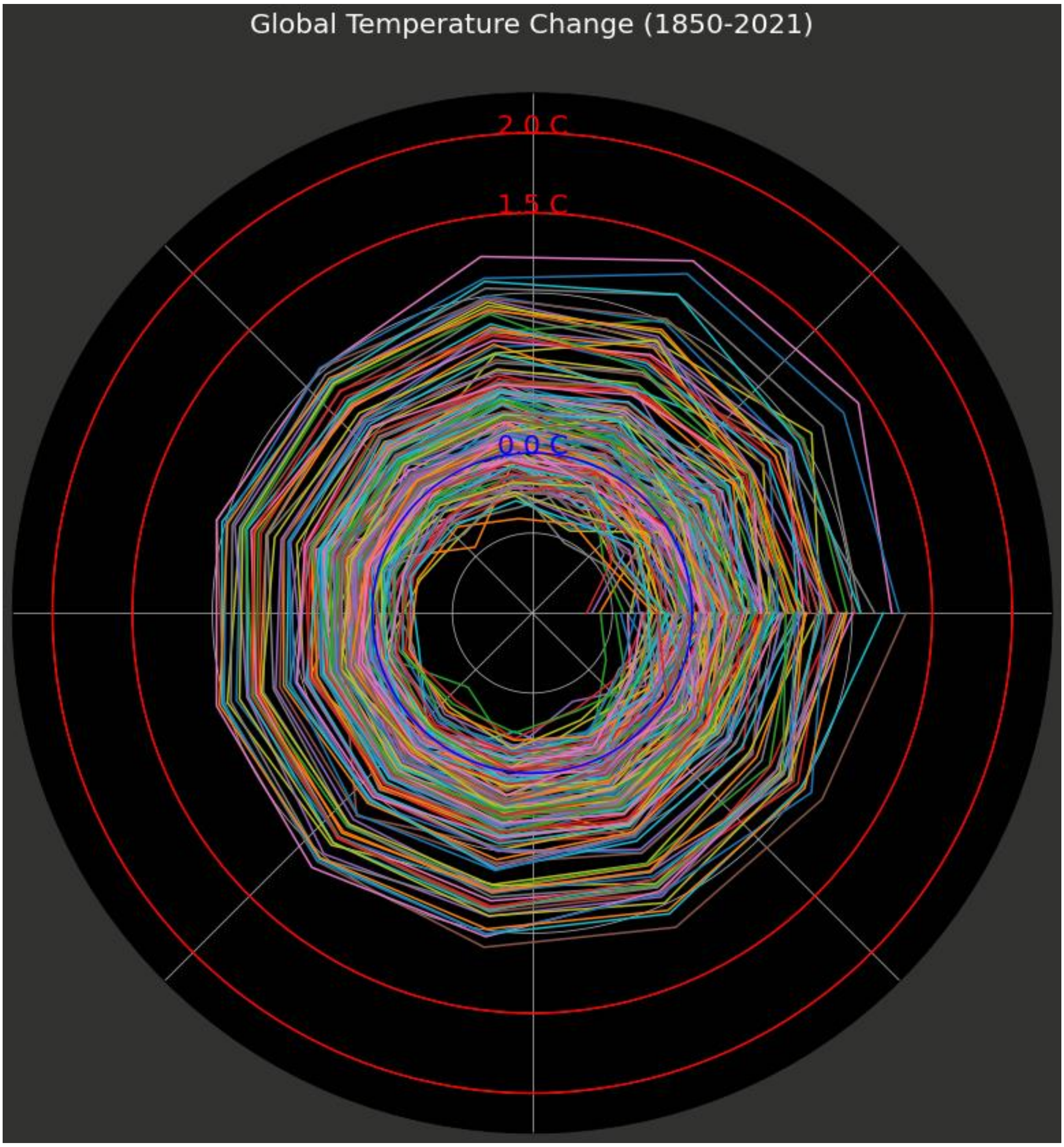
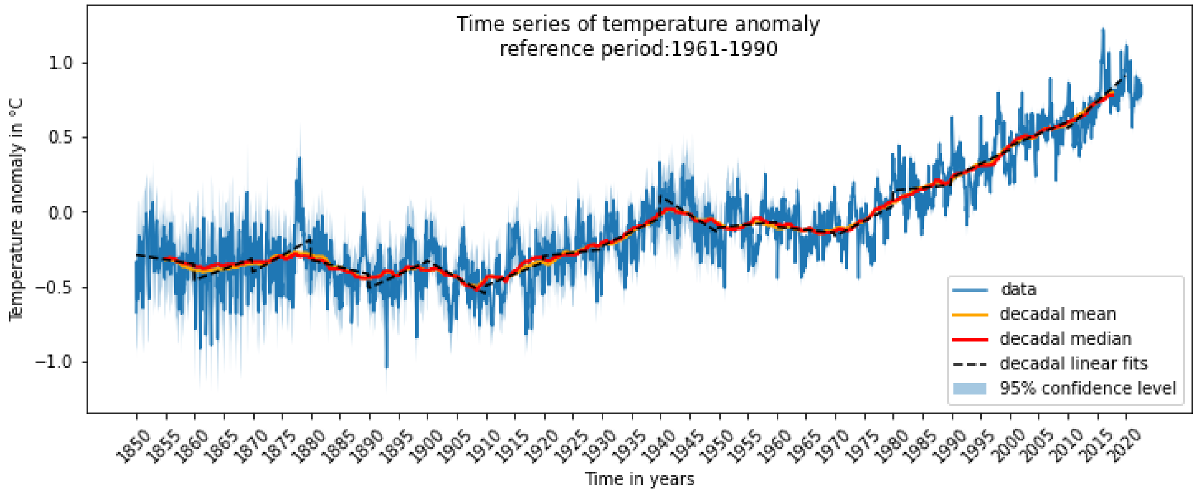
