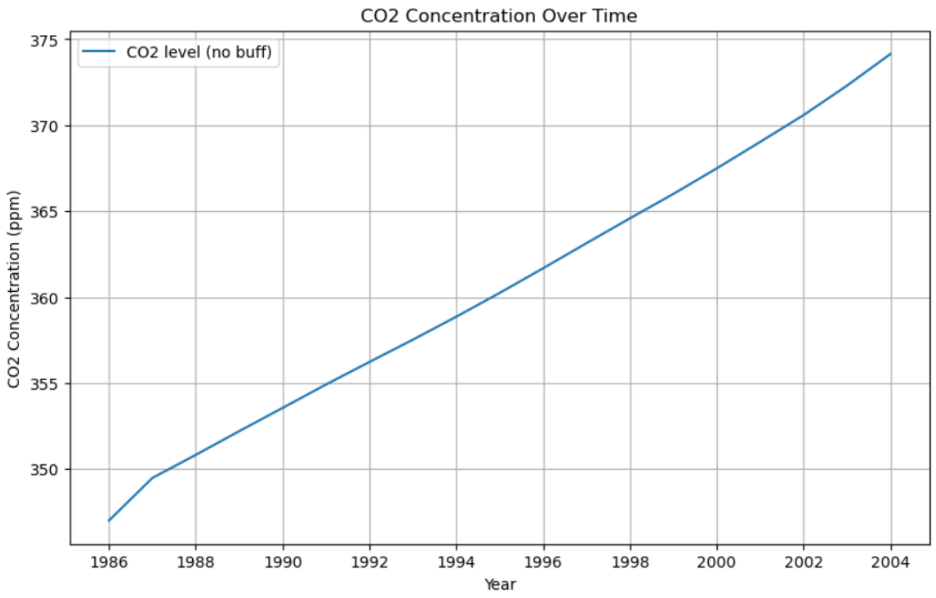
PS5

```
import netCDF4
import numpy as np
import pandas as pd
import xarray as xr
from matplotlib import pyplot as plt
%matplotlib inline
from scipy.integrate import odeint   #一开始觉得能用这个库，但是好像不用也行
import math

#Question 1.1

#  读取 CO2 的数据
df = pd.read_csv("D:\\ESE_5023\\co2_annmean_mlo.csv")
#  处理数据，使得其 index 从 0 开始，保留 1986-2004 的数据
df = df.iloc[1:, 0:2]
df = df.loc[(df['year'] > 1985) & (df['year'] < 2005)]
df = df.reset_index(drop=True)
#读取 CO2 排放的数据
da = pd.read_csv('global.1751_2014.csv')
da['Year'] = pd.to_numeric(da['Year'], errors='coerce')          #  将  'Year'  列的数据转换为数值类型
da['Year'] = da['Year'].fillna(0).astype(int)                          #  去除缺失值并将  'Year'  列转换为整数类型
da = da.loc[(da['Year'] > 1985) & (da['Year'] < 2005)]          #  筛选指定年份范围的数据
da = da.reset_index(drop=True)                                                #  重设 index
da = da.iloc[:, [0, 1]]

#数据取到 1986 年开始，定义 1986 CO2=347，方便计算，consult with malinqiang

#  合并数据
data = pd.concat([da, df], axis=1)
data = data.drop('year', axis=1)   #删掉了多余的一列 year
data = data.rename(columns={'Total carbon emissions from fossil fuel consumption and cement production (million metric tons of C)': 'carbon emission(Pg)'})   #名称太长，重命名

#  数据处理
data['carbon emission(Pg)'] = pd.to_numeric(data['carbon emission(Pg)'], errors='coerce') #将数据转换为数值类型
data['carbon emission(Pg)'] = data['carbon emission(Pg)'] / 1000   #之前忘记除 1000 了，补上，这样才是 Pg 的值
data['CO2 level in ppm(no buff)'] = 347   #创建了"CO2 level in ppm(no buff)"列，并初始化为 347。
```

```
# 模型参数初始化
k12, k21 = 105 / 740, 102 / 900
N1, N2 = 740, 900
n0 = 740 * 10**21 / 12 / 347   #大气分子总数，之后用 CO2 的数来除以总数，得出 ppm
gamma = data['carbon emission(Pg)']   #E1 中的额外源

# 模拟 CO2 浓度的变化
for i in range(len(data)):
    dN1 = -k12 * N1 + k21 * N2 + gamma[i]
    dN2 = k12 * N1 - k21 * N2
    N1 += dN1
    N2 += dN2              #根据模型方程计算了 CO2 的变化，然后更新了 N1 和 N2 的值
    if i != 0:             #0 为 1986 年
        data['CO2 level in ppm(no buff)'][i] = N1 * 10**21 / 12 / n0

# 输出数据
print(data)

# 画图
plt.figure(figsize=(10, 6))
plt.plot(data['Year'], data['CO2 level in ppm(no buff)'], label='CO2 level (no buff)')
plt.title('CO2 Concentration Over Time')
plt.xlabel('Year')
plt.ylabel('CO2 Concentration (ppm)')
plt.legend()
plt.grid(True)
# 设置横坐标刻度为整数形式，否则会以 float 的形式显示
plt.xticks(range(1986, 2005, 2))
plt.show()
```

