

- 1.1先用 $y=\exp(a_1 \cdot x+a_2)+a_3$ 作为拟合函数，得到化石燃料排放的二氧化碳随时间变化的曲线，画出真实值和拟合后的图，得到拟合函数里的三个参数，然后在不考虑buffer effect的情况下设置碳循环函数，画出没有buffer effect的二氧化碳大气浓度。
- 1.2重新定义有buffer effect的函数，画图。
- 1.3利用二氧化碳年平均数据，再把上面两个图结合起来，得到类似文献中的图2的二氧化碳模拟与观测值的变化趋势图。

```
In [1]: # Import SciPy
import scipy
import pandas as pd
import numpy as np
from scipy import constants
from scipy.interpolate import UnivariateSpline
from numpy import exp
from scipy import integrate
from scipy import optimize
import numpy as np
import matplotlib.pyplot as plt
import numpy as np
%matplotlib inline
from scipy.integrate import odeint
# got help from my senior fellow apprentice Zhao Wangchao
```

## 1.1 build a two-box model to compute the atmospheric CO2 level in ppm (parts per million) from 1987 to 2004(without the buffer effect)

```
In [2]: df1=pd.read_csv('global.1751_2014.csv')
df1
```

Out[2]:

	Year	Total carbon emissions from fossil fuel consumption and cement production (million metric tons of C)	Carbon emissions from gas fuel consumption	Carbon emissions from liquid fuel consumption	Carbon emissions from solid fuel consumption	Carbon emissions from cement production	Carbon emissions from gas flaring	Pe err af
0	1751	3	0	0	3	0	0	
1	1752	3	0	0	3	0	0	
2	1753	3	0	0	3	0	0	
3	1754	3	0	0	3	0	0	
4	1755	3	0	0	3	0	0	
...	...	...	...	...	...	...	...	
259	2010	9128	1696	3107	3812	446	67	
260	2011	9503	1756	3134	4055	494	64	
261	2012	9673	1783	3200	4106	519	65	
262	2013	9773	1806	3220	4126	554	68	
263	2014	9855	1823	3280	4117	568	68	

264 rows × 8 columns

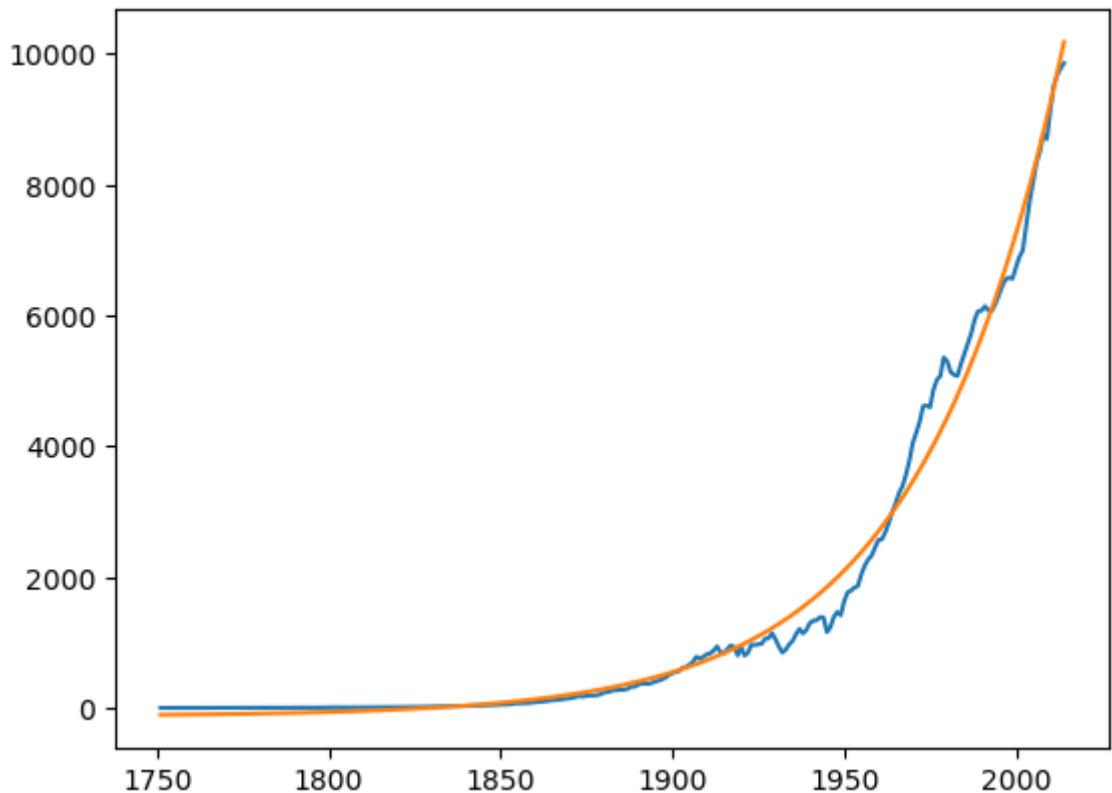
```
In [3]: # 用 $y=\exp(a_1x+a_2)+a_3$ 作为拟合函数，得到化石燃料排放的二氧化碳随时间变化的曲线
def fossil_emiss(x, a1, a2, a3):
    return np.exp(a1*x+a2)+a3

# 设置拟合的初始值
a1=0.1
a2=0.1
a3=0
p0=[a1, a2, a3]

# 调用拟合函数
df1['Year'].astype(int)
df1['Total carbon emissions from fossil fuel consumption and cement production (million tons)']
para, cov = optimize.curve_fit(fossil_emiss, df1['Year'], df1['Total carbon emissions'])

# 画真实值和拟合后的图
plt.plot(df1['Year'], df1['Total carbon emissions from fossil fuel consumption and cement production (million tons)'], 'b-')
plt.plot(df1['Year'], fossil_emiss(df1['Year'], *para), 'r-', label='fit')

plt.show()
print(para)
```

