```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import scipy
%matplotlib inline

from scipy import integrate
from scipy.integrate import odeint
from numpy import exp
from scipy import stats
```

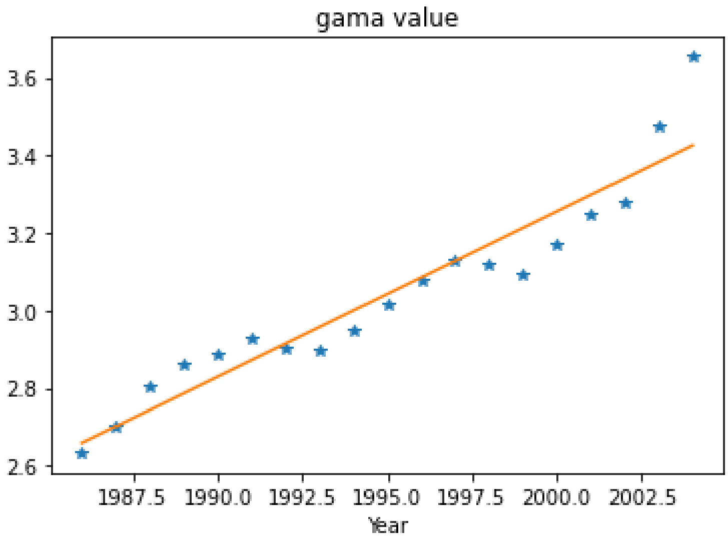
Modeling of carbon cycle

```
## read the data of co2 from fossil burning
co2_data=pd.read_csv("global.1751_2008.csv",usecols=[0,1])
co2_data=co2_data.loc[(co2_data["Year"]>1985)& (co2_data["Year"]<2005)]



## covert this data to ppm
co2_data["total emissions(ppm)"]=co2_data["Total carbon emissions from fossil-
fuels (million metric tons of C)"]/1000/2.13

## set gama value by linear regresssion and define gama() function
time=co2_data["Year"]
gamma= co2_data["total emissions(ppm)"]
gama_value=stats.linregress(time,gamma)
def gama(time):
    gama_result=gama_value.slope*time+gama_value.intercept
    return gama_result
## show the linear result
plt.plot(time,gamma,"*")
plt.plot(time,gama_value.slope*time+gama_value.intercept)
plt.title("gama value")
plt.xlabel("Year")
plt.show()
```




```
## read the data of co2 from globe earth
total_co2=pd.read_csv("co2_annmean_mlo.csv",skiprows=55)
total_co2=total_co2.loc[(total_co2["year"]>1985) & (total_co2["year"] < 2005)]
total_co2
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

	year	mean	unc
27	1986	347.61	0.12
28	1987	349.31	0.12
29	1988	351.69	0.12
30	1989	353.20	0.12
31	1990	354.45	0.12
32	1991	355.70	0.12
33	1992	356.54	0.12
34	1993	357.21	0.12
35	1994	358.96	0.12
36	1995	360.97	0.12
37	1996	362.74	0.12
38	1997	363.88	0.12
39	1998	366.84	0.12
40	1999	368.54	0.12
41	2000	369.71	0.12
42	2001	371.32	0.12
43	2002	373.45	0.12
44	2003	375.98	0.12
45	2004	377.70	0.12

1.1 following 1-2 equation to build a two-box model.