	Year	carbon emission(Pg)	mean	CO2 level in ppm(no buff)
0	1986	5.583	347.61	347.000000
1	1987	5.725	349.31	349.476592
2	1988	5.936	351.69	350.822203
3	1989	6.066	353.20	352.200804
4	1990	6.074	354.45	353.553674
5	1991	6.142	355.70	354.915942
6	1992	6.078	356.54	356.226925
7	1993	6.070	357.21	357.522571
8	1994	6.174	358.96	358.858888
9	1995	6.305	360.97	360.243684
10	1996	6.448	362.74	361.677174
11	1997	6.556	363.88	363.138118
12	1998	6.576	366.84	364.583983
13	1999	6.561	368.54	366.003269
14	2000	6.733	369.71	367.489651
15	2001	6.893	371.32	369.029517
16	2002	6.994	373.45	370.590053
17	2003	7.376	375.98	372.303119
18	2004	7.743	377.70	374.143051

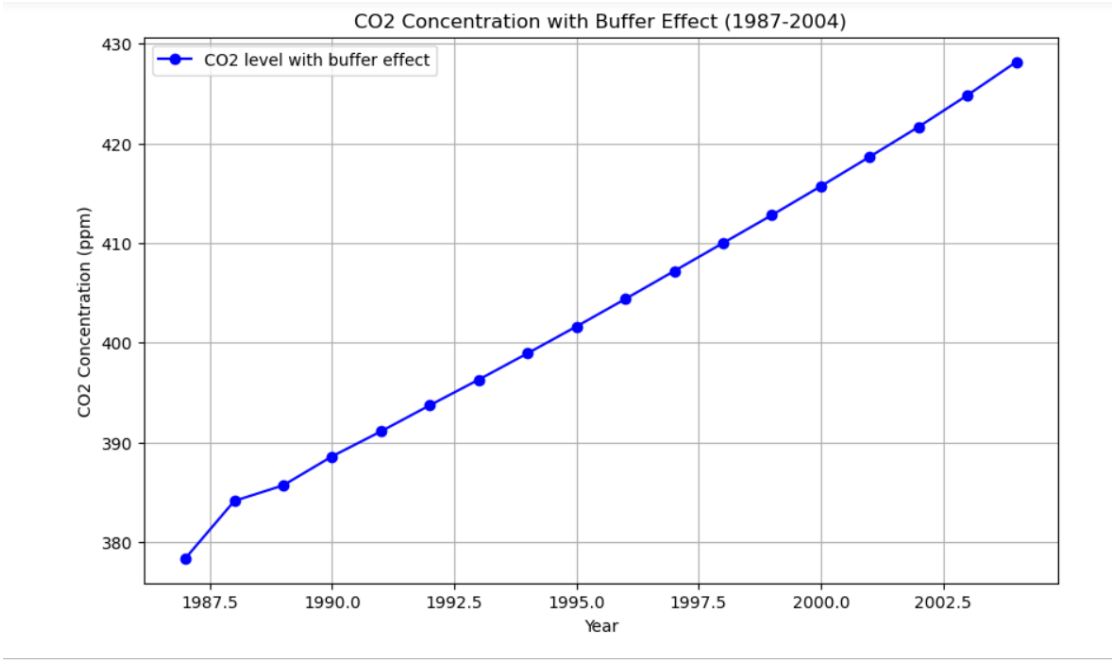


#Question 1.2 在我整理数据的时候我发现数据又变了，加了 drop 后，每次输出结果不一样

```
N20 =821
bf = 0
data['CO2 level in ppm(buff)'] = 347    #建立新的一列 CO2 level in ppm(buff)，初始化为 347。方便后面计算
for year in range(1986, 2005):      #consult with malingqiang  一开始我使用的是 for i in range(len(data))后面使用 data['CO2 level in ppm(buff)'][i]但是输出的结果很不对
    if year == 1986:
        bf = 3.69 + 1.86 * 0.01 * data['CO2 level in ppm(buff)'][year - 1986] - 1.8 * 10**(-6) * data['CO2 level in ppm(buff)'][year - 1986]**2

    dN1 = -k12 * N1 + k21 * (N20 + bf * (N2 - N20)) + gamma[year - 1986]
    dN2 = k12 * N1 - k21 * (N20 + bf * (N2 - N20))

    N1 += dN1
    N2 += dN2

    if year != 1986:
        data['CO2 level in ppm(buff)'][year - 1986] = N1 * 10**21 / 12 / n0

    bf = 3.69 + 1.86 * 0.01 * data['CO2 level in ppm(buff)'][year - 1986] - 1.8 * 10**(-6) * data['CO2 level in ppm(buff)'][year - 1986]**2

N1, N2 = 740, 900    #防止每次输出结果会变化，设定初始值

data = data.drop(0).reset_index(drop=True)  #除去无用的第 0 行，方便画图
```

```
print(data)

#画出 CO2 level in ppm(buff) 的图
plt.figure(figsize=(10, 6))
plt.plot(data['Year'], data['CO2 level in ppm(buff)'], marker='o', label='CO2 level with buffer effect', color='blue')
plt.title('CO2 Concentration with Buffer Effect (1987-2004)')
plt.xlabel('Year')
plt.ylabel('CO2 Concentration (ppm)')
plt.grid(True)
plt.legend()
plt.show()
```