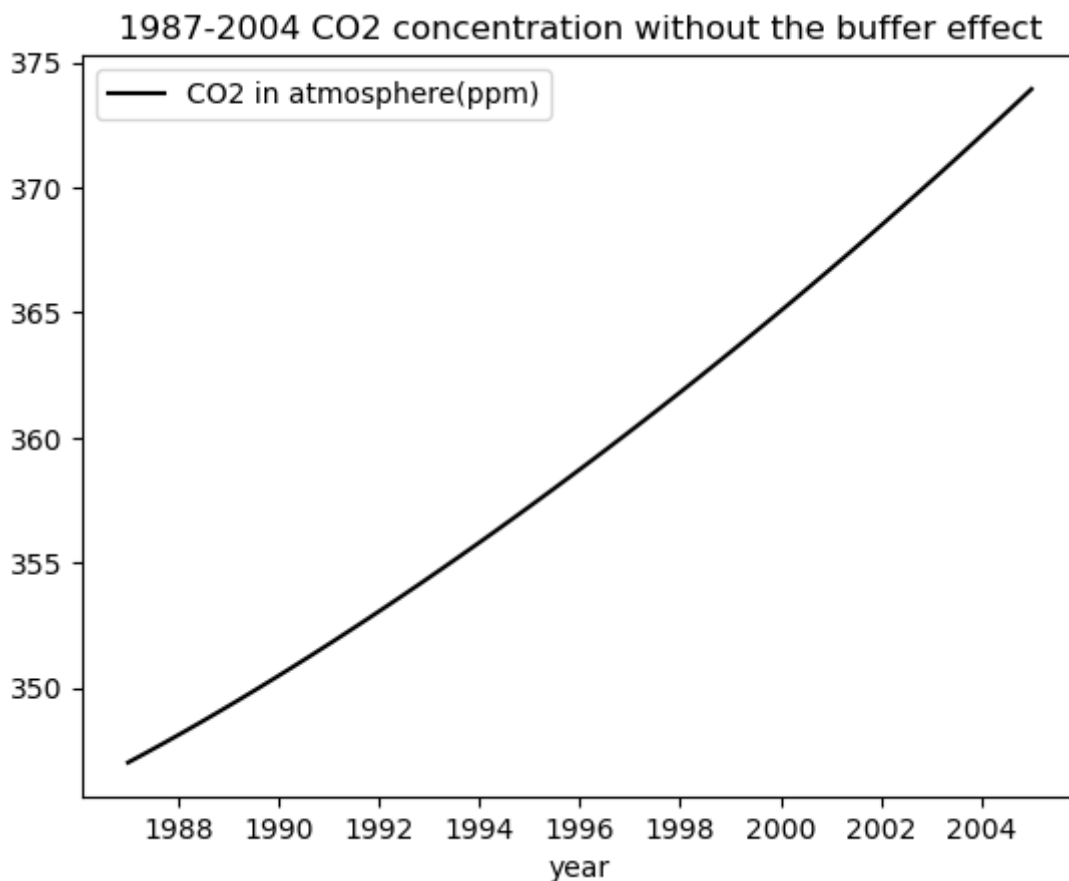


```
[ 2.39596800e-02 -3.90147674e+01 -1.2229282e+02]
```

```
In [4]: #https://zhuanlan.zhihu.com/p/484167038
# 定义没有buffer效应的碳循环函数
def model1(y, t, k12, k21):
    N1, N2, a = y #a是 $\gamma$ 
    dydt = [-k12*N1+k21*N2+a, k12*N1-k21*N2, 2.39596800e-02*a+2.39596800e-02*1.2229282e+02]
    return dydt
```

```
In [5]: # 设置初始值
t1=np.linspace(1987, 2005)
a=fossil_emiss(t1,*para)
k12=105/740
k21=102/900
N1=740*1000
N2=900*1000
y0=[N1,N2,a[0]]
#转化单位
sol = odeint(model1, y0, t1, args=(k12,k21))/1000/740*347
```

```
In [13]: # 画图
from matplotlib.ticker import MaxNLocator
plt.plot(t1, sol[:, 0], 'k', label='CO2 in atmosphere(ppm)')
plt.legend(loc='best')
plt.xlabel('year')
# 设置横坐标轴刻度为整数
plt.gca().xaxis.set_major_locator(MaxNLocator(integer=True))
plt.title('1987-2004 CO2 concentration without the buffer effect')
plt.show()
```



**1.2 build a two-box model to compute the atmospheric CO2 level in ppm from 1987 to 2004(with the buffer effect)**

```
In [7]: # 定义有buffer效应的函数
def model2(y, t, k12, k21, N0):
    N1, N2, a2 = y
    bf=3.69+1.86e-2*(N1/740/1000*347)-1.8e-6*((N1/740/1000*347)**2) #buffer factor
    dydt=[-k12*N1+k21*(N0+bf*(N2-N0))+a2,
          k12*N1-k21*(N0+bf*(N2-N0)),
          2.39596800e-02*a2+2.39596800e-02*1.22229282e+02]
    return dydt
```

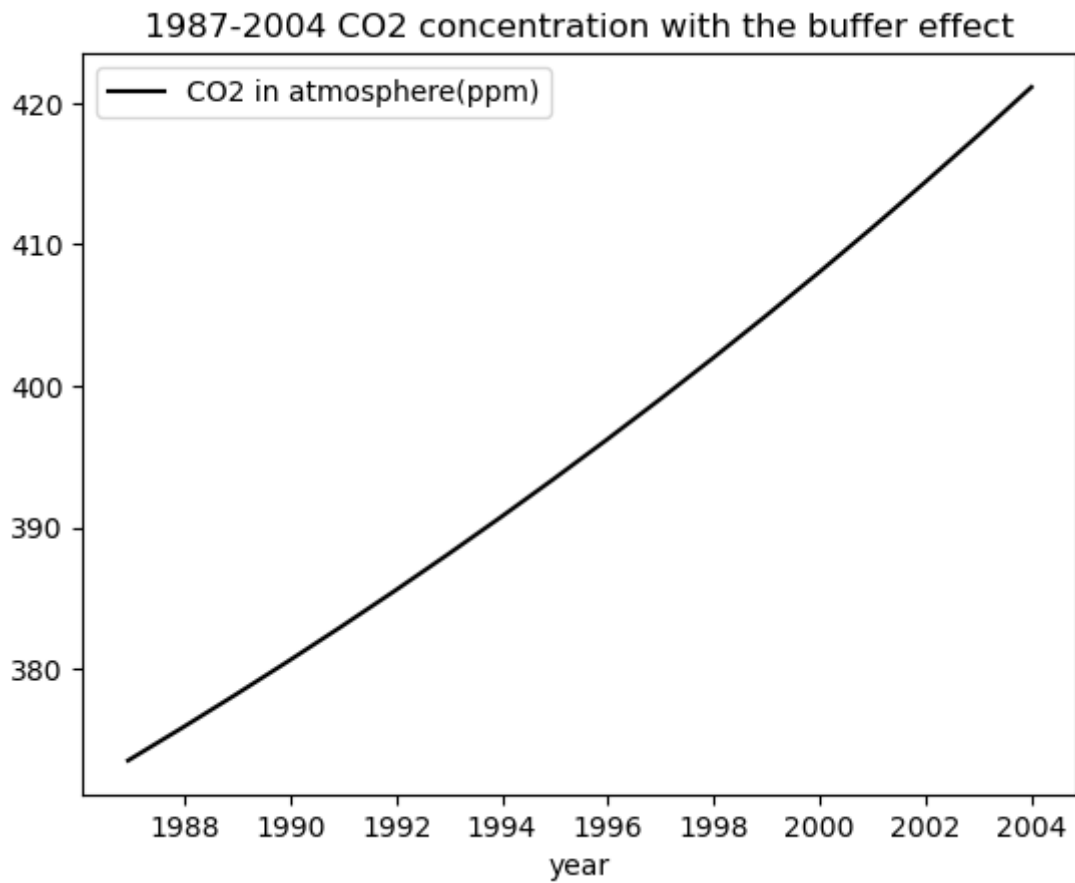
```
In [8]: # 设置初始值
t2=np.linspace(0, 253, 253)+1751
a2=fossil_emiss(t2,*para)

k12=105/740
k21=102/900
N0=821*1000
N1=618*1000
N2=821*1000
y0=[N1, N2, a2[0]]
sol2 = odeint(model2, y0, t2, args=(k12, k21, N0))/740/1000*347 #计算微分方程，并且转化
```

```
In [9]: sol2
```

```
Out[9]: array([[ 2.89791892e+02,  3.84982432e+02, -4.84577482e-02],
 [ 2.91238045e+02,  3.83487737e+02, -4.82420907e-02],
 [ 2.91660746e+02,  3.83016713e+02, -4.80211828e-02],
 [ 2.91763603e+02,  3.82865757e+02, -4.77948966e-02],
 [ 2.91766902e+02,  3.82814589e+02, -4.75631011e-02],
 [ 2.91739337e+02,  3.82794521e+02, -4.73256623e-02],
 [ 2.91702311e+02,  3.82784156e+02, -4.70824426e-02],
 [ 2.91662489e+02,  3.82776834e+02, -4.68333014e-02],
 [ 2.91621951e+02,  3.82770480e+02, -4.65780946e-02],
 [ 2.91581350e+02,  3.82764449e+02, -4.63166743e-02],
 [ 2.91540891e+02,  3.82758540e+02, -4.60488894e-02],
