In [63]:
```python
import numpy as np
import pandas as pd
import xarray as xr
from matplotlib import pyplot as plt
from netCDF4 import num2date
import seaborn as sns
import cftime
import math
%matplotlib inline
```

In [65]:
```python
# 读取文件，检查数据
co2_sea = pd.read_csv("co2_annmean_gl.csv", skiprows=37)
#print(co2_sea.head(40))
#co2_sea.info()

co2_emi = pd.read_csv("global.1751_2014.ems", skiprows=33, sep=r'\s+')
#print(co2_emi.head())
#co2_emi.info()

co2_atm = pd.read_csv("co2_annmean_mlo.csv", skiprows=43)
#print(co2_atm.head(40))
#co2_atm.info()

co2_land = pd.read_excel("Global_land-use_flux-1850_2005.xls")
#print(co2_land.head(40))
#co2_land.info()
```

In [67]:
```python
#定义转移系数
K_12 = 105/740
K_21 = 102/900

#创建空表格
co2_cal_12 = pd.DataFrame(columns=['year', 'co2_sea_pgc', 'co2_atm_pgc', 'co2_gamma'])

#填充年份列
years = range(1986, 2005)
co2_cal_12['year'] = years

#定义初始值（与论文使用相同）
co2_sea_1986 = 900
co2_atm_1986 = 740

#填充海平面列
co2_cal_12['co2_sea_pgc'] = 0.00
```

```python
co2_cal_12.loc[co2_cal_12['year'] == 1986, 'co2_sea_pgc'] = co2_sea_1986

#填充大气列
co2_cal_12['co2_atm_pgc'] = 0.00
co2_cal_12.loc[co2_cal_12['year'] == 1986, 'co2_atm_pgc'] = co2_atm_1986

#填充排放列（进行单位转换）
for years in range(1986, 2005):
    co2_cal_12.loc[co2_cal_12['year'] == years, 'co2_gamma'] = co2_emi.loc[co2_emi['Year'] == years, 'Total'].values/1000
#print(co2_cal_12.head())

#使用公式创建两箱模型
for years in range(1987, 2005):

    #获取用于计算的数值
    N1 = co2_cal_12.loc[co2_cal_12['year'] == years-1, 'co2_atm_pgc'].values[0]
    #print(f"The N1 is: {N1}")
    N2 = co2_cal_12.loc[co2_cal_12['year'] == years-1, 'co2_sea_pgc'].values[0]
    #print(f"The N2 is: {N2}")
    gamma = co2_cal_12.loc[co2_cal_12['year'] == years, 'co2_gamma'].values[0]

    #进行计算
    N1_new = N1 - K_12*N1 + K_21*N2 + gamma
    #print(f"The new N1 is: {N1_new}")
    N2_new = N2 + K_12*N1 - K_21*N2
    #print(f"The new N2 is: {N2_new}")

    #更新数值
    co2_cal_12.loc[co2_cal_12['year'] == years, 'co2_atm_pgc'] = N1_new
    co2_cal_12.loc[co2_cal_12['year'] == years, 'co2_sea_pgc'] = N2_new

#单位换算
co2_cal_12['co2_sea_cal_ppm'] = co2_cal_12['co2_sea_pgc']/2.13
co2_cal_12['co2_atm_cal_ppm'] = co2_cal_12['co2_atm_pgc']/2.13

#检查结果
print(co2_cal_12)
```

	year	co2_sea_pgc	co2_atm_pgc	co2_gamma	co2_sea_cal_ppm	co2_atm_cal_ppm
0	1986	900.000000	740.000000	5.583	422.535211	347.417840
1	1987	903.000000	742.725000	5.725	423.943662	348.697183
2	1988	906.046655	745.614345	5.936	425.374017	350.053683
3	1989	909.157998	748.569002	6.066	426.834741	351.440846
4	1990	912.335963	751.465037	6.074	428.326743	352.800487
5	1991	915.564683	754.378317	6.142	429.842574	354.168224
6	1992	918.840852	757.180148	6.078	431.380682	355.483637
7	1993	922.143279	759.947721	6.07	432.931117	356.782967
8	1994	925.464128	762.800872	6.174	434.490201	358.122475
9	1995	928.813452	765.756548	6.305	436.062654	359.510116
10	1996	932.202573	768.815427	6.448	437.653790	360.946210
11	1997	935.641623	771.932377	6.556	439.268368	362.409567
12	1998	939.133185	775.016815	6.576	440.907598	363.857660
13	1999	942.666693	778.044307	6.561	442.566522	365.279018
14	2000	946.229313	781.214687	6.733	444.239114	366.767459
15	2001	949.838021	784.498979	6.893	445.933343	368.309380
16	2002	953.503756	787.827244	6.994	447.654346	369.871946
17	2003	957.226295	791.480705	7.376	449.402016	371.587185
18	2004	961.045343	795.404657	7.743	451.194997	373.429416