```
which is without buffer effect
```

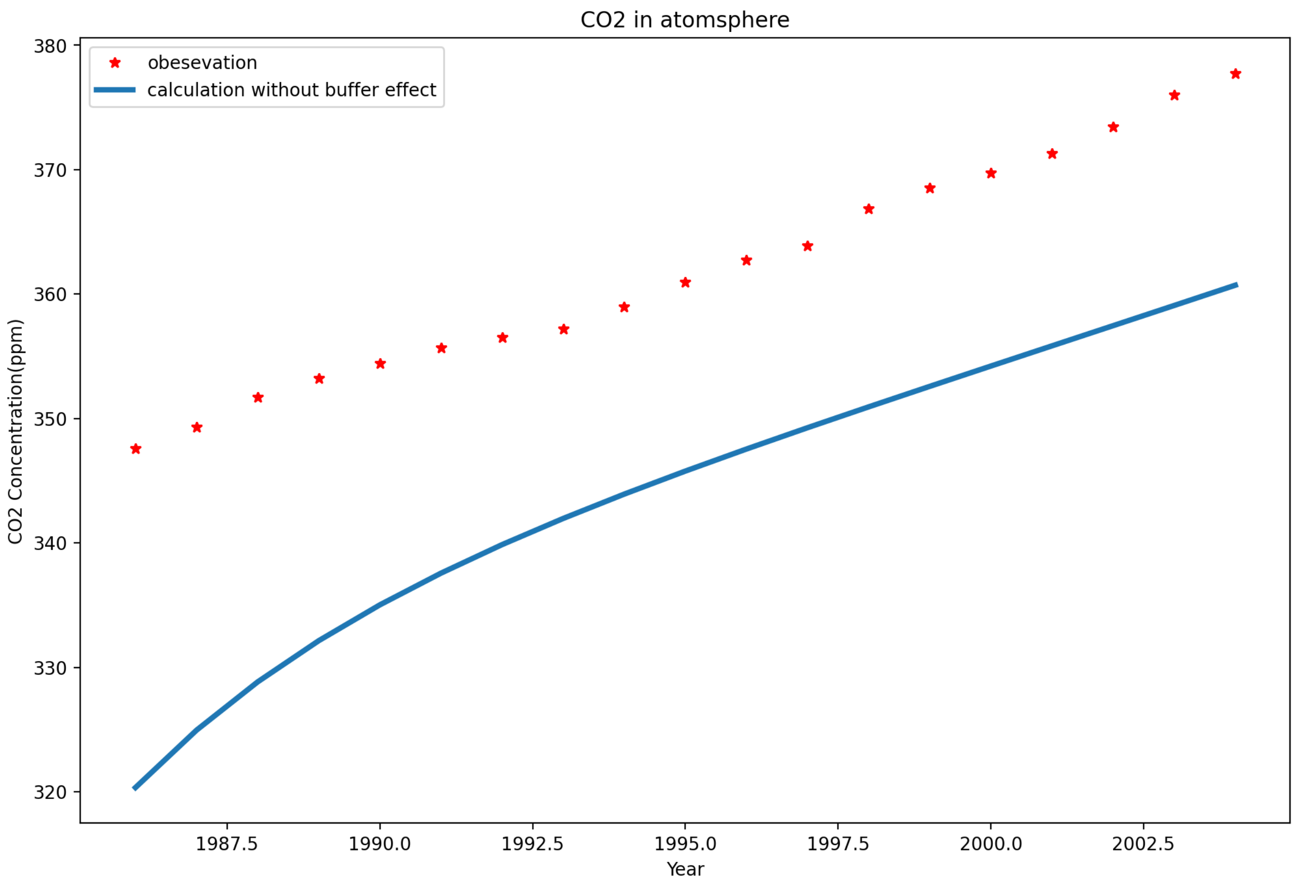
```
# complete the no buffer model
def TwoBoxModel_one(f,t,k12,k21):
    N1,N2=f
    dfdt=[-k12*N1+k21*N2+gama(t),k12*N1-k21*N2]
```

```
    return dfdt
# use the given value for the equation
t=np.arange(1985,2004)
k12=105/740
k21=102/900
# intial condition
f0=[740/2.31,900/2.13]

# set the equation and sovle it
f_1= integrate.odeint(TwoBoxModel_one,f0,t,args=(k12,k21))
f_1[:,0]
```

```
array([320.34632035, 324.95918992, 328.83664038, 332.1485823 ,
       335.02667461, 337.57290553, 339.86629213, 341.96806654,
       343.92563648, 345.77575675, 347.54689528, 349.26110681,
       350.9354794 , 352.58325072, 354.21467589, 355.83770193,
       357.45848441, 359.08179272, 360.71132198])
```