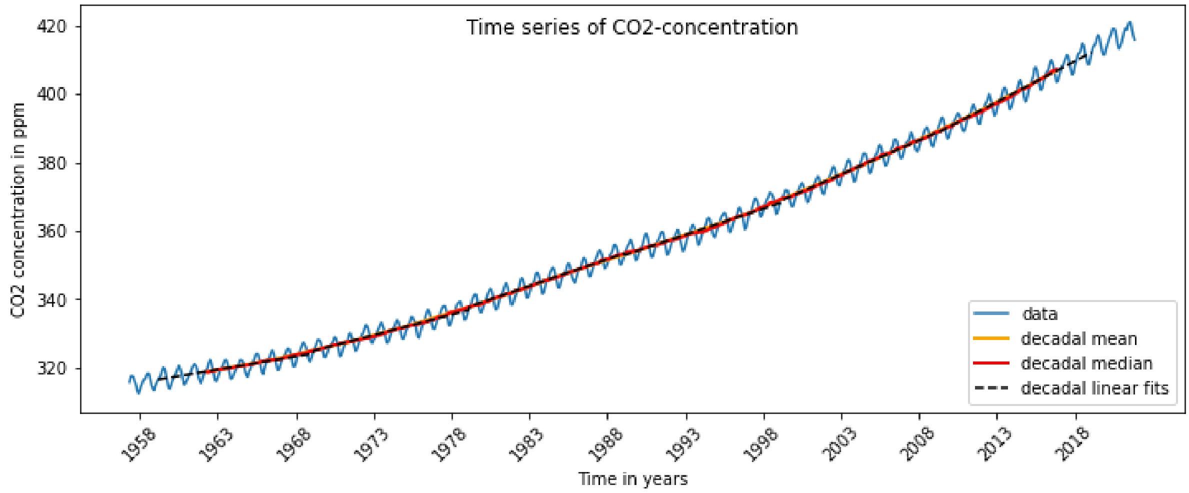