In [101…

```
#定义转移系数
K_12 = 105/740
K_21 = 102/900

#创建空表格
co2_cal_34 = pd.DataFrame(columns=['year', 'co2_sea_pgc', 'co2_atm_pgc', 'co2_gamma'])

#填充年份列
years = range(1986, 2005)
co2_cal_34['year'] = years

#定义初始值（与论文使用相同）
co2_sea_1986 = 900
co2_atm_1986 = 740

#填充海平面列
co2_cal_34['co2_sea_pgc'] = 0.00
co2_cal_34.loc[co2_cal_34['year'] == 1986, 'co2_sea_pgc'] = co2_sea_1986

#填充大气列
co2_cal_34['co2_atm_pgc'] = 0.00
co2_cal_34.loc[co2_cal_34['year'] == 1986, 'co2_atm_pgc'] = co2_atm_1986

#填充排放列（进行单位转换）
for years in range(1986, 2005):
```

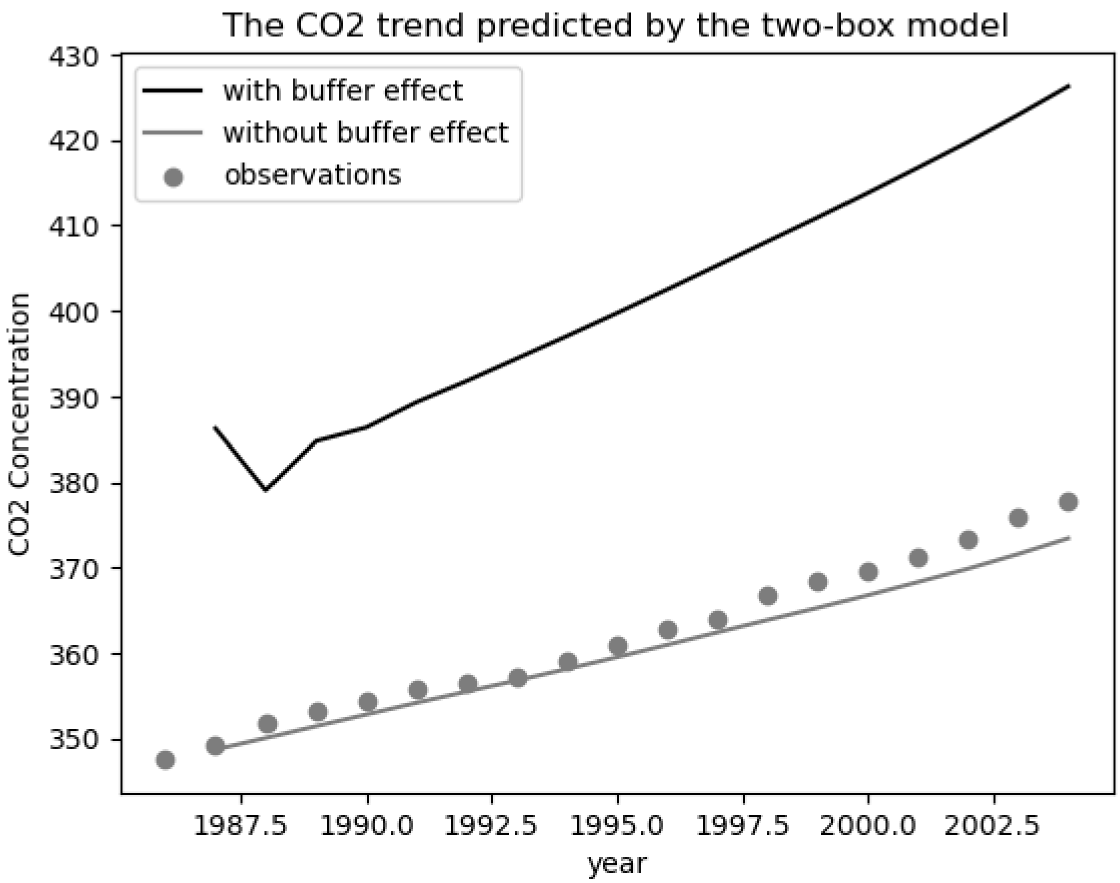
```python
    co2_cal_34.loc[co2_cal_34['year'] == years, 'co2_gamma'] = co2_emi.loc[co2_emi['Year'] == years, 'Total'].values/1000
#print(co2_cal_34.head())

#使用公式创建两箱模型（有缓冲效应）
for years in range(1987, 2005):

    #获取用于计算的数值
    N1 = co2_cal_34.loc[co2_cal_34['year'] == years-1, 'co2_atm_pgc'].values[0]
    #print(f"The N1 is: {N1}")
    N2 = co2_cal_34.loc[co2_cal_34['year'] == years-1, 'co2_sea_pgc'].values[0]
    #print(f"The N2 is: {N2}")
    gamma = co2_cal_34.loc[co2_cal_34['year'] == years, 'co2_gamma'].values[0]

    #计算缓冲系数
    z = N1/2.13
    alpha = 3.69 + 1.86e-2*z - 1.80e-6*z**2
    #print(alpha)

    #进行计算
    N1_new = N1 - K_12*N1 + K_21*(821+alpha*(N2-821)) + gamma
    #print(f"The new N1 is: {N1_new}")
    N2_new = N2 + K_12*N1 - K_21*(821+alpha*(N2-821))
    #print(f"The new N2 is: {N2_new}")

    #更新数值
    co2_cal_34.loc[co2_cal_34['year'] == years, 'co2_atm_pgc'] = N1_new
    co2_cal_34.loc[co2_cal_34['year'] == years, 'co2_sea_pgc'] = N2_new

#进行单位换算
co2_cal_34['co2_sea_cal_ppm'] = co2_cal_34['co2_sea_pgc']/2.13
co2_cal_34['co2_atm_cal_ppm'] = co2_cal_34['co2_atm_pgc']/2.13

#检查结果
print(co2_cal_34)
```