```
## Plot the results
plt.figure(figsize=(12,8),dpi=200)
plt.plot(total_co2["year"],total_co2["mean"],"r*",label="obesevation")
plt.plot(total_co2["year"],f_1[:,0],label="calculation without buffer
effect",linewidth=3)
plt.xlabel("Year")
plt.ylabel("CO2 Concentration(ppm)")
plt.legend(loc=2)
plt.title("CO2 in atomsphere")
plt.show()
```



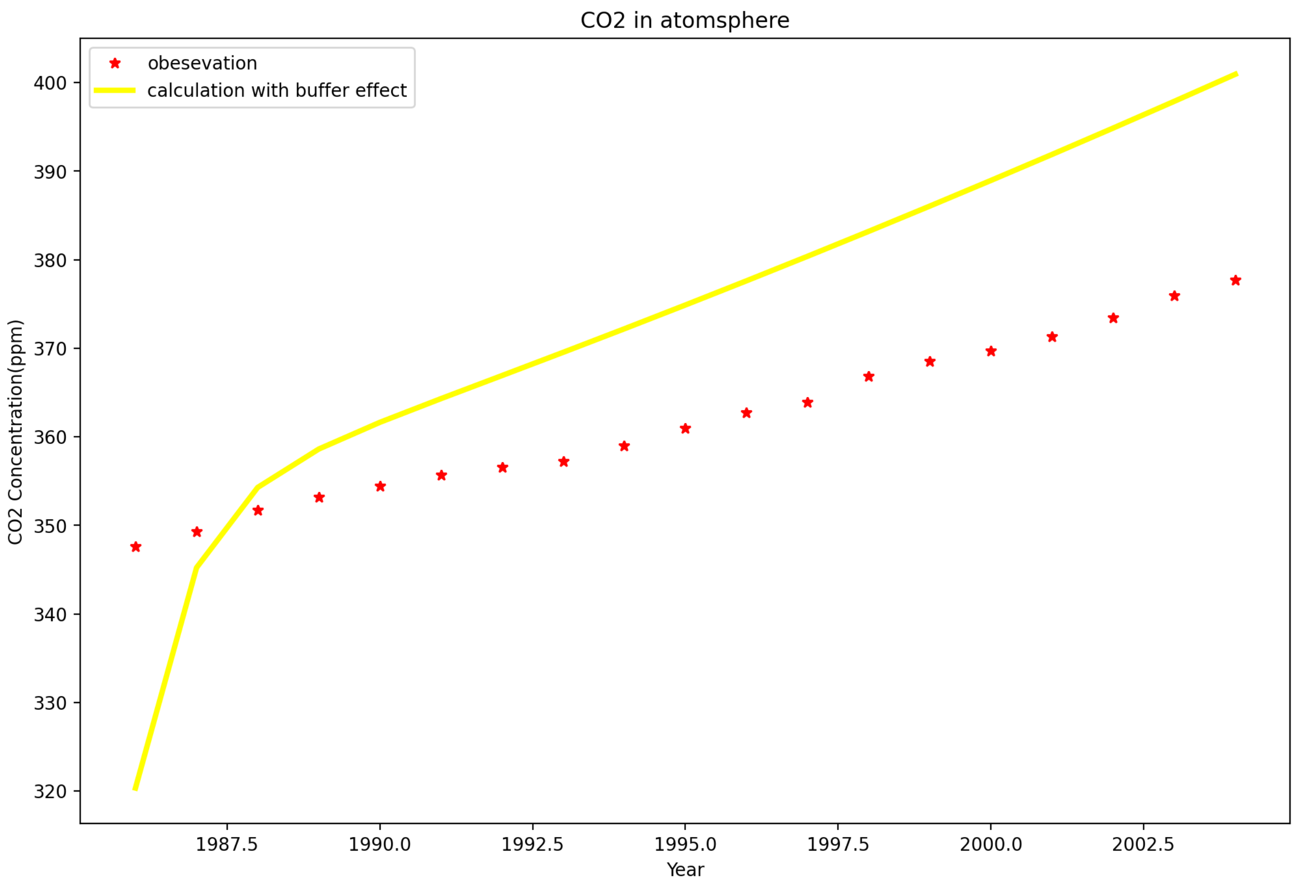
1.2 Following 3-4 equation

indicating buffering infulence

```
# use the given value for the equation
t=np.arange(1985,2004)
k12=105/740
k21=102/900
N20=821/2.13
# intial condition
f0=[740/2.31,900/2.13]
# Define the function with buffer effect
def TwoBoxModel_two(f,t,k12,k21):
    N1,N2=f
    kexi=3.69+1.86*(10**-2)*N1-1.8*(10**-6)*(N1)**2
    dfdt=[-k12*N1+k21*(N20+kexi*(N2-N20))+gama(t),k12*N1-k21*(N20+kexi*(N2-N20))]
    return dfdt
# solve the equation
f_2=odeint(TwoBoxModel_two,f0,t,args=(k12,k21))
f_2[:,0]
```

```
array([320.34632035, 345.23753352, 354.29047624, 358.62654144,
       361.64348401, 364.31868769, 366.92777227, 369.54783054,
       372.20034361, 374.89130786, 377.62242688, 380.39422288,
       383.2068875 , 386.06052631, 388.95522051, 391.8910426 ,
       394.86806286, 397.88635043, 400.94597397])
```

```
## Plot the results
plt.figure(figsize=(12,8),dpi=200)
plt.plot(total_co2["year"],total_co2["mean"],"r*",label="obesevation")
plt.plot(total_co2["year"],f_2[:,0],label="calculation with buffer
effect",linewidth=3,color="yellow")
plt.xlabel("Year")
plt.ylabel("CO2 Concentration(ppm)")
plt.legend(loc=2)
plt.title("CO2 in atomsphere")
plt.show()
```



1.3 Reproduce Figure2 in Tomizuka

```
plt.figure(figsize=(12,8),dpi=200)
plt.plot(total_co2["year"],total_co2["mean"],"r*",label="obesevation")
plt.plot(total_co2["year"],f_1[:,0],label="calculation without buffer
effect",linewidth=3,color="blue")
plt.plot(total_co2["year"],f_2[:,0],label="calculation with buffer
effect",linewidth=3,color="yellow")
```

```
plt.xlabel("Year",fontsize=15)
plt.ylabel("CO2 Concentration(ppm)",fontsize=15)
plt.legend(loc=2)
plt.xlim(1985,2008)
plt.ylim(310,420)
plt.annotate("Calculation with buffer effect",(1987,380),fontsize=12)
plt.annotate("Calculation without buffer effect",(1990,330),fontsize=12)
plt.annotate("Observations",(2000,380),fontsize=12)
plt.title("CO2 in atomsphere")
plt.show()
```