 [ 2.91500644e+02,  3.82752693e+02, -4.57745849e-02],
 [ 2.91460633e+02,  3.82746889e+02, -4.54936021e-02],
 [ 2.91420870e+02,  3.82741121e+02, -4.52057783e-02],
 [ 2.91381363e+02,  3.82735390e+02, -4.49109471e-02],
 [ 2.91342120e+02,  3.82729695e+02, -4.46089378e-02],
 [ 2.91303146e+02,  3.82724038e+02, -4.42995755e-02],
 [ 2.91264449e+02,  3.82718418e+02, -4.39826815e-02],
 [ 2.91226034e+02,  3.82712838e+02, -4.36580724e-02],
 [ 2.91187900e+02,  3.82707298e+02, -4.33355602e-02],
 [ 2.91150050e+02,  3.82701798e+02, -4.30151400e-02],
 [ 2.91112485e+02,  3.82696337e+02, -4.26968150e-02],
 [ 2.91075205e+02,  3.82690915e+02, -4.23805800e-02],
 [ 2.91038210e+02,  3.82685532e+02, -4.20664300e-02],
 [ 2.91001500e+02,  3.82680188e+02, -4.17543600e-02],
 [ 2.90965075e+02,  3.82674883e+02, -4.14443750e-02],
 [ 2.90928935e+02,  3.82669617e+02, -4.11364700e-02],
 [ 2.90893080e+02,  3.82664390e+02, -4.08306400e-02],
 [ 2.90857510e+02,  3.82659192e+02, -4.05268800e-02],
 [ 2.90822225e+02,  3.82654023e+02, -4.02251850e-02],
 [ 2.90787225e+02,  3.82648883e+02, -4.09255500e-02],
 [ 2.90752510e+02,  3.82643772e+02, -4.06275000e-02],
 [ 2.90718080e+02,  3.82638690e+02, -4.03310200e-02],
 [ 2.90683935e+02,  3.82633637e+02, -4.00361000e-02],
 [ 2.90650075e+02,  3.82628612e+02, -3.97427200e-02],
 [ 2.90616500e+02,  3.82623615e+02, -3.94508800e-02],
 [ 2.90583210e+02,  3.82618646e+02, -3.91605700e-02],
 [ 2.90550205e+02,  3.82613704e+02, -3.88717800e-02],
 [ 2.90517485e+02,  3.82608789e+02, -3.85845000e-02],
 [ 2.90485050e+02,  3.82603900e+02, -3.82987200e-02],
 [ 2.90452900e+02,  3.82599037e+02, -3.80144400e-02],
 [ 2.90421035e+02,  3.82594200e+02, -3.77316500e-02],
 [ 2.90389455e+02,  3.82589389e+02, -3.74503500e-02],
 [ 2.90358160e+02,  3.82584604e+02, -3.71705400e-02],
 [ 2.90327150e+02,  3.82579845e+02, -3.68922100e-02],
 [ 2.90296425e+02,  3.82575112e+02, -3.66153600e-02],
 [ 2.90265985e+02,  3.82570405e+02, -3.63400000e-02],
 [ 2.90235830e+02,  3.82565724e+02, -3.60661200e-02],
 [ 2.90205960e+02,  3.82561069e+02, -3.57937200e-02],
 [ 2.90176375e+02,  3.82556440e+02, -3.55228000e-02],
 [ 2.90147075e+02,  3.82551837e+02, -3.52533500e-02],
 [ 2.90118060e+02,  3.82547260e+02, -3.49853700e-02],