	year	co2_sea_pgc	co2_atm_pgc	co2_gamma	co2_sea_cal_ppm	co2_atm_cal_ppm
0	1986	900.000000	740.000000	5.583	422.535211	347.417840
1	1987	823.004533	822.720467	5.725	386.387105	386.253740
2	1988	844.285806	807.375194	5.936	396.378313	379.049387
3	1989	838.137326	819.589674	6.066	393.491702	384.783885
4	1990	840.834071	822.966929	6.074	394.757780	386.369450
5	1991	840.714953	829.228047	6.142	394.701856	389.308942
6	1992	841.514449	834.506551	6.078	395.077206	391.787113
7	1993	841.998109	840.092891	6.07	395.304276	394.409808
8	1994	842.580597	845.684403	6.174	395.577745	397.034931
9	1995	843.136798	851.433202	6.305	395.838872	399.733897
10	1996	843.712244	857.305756	6.448	396.109035	402.490965
11	1997	844.292417	863.281583	6.556	396.381416	405.296518
12	1998	844.877823	869.272177	6.576	396.656255	408.109003
13	1999	845.457474	875.253526	6.561	396.928392	410.917148
14	2000	846.031142	881.412858	6.733	397.197719	413.808854
15	2001	846.621298	887.715702	6.893	397.474788	416.767935
16	2002	847.217817	894.113183	6.994	397.754844	419.771447
17	2003	847.817133	900.889867	7.376	398.036212	422.952989
18	2004	848.453407	907.996593	7.743	398.334933	426.289480