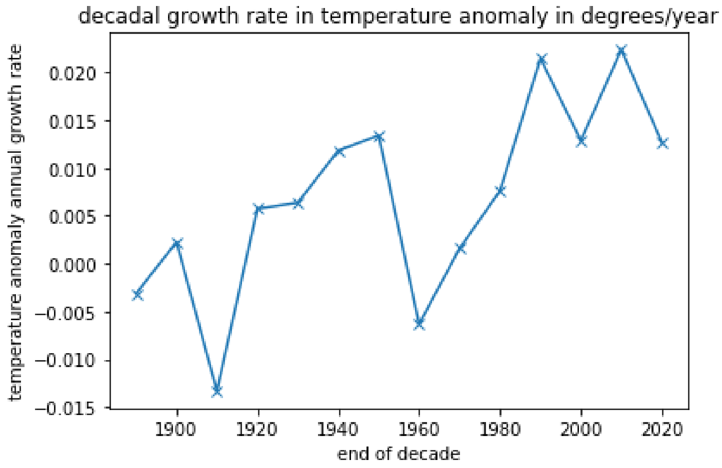


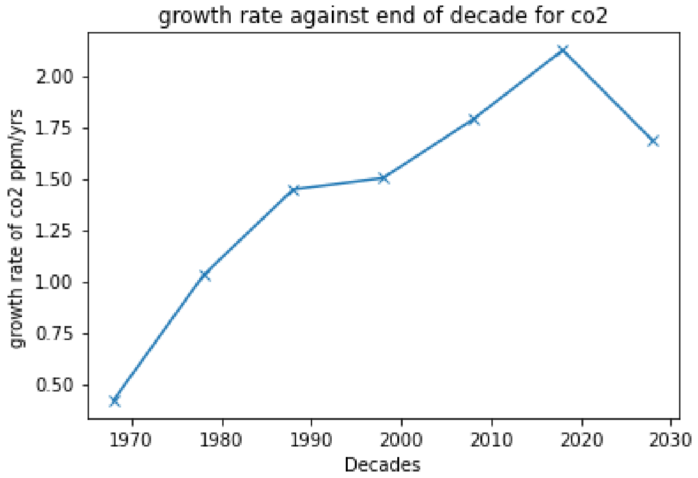
Annual grow rate of temperature in the decades
(obtained from decadal linear fits)
1850s: -0.006184 ppm/yr
1860s: 0.014405 ppm/yr
1870s: 0.021828 ppm/yr
1880s: -0.009696 ppm/yr
1890s: 0.017780 ppm/yr
1900s: -0.022225 ppm/yr
1910s: 0.015747 ppm/yr
1920s: 0.004409 ppm/yr
1930s: 0.019005 ppm/yr
1940s: -0.024541 ppm/yr
1950s: 0.003742 ppm/yr
1960s: -0.003890 ppm/yr
1970s: 0.020147 ppm/yr
1980s: 0.003682 ppm/yr
1990s: 0.018816 ppm/yr
2000s: 0.016271 ppm/yr
2010s: 0.035353 ppm/yr

Annual grow rate of CO2 concentration in the decades
(obtained from decadal linear fits)
1960s: 0.767081 °C/yr
1970s: 1.192464 °C/yr
1980s: 1.559946 °C/yr
1990s: 1.525992 °C/yr
2000s: 1.989682 °C/yr
2010s: 2.378256 °C/yr

Temperature prediction for year 2050: 1.5 °C higher than average 1961-1990
(using quadratic fit for the data from 1970 on)

The growth rates of both temperature and CO2 are generally increasing with time:





Thermodynamic equilibrium of Earth Surface Atmosphere – as both temperature and CO2 are growing at increasing rates, thermodynamic equilibrium is shifting to higher mean temperatures. Increase in CO2 will augment greenhouse effect, creating a feedback effect that further increases warming.

E_a changes – emissivity of atmosphere increases due to more trapping.

In[3]:

Code:

```
#!/usr/bin/env python
# coding: utf-8

# In[9]:


import matplotlib.pyplot as plt
import numpy as np
from scipy.optimize import curve_fit
import pandas as pd


# In[3]:


def linear(x, a, b):
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```
    return a*x + b
def quadratic(x,a,b,c):
    return a*x**2 + b*x + c


# # Data analysis

# In[5]:


#Load temperature data
t_mean, t_low_conf, t_up_conf =
np.loadtxt("HadCRUT.5.0.1.0.analysis.summary_series.global.monthly.csv",
                                          unpack=True, delimiter=",", skiprows=1, usecols=(1,2,3))
t_date = np.loadtxt("HadCRUT.5.0.1.0.analysis.summary_series.global.monthly.csv",
                    unpack=True, delimiter=",", skiprows=1, usecols=0, dtype=str)

#Unpack datestring
t_year  = np.array([])
t_month = np.array([])
for timestr in t_date:
    t_year = np.append(t_year, int(timestr.split("-")[0]))
    t_month = np.append(t_month, int(timestr.split("-")[1]))

#Decadal mean and median
t_dec_mean   = np.array([])
t_dec_median = np.array([])
for i in range(0, len(t_mean[120:])):
    t_dec_mean   = np.append(t_dec_mean, np.mean(t_mean[i:120+i]))
    t_dec_median = np.append(t_dec_median, np.median(t_mean[i:120+i]))

#Fitting (linear fits of decades)
t_popt_array = np.array([])
t_pcov_array = np.array([])
t_fit = np.array([])
for d in range(185,202): #from 1850s to 2010s
    decade = d*10
    mask   = np.logical_and(t_year>=decade, t_year<(decade+10))
    popt, pcov = curve_fit(linear, np.linspace(decade, decade+10, 120, endpoint=False),
                           t_mean[mask]) #Parameter a is then in °C/year
    t_popt_array = np.append(t_popt_array, popt)
    t_pcov_array = np.append(t_pcov_array, pcov)
    t_fit = np.append(t_fit, linear(np.linspace(decade, decade+10, 120, endpoint=False), *popt))

#Load CO2 data
c_mean = np.loadtxt("co2_mm_mlo.txt", usecols=3)
c_year, c_month = np.loadtxt("co2_mm_mlo.txt", usecols=(0,1), unpack=True, dtype=int)

#Create datestring
c_date = np.array([])
for i in range(0, len(c_mean)):
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```
    c_date = np.append(c_date, "{0:4d}-{1:02d}".format(c_year[i], c_month[i]))

#Decadal mean and median
c_dec_mean  = np.array([])
c_dec_median = np.array([])
for i in range(0, len(c_mean[120:])):
    c_dec_mean  = np.append(c_dec_mean, np.mean(c_mean[i:120+i]))
    c_dec_median = np.append(c_dec_median, np.median(c_mean[i:120+i]))

#Fitting (linear fits of decades)
c_popt_array = np.array([])
c_pcov_array = np.array([])
c_fit = np.array([])
for d in range(196,202): #from 1960s-2010s
    decade = d*10
    mask   = np.logical_and(c_year>=decade, c_year<decade+10)
    popt, pcov = curve_fit(linear, np.linspace(decade, decade+10, 120, endpoint=False),
                        c_mean[mask]) #Parameter a is then in °C/year
    c_popt_array = np.append(c_popt_array, popt)
    c_pcov_array = np.append(c_pcov_array, pcov)
    c_fit = np.append(c_fit, linear(np.linspace(decade, decade+10, 120, endpoint=False), *popt))

#Print out grow rates
#Temperature
print("\nAnnual grow rate of temperature in the decades")
print("(obtained from decadal linear fits)")
dec = 1850
for a in t_popt_array[::2]:
    print("{0:d}s: {1:9f} ppm/yr".format(dec, a))
    dec=dec+10

#CO2
print("\nAnnual grow rate of CO2 concentration in the decades")
print("(obtained from decadal linear fits)")
dec = 1960
for a in c_popt_array[::2]:
    print("{0:d}s: {1:9f} °C/yr".format(dec, a))
    dec=dec+10



# # Plots

# In[6]:


#Plot
fig = plt.figure(figsize=(12,10))
ax = fig.add_subplot(211)
x = np.linspace(0,len(t_mean), len(t_mean))
ax.set_xticks(x[::60])
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ax.set_xticklabels(t_year[::60].astype(int), rotation=45)
ax.plot(x, t_mean, label="data")
ax.fill_between(x,t_up_conf, t_low_conf, alpha=0.4, label="95% confidence level")
ax.plot(x[60:-60], t_dec_mean, linewidth=2, color="orange", label="decadal mean")
ax.plot(x[60:-60], t_dec_median, linewidth=2, color="red", label="decadal median")
#decadal mean/median plotted at time t is mean/median of period (t-5yr, t+5yr)
ax.plot(x[np.logical_and(t_year>=1850, t_year<2020)], t_fit, ls="--", color="black", label="decadal