 [ 2.90089330e+02,  3.82542708e+02, -3.47188600e-02],
 [ 2.90060885e+02,  3.82538181e+02, -3.44538200e-02],
 [ 2.90032725e+02,  3.82533679e+02, -3.41902500e-02],
 [ 2.90004850e+02,  3.82529202e+02, -3.39281500e-02],
 [ 2.89977260e+02,  3.82524750e+02, -3.36675200e-02],
 [ 2.89950055e+02,  3.82520323e+02, -3.34083500e-02],
 [ 2.89923235e+02,  3.82515920e+02, -3.31506400e-02],
 [ 2.89896800e+02,  3.82511541e+02, -3.28943900e-02],
 [ 2.89870750e+02,  3.82507186e+02, -3.26396000e-02],
 [ 2.89845085e+02,  3.82502855e+02, -3.23862700e-02],
 [ 2.89819805e+02,  3.82498548e+02, -3.21344000e-02],
 [ 2.89794910e+02,  3.82494264e+02, -3.18840000e-02],
 [ 2.89770400e+02,  3.82489994e+02, -3.16350700e-02],
 [ 2.89746275e+02,  3.82485738e+02, -3.13876100e-02],
 [ 2.89722535e+02,  3.82481496e+02, -3.11416200e-02],
 [ 2.89699180e+02,  3.82477268e+02, -3.08971000e-02],
 [ 2.89676210e+02,  3.82473054e+02, -3.06540500e-02],
 [ 2.89653725e+02,  3.82468854e+02, -3.04124700e-02],
 [ 2.89631725e+02,  3.82464668e+02, -3.01723600e-02],
 [ 2.89610210e+02,  3.82460496e+02, -2.99337200e-02],
 [ 2.89589180e+02,  3.82456338e+02, -2.96965500e-02],
 [ 2.89568635e+02,  3.82452194e+02, -2.94608500e-02],
 [ 2.89548575e+02,  3.82448064e+02, -2.92266200e-02],
 [ 2.89529000e+02,  3.82443948e+02, -2.89938600e-02],
 [ 2.89510010e+02,  3.82439846e+02, -2.87625700e-02],
 [ 2.89491605e+02,  3.82435758e+02, -2.85327500e-02],
 [ 2.89473785e+02,  3.82431684e+02, -2.83044000e-02],
 [ 2.89456450e+02,  3.82427624e+02, -2.80775200e-02],
 [ 2.89439690e+02,  3.82423578e+02, -2.78521100e-02],
 [ 2.89423505e+02,  3.82419546e+02, -2.76281700e-02],
 [ 2.89407895e+02,  3.82415528e+02, -2.74057000e-02],
 [ 2.89392860e+02,  3.82411524e+02, -2.71847100e-02],
 [ 2.89378400e+02,  3.82407534e+02, -2.69652000e-02],
 [ 2.89363515e+02,  3.82403558e+02, -2.67471700e-02],
 [ 2.89349105e+02,  3.82400000e+02, -2.65306200e-02],
 [ 2.89335270e+02,  3.82396459e+02, -2.63155500e-02],
 [ 2.89321910e+02,  3.82392936e+02, -2.61019600e-02],
 [ 2.89309025e+02,  3.82389431e+02, -2.58898500e-02],
 [ 2.89296615e+02,  3.82385944e+02, -2.56792200e-02],
 [ 2.89284680e+02,  3.82382475e+02, -2.54700700e-02],
 [ 2.89273220e+02,  3.82379024e+02, -2.52624000e-02],
 [ 2.89262235e+02,  3.82375591e+02, -2.50562100e-02],