In [99]:

```
# 创建一个图形
plt.figure()

#画折线图（有缓冲）
plt.plot(co2_cal_34[co2_cal_34['year'] != 1986]['year'],
         co2_cal_34[co2_cal_34['year'] != 1986]['co2_atm_cal_ppm'],
         label='with buffer effect', color='black')

#画折线图（无缓冲）
plt.plot(co2_cal_12[co2_cal_12['year'] != 1986]['year'],
         co2_cal_12[co2_cal_12['year'] != 1986]['co2_atm_cal_ppm'],
         label='without buffer effect', color='grey')

#填充观测值
for years in range(1986, 2005):
    co2_cal_12.loc[co2_cal_12['year'] == years, 'co2_atm_obs_ppm'] = co2_atm.loc[co2_atm['year'] == years, 'mean'].values

#画散点图（实测值）
plt.scatter(co2_cal_12['year'], co2_cal_12['co2_atm_obs_ppm'], label='observations', color='grey')

# 添加图例
plt.legend()

# 添加标题和轴标签
plt.title('The CO2 trend predicted by the two-box model')
```

```python
plt.xlabel('year')
plt.ylabel('CO2 Concentration')

# 显示图形
plt.show()
```



In [105…

```python
#定义转移系数
K12 = 60/615
K21 = 60/842
K23 = 9/842
K24 = 43/842
K32 = 52/9744
K34 = 162/9744
K43 = 205/26280
K45 = 0.2/26280
K51 = 0.2/90000000
K67 = 62/731
K71 = 62/1328
```

```python
#定义功能，计算缓冲系数
def buffer(i):
    alpha = 3.69 + 1.86e-2*i - 1.80e-6*i**2
    return alpha

#定义功能，计算生产力
def bio(i,beta):
    f = 62*(1+beta*math.log(i/289))
    return f

#生成新表格
co2_cal_513 = pd.DataFrame(columns=['year', 'co2_atm_pgc', 'co2_sea_pgc', 'co2_mesea',
                                    'co2_desea', 'co2_sedi', 'co2_bio','co2_soil',
                                    'co2_gamma', 'co2_landuse'])

#填充年份
years = range(1750, 2001)
co2_cal_513['year'] = years

#填充土地使用排放值（来源于原文的引用）
for years in range(1850, 2001):
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_landuse'] = co2_land.loc[co2_land['Year'] == years, 'Global'].values/1000

#使用插值填充未记录的土地使用排放值（与原文相同）
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_landuse'] = 0.2
co2_cal_513.loc[co2_cal_513['year'] == 1849, 'co2_landuse'] = 0.5
co2_cal_513['co2_landuse'] = pd.to_numeric(co2_cal_513['co2_landuse'], errors='coerce')
co2_cal_513['co2_landuse'] = co2_cal_513['co2_landuse'].interpolate(method='linear', limit_direction='both', axis=0)

#填充排放值
for years in range(1751, 2001):
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_gamma'] = co2_emi.loc[co2_emi['Year'] == years, 'Total'].values/1000
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_gamma'] = 0.003

#填充各box初始值
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_atm_pgc'] = 616
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_sea_pgc'] = 842
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_mesea'] = 9744
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_desea'] = 26280
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_sedi'] = 90000000
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_bio'] = 731
co2_cal_513.loc[co2_cal_513['year'] == 1750, 'co2_soil'] = 1238

#使用公式创建七箱模型
for years in range(1751, 2001):
```

```python
    #获取数值
    N1 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_atm_pgc'].values[0]
    #print(f"The N1 is: {N1}")
    N2 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_sea_pgc'].values[0]
    #print(f"The N2 is: {N2}")
    N3 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_mesea'].values[0]
    #print(f"The N3 is: {N3}")
    N4 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_desea'].values[0]
    N5 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_sedi'].values[0]
    N6 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_bio'].values[0]
    N7 = co2_cal_513.loc[co2_cal_513['year'] == years-1, 'co2_soil'].values[0]
    gamma = co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_gamma'].values[0]
    land = co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_landuse'].values[0]

    #计算各效应
    z = N1/2.13
    bu = buffer(z)
    biolo = bio(z,0.38)

    #代入公式进行计算
    N1_new = N1 - K12*N1 + K21*(821+bu*(N2-821)) + gamma - biolo + land + K51*N5 + K71*N7
    #print(f"The new N1 is: {N1_new}")
    N2_new = N2 + K12*N1 - K21*(821+bu*(N2-821)) - K23*N2 + K32*N3 - K24*N2
    N3_new = N3 + K23*N2 - K32*N3 - K34*N3 + K43*N4
    N4_new = N4 + K34*N3 - K43*N4 + K24*N2 - K45*N4
    N5_new = N5 + K45*N4 - K51*N5
    N6_new = N6 + biolo - K67*N6 - 2*land
    N7_new = N7 + K67*N6 - K71*N7 + land
    #print(f"The new N2 is: {N2_new}")

    #更新数值
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_atm_pgc'] = N1_new
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_sea_pgc'] = N2_new
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_mesea'] = N3_new
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_desea'] = N4_new
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_sedi'] = N5_new
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_bio'] = N6_new
    co2_cal_513.loc[co2_cal_513['year'] == years, 'co2_soil'] = N7_new

#换算单位并检查
co2_cal_513['co2_sea_cal_ppm'] = co2_cal_513['co2_sea_pgc']/2.13
co2_cal_513['co2_atm_cal_ppm'] = co2_cal_513['co2_atm_pgc']/2.13
#print(co2_cal_513)
```