linear fits") #Fits

ax.set_title("Time series of temperature anomaly\nreference period:1961-1990", y=0.85)
ax.set_ylabel("Temperature anomaly in °C")
ax.set_xlabel("Time in years")
ax.legend(loc="lower right")

#Plot
ax2 = fig.add_subplot(212)
x = np.linspace(0,len(c_mean), len(c_mean))
ax2.set_xticks(x[8::60])
ax2.set_xticklabels(c_year[8::60], rotation=45)
ax2.plot(x, c_mean, label="data")
ax2.plot(x[60:-60], c_dec_mean, linewidth=2, color="orange", label="decadal mean")
ax2.plot(x[60:-60], c_dec_median, linewidth=2, color="red", label="decadal median")
#decadal mean/median plotted at time t is mean/median of period (t-5yr, t+5yr)
ax2.plot(x[np.logical_and(c_year>=1960, c_year<2020)], c_fit, ls="--", color="black", label="decadal
linear fits") #Fits
ax2.set_title("Time series of CO2-concentration", y=0.9)
ax2.set_ylabel("CO2 concentration in ppm")
ax2.set_xlabel("Time in years")
ax2.legend(loc="lower right")


# Temperature: Decaddal mean (and median) show an increasing trend (since the ~1970s), the slope
is becoming steeper.
#
#
# CO2: Decadal mean (and median) of CO2 show an increasing trend

# ### C
# Increasing temperatures imply that a thermodynamic equilibrium does not exist anymore.

# ### D

# In[8]:




#Quadratic Fit to predict 2050
#We do a quadratic fit for all data from 1970 on

#Temperature
```

```
mask = t_year >= 1970
t_predict_popt, t_predict_pcov = curve_fit(quadratic, t_year[mask] + t_month[mask]/12,
t_mean[mask])
print("\nTemperature prediction for year 2050: {0:0.1f} °C higher than average 1961-
1990".format(quadratic(2050, *t_predict_popt)))
print("(using quadratic fit for the data from 1970 on)")


# ### E

# $$T_{s}=(\frac{S_0(1-A)}{2\sigma})^{\frac{1}{4}}\cdot\frac{1}{(2-\varepsilon_{a})}^{\frac{1}{4}}\\
#       \frac{dT_{s}}{d\varepsilon_{a}}= (\frac{S_0(1-A)}{2\sigma})^{\frac{1}{4}}\cdot\frac{1}{4(2-
\varepsilon_{a})^{\frac{5}{4}}}= \frac{1}{4}\cdot\frac{T}{\varepsilon_{a}}\\
#       \Delta T \approx dT,\ \Delta\varepsilon_{a}\approx \varepsilon_{a}\\
#       \Rightarrow \frac{\Delta T}{\Delta\varepsilon_{a}}=\frac{1}{4}\frac{T}{\varepsilon}\\
#       \Rightarrow \frac{\Delta T}{T}= \frac{1}{4}\frac{\Delta\varepsilon_{a}}{\varepsilon_{a}}
# $$
#

# S doesn't change significantly. A might change because of melting Ice, but this can't be the driving
factor. With increasing $CO_2$ levels the emissivity $\epsilon$ increases, which leads to the
observed change in temperature.

# In[10]:


#Extra Temperature Graph

hadcrut = pd.read_csv(
   "monthlyclimatedata.txt",
   delim_whitespace=True,
   usecols=[0, 1],
   header=None)

hadcrut['year'] = hadcrut.iloc[:, 0].apply(lambda x: x.split("/")[0]).astype(int)
hadcrut['month'] = hadcrut.iloc[:, 0].apply(lambda x: x.split("/")[1]).astype(int)
hadcrut = hadcrut.rename(columns={1: "value"})
hadcrut = hadcrut.iloc[:, 1:]


# In[12]:


hadcrut = hadcrut.set_index(['year', 'month'])
hadcrut -= hadcrut.loc[1850:1900].mean()
hadcrut = hadcrut.reset_index()


# In[13]:
```

```
fig = plt.figure(figsize=(14,14))
ax1 = plt.subplot(111, projection='polar')

ax1.axes.get_yaxis().set_ticklabels([])
ax1.axes.get_xaxis().set_ticklabels([])
fig.set_facecolor("#323331")
ax1.set_ylim(0, 3.25)

theta = np.linspace(0, 2*np.pi, 12)

ax1.set_title("Global Temperature Change (1850-2021)", color='white', fontdict={'fontsize': 20})
ax1.set_facecolor('#000100')

years = hadcrut['year'].unique()

for year in years:
    r = hadcrut[hadcrut['year'] == year]['value'] + 1
    # ax1.text(0,0, str(year), color='white', size=30, ha='center')
    ax1.plot(theta, r)


#Temperature rings

full_circle_thetas = np.linspace(0, 2*np.pi, 1000)
blue_line_one_radii = [1.0]*1000
red_line_one_radii = [2.5]*1000
red_line_two_radii = [3.0]*1000

ax1.plot(full_circle_thetas, blue_line_one_radii, c='blue')
ax1.plot(full_circle_thetas, red_line_one_radii, c='red')
ax1.plot(full_circle_thetas, red_line_two_radii, c='red')

ax1.text(np.pi/2, 1.0, "0.0 C", color="blue", ha='center', fontdict={'fontsize': 20})
ax1.text(np.pi/2, 2.5, "1.5 C", color="red", ha='center', fontdict={'fontsize': 20})
ax1.text(np.pi/2, 3.0, "2.0 C", color="red", ha='center', fontdict={'fontsize': 20})


# In[ ]:
```