 [ 2.89251725e+02,  3.82372176e+02, -2.48515000e-02],
 [ 2.89241690e+02,  3.82368779e+02, -2.46482700e-02],
 [ 2.89232130e+02,  3.82365399e+02, -2.44465200e-02],
 [ 2.89223045e+02,  3.82362037e+02, -2.42462500e-02],
 [ 2.89214435e+02,  3.82358692e+02, -2.40474600e-02],
 [ 2.89206300e+02,  3.82355364e+02, -2.38491500e-02],
 [ 2.89198640e+02,  3.82352053e+02, -2.36523200e-02],
 [ 2.89191455e+02,  3.82348760e+02, -2.34569700e-02],
 [ 2.89184745e+02,  3.82345484e+02, -2.32631000e-02],
 [ 2.89178510e+02,  3.82342225e+02, -2.30707100e-02],
 [ 2.89172750e+02,  3.82338984e+02, -2.28798000e-02],
 [ 2.89167465e+02,  3.82335760e+02, -2.26903700e-02],
 [ 2.89162655e+02,  3.82332554e+02, -2.25024200e-02],
 [ 2.89158320e+02,  3.82329365e+02, -2.23159500e-02],
 [ 2.89154460e+02,  3.82326194e+02, -2.21309600e-02],
 [ 2.89151075e+02,  3.82323041e+02, -2.19474500e-02],
 [ 2.89148165e+02,  3.82319906e+02, -2.17654200e-02],
 [ 2.89145730e+02,  3.82316789e+02, -2.15848700e-02],
 [ 2.89143770e+02,  3.82313690e+02, -2.14058000e-02],
 [ 2.89142285e+02,  3.82310609e+02, -2.12282100e-02],
 [ 2.89141275e+02,  3.82307546e+02, -2.10521000e-02],
 [ 2.89140740e+02,  3.82304501e+02, -2.08774700e-02],
 [ 2.89140680e+02,  3.82301474e+02, -2.07043200e-02],
 [ 2.89141095e+02,  3.82298465e+02, -2.05326500e-02],
 [ 2.89141975e+02,  3.82295474e+02, -2.03624600e-02],
 [ 2.89143320e+02,  3.82292501e+02, -2.01937500e-02],
 [ 2.89145130e+02,  3.82289546e+02, -2.00265200e-02],
 [ 2.89147405e+02,  3.82286609e+02, -1.98607700e-02],
 [ 2.89150145e+02,  3.82283690e+02, -1.96965000e-02],
 [ 2.89153350e+02,  3.82280799e+02, -1.95337100e-02],
 [ 2.89157020e+02,  3.82277936e+02, -1.93724000e-02],
 [ 2.89161155e+02,  3.82275091e+02, -1.92125700e-02],
 [ 2.89165755e+02,  3.82272264e+02, -1.90542200e-02],
 [ 2.89170820e+02,  3.82269455e+02, -1.88973500e-02],
 [ 2.89176350e+02,  3.82266664e+02, -1.87419600e-02],
 [ 2.89182345e+02,  3.82263891e+02, -1.85880500e-02],
 [ 2.89188805e+02,  3.82261136e+02, -1.84356200e-02],
 [ 2.89195730e+02,  3.82258400e+02, -1.82846700e-02],
 [ 2.89203120e+02,  3.82255682e+02, -1.81352000e-02],
 [ 2.89210975e+02,  3.82252983e+02, -1.79872100e-02],
 [ 2.89219295e+02,  3.82250303e+02, -1.78407000e-02],