In [93]:

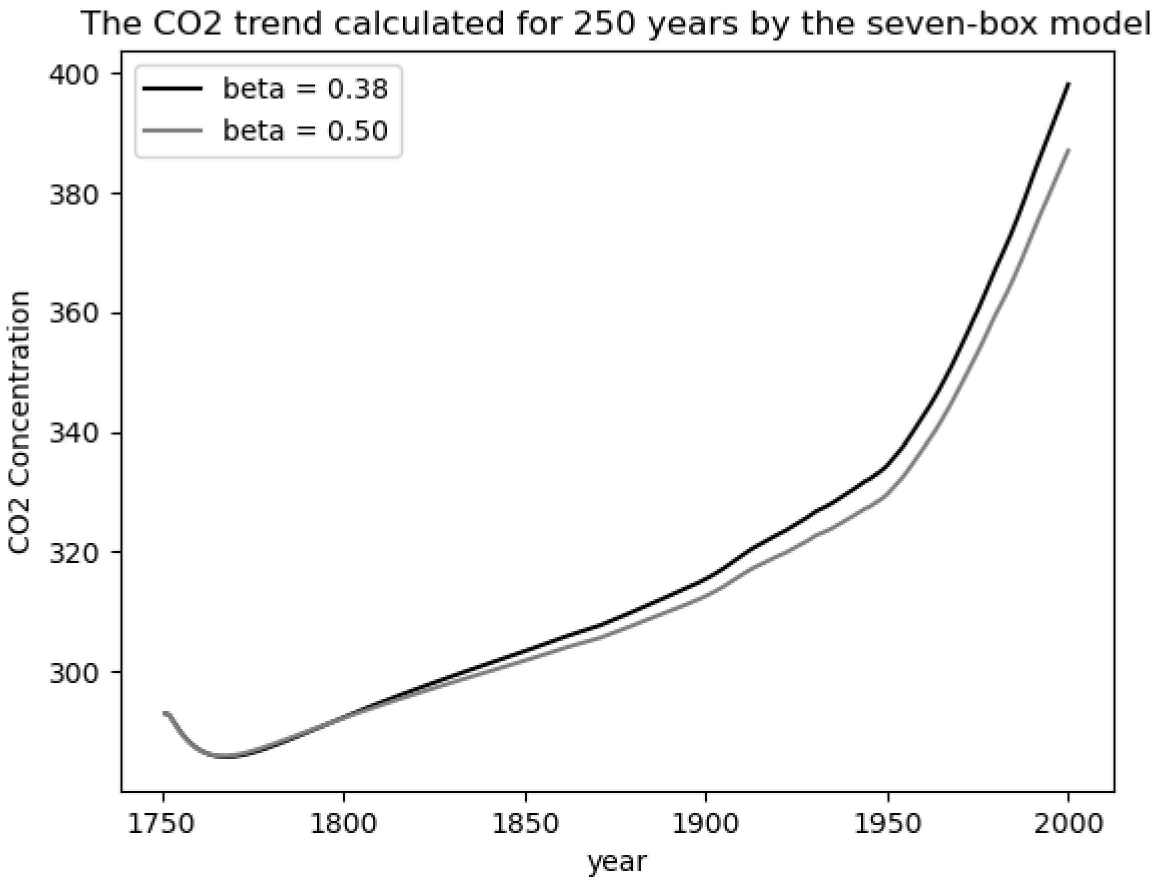
```python
#使用不同β计算
co2_cal_513_2 = pd.DataFrame(columns=['year', 'co2_atm_pgc', 'co2_sea_pgc', 'co2_mesea',
```

```python
                                    'co2_desea', 'co2_sedi', 'co2_bio','co2_soil',
                                    'co2_gamma', 'co2_landuse'])

years = range(1750, 2001)
co2_cal_513_2['year'] = years

for years in range(1850, 2001):
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_landuse'] = co2_land.loc[co2_land['Year'] == years, 'Global'].values/1000

co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_landuse'] = 0.2
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1849, 'co2_landuse'] = 0.5
co2_cal_513_2['co2_landuse'] = pd.to_numeric(co2_cal_513_2['co2_landuse'], errors='coerce')
co2_cal_513_2['co2_landuse'] = co2_cal_513_2['co2_landuse'].interpolate(method='linear', limit_direction='both', axis=0)

for years in range(1751, 2001):
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_gamma'] = co2_emi.loc[co2_emi['Year'] == years, 'Total'].values/1000
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_gamma'] = 0.003

co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_atm_pgc'] = 616
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_sea_pgc'] = 842
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_mesea'] = 9744
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_desea'] = 26280
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_sedi'] = 90000000
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_bio'] = 731
co2_cal_513_2.loc[co2_cal_513_2['year'] == 1750, 'co2_soil'] = 1238

for years in range(1751, 2001):
    N1 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_atm_pgc'].values[0]
    #print(f"The N1 is: {N1}")
    N2 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_sea_pgc'].values[0]
    #print(f"The N2 is: {N2}")
    N3 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_mesea'].values[0]
    #print(f"The N3 is: {N3}")
    N4 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_desea'].values[0]
    N5 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_sedi'].values[0]
    N6 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_bio'].values[0]