 [ 2.89228080e+02,  3.82247642e+02, -1.76956700e-02],
 [ 2.89237330e+02,  3.82245000e+02, -1.75521200e-02],
 [ 2.89247045e+02,  3.82242377e+02, -1.74100500e-02],
 [ 2.89257225e+02,  3.82239773e+02, -1.72694600e-02],
 [ 2.89267870e+02,  3.82237188e+02, -1.71303500e-02],
 [ 2.89278980e+02,  3.82234622e+02, -1.69927200e-02],
 [ 2.89290555e+02,  3.82232075e+02, -1.68565700e-02],
 [ 2.89302595e+02,  3.82229547e+02, -1.67219000e-02],
 [ 2.89315090e+02,  3.82227038e+02, -1.65887100e-02],
 [ 2.89328040e+02,  3.82224548e+02, -1.64560000e-02],
 [ 2.89341445e+02,  3.82222067e+02, -1.63247700e-02],
 [ 2.89355305e+02,  3.82219605e+02, -1.61950200e-02],
 [ 2.89369620e+02,  3.82217162e+02, -1.60667500e-02],
 [ 2.89384390e+02,  3.82214738e+02, -1.59399600e-02],
 [ 2.89399615e+02,  3.82212333e+02, -1.58146500e-02],
 [ 2.89415295e+02,  3.82210000e+02, -1.56908200e-02],
 [ 2.89431430e+02,  3.82207639e+02, -1.55684700e-02],
 [ 2.89448020e+02,  3.82205250e+02, -1.54476000e-02],
 [ 2.89465065e+02,  3.82202843e+02, -1.53282100e-02],
 [ 2.89482565e+02,  3.82200408e+02, -1.52093000e-02],
 [ 2.89500520e+02,  3.82197946e+02, -1.50918700e-02],
 [ 2.89518930e+02,  3.82195457e+02, -1.49759200e-02],
 [ 2.89537795e+02,  3.82192941e+02, -1.48614500e-02],
 [ 2.89557115e+02,  3.82190398e+02, -1.47484600e-02],
 [ 2.89576890e+02,  3.82187828e+02, -1.46369500e-02],
 [ 2.89597120e+02,  3.82185231e+02, -1.45269200e-02],
 [ 2.89617805e+02,  3.82182606e+02, -1.44183700e-02],
 [ 2.89638945e+02,  3.82180000e+02, -1.43113000e-02],
 [ 2.89660540e+02,  3.82177414e+02, -1.42057100e-02],
 [ 2.89682590e+02,  3.82174848e+02, -1.41016000e-02],
 [ 2.89705095e+02,  3.82172302e+02, -1.39989700e-02],
 [ 2.89728055e+02,  3.82169776e+02, -1.38968200e-02],
 [ 2.89751470e+02,  3.82167269e+02, -1.37961500e-02],
 [ 2.89775340e+02,  3.82164782e+02, -1.36969600e-02],
 [ 2.89799665e+02,  3.82162314e+02, -1.35992500e-02],
 [ 2.89824445e+02,  3.82159865e+02, -1.35030200e-02],
 [ 2.89849680e+02,  3.82157435e+02, -1.34082700e-02],
 [ 2.89875370e+02,  3.82155024e+02, -1.33140000e-02],
 [ 2.89901515e+02,  3.82152632e+02, -1.32212100e-02],
 [ 2.89928115e+02,  3.82150259e+02, -1.31299000e-02],
 [ 2.89955170e+02,  3.82147904e+02, -1.30400700e-02],