    N7 = co2_cal_513_2.loc[co2_cal_513_2['year'] == years-1, 'co2_soil'].values[0]

    gamma = co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_gamma'].values[0]
    land = co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_landuse'].values[0]

    z = N1/2.13
    bu = buffer(z)
    biolo = bio(z,0.50)

    N1_new = N1 - K12*N1 + K21*(821+bu*(N2-821)) + gamma - biolo + land + K51*N5 + K71*N7
```

```python
    #print(f"The new N1 is: {N1_new}")
    N2_new = N2 + K12*N1 - K21*(821+bu*(N2-821)) - K23*N2 + K32*N3 - K24*N2
    N3_new = N3 + K23*N2 - K32*N3 - K34*N3 + K43*N4
    N4_new = N4 + K34*N3 - K43*N4 + K24*N2 - K45*N4
    N5_new = N5 + K45*N4 - K51*N5
    N6_new = N6 + biolo - K67*N6 - 2*land
    N7_new = N7 + K67*N6 - K71*N7 + land

    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_atm_pgc'] = N1_new
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_sea_pgc'] = N2_new
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_mesea'] = N3_new
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_desea'] = N4_new
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_sedi'] = N5_new
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_bio'] = N6_new
    co2_cal_513_2.loc[co2_cal_513_2['year'] == years, 'co2_soil'] = N7_new
co2_cal_513_2['co2_sea_cal_ppm'] = co2_cal_513_2['co2_sea_pgc']/2.13
co2_cal_513_2['co2_atm_cal_ppm'] = co2_cal_513_2['co2_atm_pgc']/2.13
#print(co2_cal_513_2)
```

In [97]:

```python
# 创建一个图形
plt.figure()

plt.plot(co2_cal_513[co2_cal_513['year'] != 1750]['year'],
         co2_cal_513[co2_cal_513['year'] != 1750]['co2_atm_cal_ppm'],
         label='beta = 0.38', color='black')

plt.plot(co2_cal_513_2[co2_cal_513['year'] != 1750]['year'],
         co2_cal_513_2[co2_cal_513['year'] != 1750]['co2_atm_cal_ppm'],
         label='beta = 0.50', color='grey')

# 添加图例
plt.legend()

# 添加标题和轴标签
plt.title('The CO2 trend calculated for 250 years by the seven-box model')
plt.xlabel('year')
plt.ylabel('CO2 Concentration')

# 显示图形
plt.show()
```


The CO2 trend calculated for 250 years by the seven-box model
beta = 0.38
beta = 0.50
CO2 Concentration
400
380
360
340
320
300
1750
1800
1850
1900
1950
2000
year