 [ 2.89982680e+02,  3.82145568e+02, -1.29517200e-02],
 [ 2.90010645e+02,  3.82143250e+02, -1.28648500e-02],
 [ 2.90039065e+02,  3.82140951e+02, -1.27794600e-02],
 [ 2.90067940e+02,  3.82138671e+02, -1.26955500e-02],
 [ 2.90097270e+02,  3.82136410e+02, -1.26131200e-02],
 [ 2.90127055e+02,  3.82134167e+02, -1.25321700e-02],
 [ 2.90157295e+02,  3.82131942e+02, -1.24527000e-02],
 [ 2.90187990e+02,  3.82129735e+02, -1.23747100e-02],
 [ 2.90219140e+02,  3.82127546e+02, -1.22982000e-02],
 [ 2.90250745e+02,  3.82125365e+02, -1.22231700e-02],
 [ 2.90282805e+02,  3.82123192e+02, -1.21496200e-02],
 [ 2.90315320e+02,  3.82121027e+02, -1.20775500e-02],
 [ 2.90348290e+02,  3.82118880e+02, -1.20069600e-02],
 [ 2.90381715e+02,  3.82116750e+02, -1.19378500e-02],
 [ 2.90415595e+02,  3.82114638e+02, -1.18692200e-02],
 [ 2.90450030e+02,  3.82112543e+02, -1.18020700e-02],
 [ 2.90485020e+02,  3.82110465e+02, -1.17364000e-02],
 [ 2.90520565e+02,  3.82108404e+02, -1.16722100e-02],
 [ 2.90556665e+02,  3.82106360e+02, -1.16095000e-02],
 [ 2.90593320e+02,  3.82104333e+02, -1.15482700e-02],
 [ 2.90630530e+02,  3.82102323e+02, -1.14885200e-02],
 [ 2.90668295e+02,  3.82100330e+02, -1.14302500e-02],
 [ 2.90706615e+02,  3.82098354e+02, -1.13734600e-02],
 [ 2.90745490e+02,  3.82096395e+02, -1.13181500e-02],
 [ 2.90784920e+02,  3.82094453e+02, -1.12643200e-02],
 [ 2.90824905e+02,  3.82092528e+02, -1.12119700e-02],
 [ 2.90865445e+02,  3.82090620e+02, -1.11611000e-02],
 [ 2.90906540e+02,  3.82088729e+02, -1.11117100e-02],
 [ 2.90948190e+02,  3.82086855e+02, -1.10638000e-02],
 [ 2.90990395e+02,  3.82084998e+02, -1.10173700e-02],
 [ 2.91033155e+02,  3.82083158e+02, -1.09724200e-02],
 [ 2.91076470e+02,  3.82081335e+02, -1.09289500e-02],
 [ 2.91120340e+02,  3.82079528e+02, -1.08869600e-02],
 [ 2.91164765e+02,  3.82077737e+02, -1.08464500e-02],
 [ 2.91209745e+02,  3.82075962e+02, -1.08074200e-02],
 [ 2.91255280e+02,  3.82074203e+02, -1.07698700e-02],
 [ 2.91301370e+02,  3.82072460e+02, -1.07338000e-02],
 [ 2.91348015e+02,  3.82070733e+02, -1.06992100e-02],
 [ 2.91395215e+02,  3.82069022e+02, -1.06661000e-02],
 [ 2.91442970e+02,  3.82067327e+02, -1.06344700e-02],
 [ 2.91491280e+02,  3.82065648e+02, -1.06043200e-02],
 [ 2.91540145e+02,  3.82063984e+02, -1.05756500e-02],
 [ 2.91589565e+02,  3.82062336e+02, -1.05484600e-02],
 [ 2.91639540e+02,  3.82060703e+02, -1.05227500e-02],
 [ 2.91690070e+02,  3.82059085e+02, -1.04985200e-02],
 [ 2.91741165e+02,  3.82057482e+02, -1.04747700e-02],
 [ 2.91792825e+02,  3.82055894e+02, -1.04525000e-02],
 [ 2.91845050e+02,  3.82054321e+02, -1.04317100e-02],
 [ 2.91897840e+02,  3.82052763e+02, -1.04124000e-02],
 [ 2.91951195e+02,  3.82051220e+02, -1.03945700e-02],
 [ 2.92005115e+02,  3.82049692e+02, -1.03782200e-02],
 [ 2.92059600e+02,  3.82048179e+02, -1.03633500e-02],
 [ 2.92114650e+02,  3.82046681e+02, -1.03499600e-02],
 [ 2.92170265e+02,  3.82045198e+02, -1.03380500e-02],
 [ 2.92226445e+02,  3.82043730e+02, -1.03276200e-02],
 [ 2.92283190e+02,  3.82042277e+02, -1.03186700e-02],
 [ 2.92340500e+02,  3.82040839e+02, -
```

```
In [14]: # 画图
plt.plot(t2[235:253], sol2[235:253,0], 'k', label='CO2 in atmosphere(ppm)')
plt.legend(loc='best')
plt.xlabel('year')
plt.gca().xaxis.set_major_locator(MaxNLocator(integer=True))
plt.title('1987-2004 CO2 concentration with the buffer effect')
plt.show()
```



### 1.3 reproduce Figure 2 in Tomizuka (2009)

```
In [11]: # 导入观测值数据
df2=pd.read_csv('co2_annmean_mlo.csv')
df2
```

Out[11]:

	year	mean	unc
0	1959	315.98	0.12
1	1960	316.91	0.12
2	1961	317.64	0.12
3	1962	318.45	0.12
4	1963	318.99	0.12
...	...	...	...
59	2018	408.72	0.12
60	2019	411.65	0.12
61	2020	414.21	0.12
62	2021	416.41	0.12
63	2022	418.53	0.12

64 rows × 3 columns

```
In [12]: # 画图
plt.plot(t1, sol[:, 0], linewidth=2, color='grey') # without buffer effect
plt.plot(t2[235:253], sol2[235:253,0], linewidth=4, color='black') # with buffer effect
plt.scatter(df2['year'][30:47], df2['mean'][30:47], color='gray') # observed data
# 设置图例
plt.legend(['without buffer effect', 'with buffer effect', 'observations'], loc='best')
plt.xlabel('Year')
# 设置横纵坐标
plt.gca().axis.set_major_locator(MaxNLocator(integer=True))
plt.xticks([1985, 1990, 1995, 2000], fontsize=12)
plt.yticks([360, 380, 400, 420], fontsize=12)
# 隐藏右边和上边的边框
plt.gca().spines['right'].set_visible(False)
plt.gca().spines['top'].set_visible(False)
plt.title('1987-2004 CO2 trend')
plt.show()
# 不考虑buffer效应时比观测值低估，可能是由于人为源排放拟合时有一定的低估，因此积分之后
```