	Year	carbon emission(Pg)	mean	CO2 level in ppm(no buff)	CO2 level in ppm(buff)
0	1987	5.725	349.31	349.476592	378.373290
1	1988	5.936	351.69	350.822203	384.121646
2	1989	6.066	353.20	352.200804	385.687094
3	1990	6.074	354.45	353.553674	388.594575
4	1991	6.142	355.70	354.915942	391.102546
5	1992	6.078	356.54	356.226925	393.720567
6	1993	6.070	357.21	357.522571	396.294641
7	1994	6.174	358.96	358.858888	398.934102
8	1995	6.305	360.97	360.243684	401.625967
9	1996	6.448	362.74	361.677174	404.383222
10	1997	6.556	363.88	363.138118	407.186360
11	1998	6.576	366.84	364.583983	409.997335
12	1999	6.561	368.54	366.003269	412.803636
13	2000	6.733	369.71	367.489651	415.693488
14	2001	6.893	371.32	369.029517	418.650605
15	2002	6.994	373.45	370.590053	421.652144
16	2003	7.376	375.98	372.303119	424.831489
17	2004	7.743	377.70	374.143051	428.165654

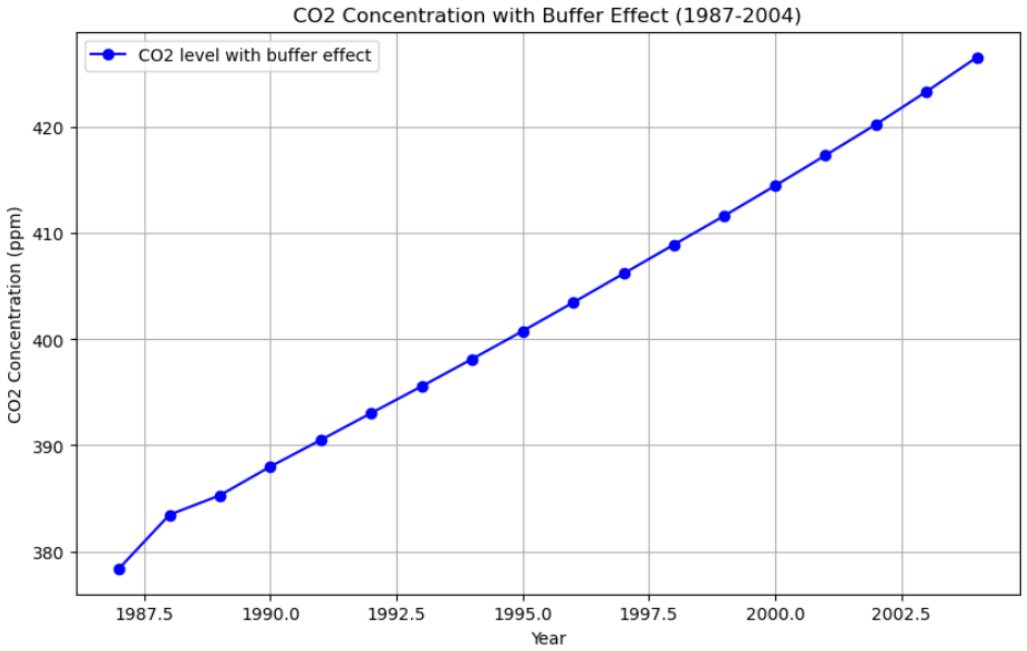


Question 1.2

```
k12, k21 = 105/740, 102/900
N1, N2, N20= 740, 900, 821
year = 1986
n0 = 740*10**21/12/347
bf = 0
data['CO2 level in ppm(buff)'] = 347    # 建立新的一列 CO2 level in ppm(buff)，初始化为347。方便后面计算
for year in range(1986, 2005):
    if year - 1986 < len(data):
        bf = 3.69 + 1.86 * 0.01 * data['CO2 level in ppm(buff)'][year - 1986] - 1.8 * 10**(-6) * data['CO2 level in ppm(buff)'][year - 1986]**2

        dN1 = -k12 * N1 + k21 * (N20 + bf * (N2 - N20)) + gamma[year - 1986]
        dN2 = k12 * N1 - k21 * (N20 + bf * (N2 - N20))

        N1 += dN1
        N2 += dN2

        if year != 1986:
            data['CO2 level in ppm(buff)'][year - 1986] = N1 * 10**21 / 12 / n0

        bf = 3.69 + 1.86 * 0.01 * data['CO2 level in ppm(buff)'][year - 1986] - 1.8 * 10**(-6) * data['CO2 level in ppm(buff)'][year - 1986]**2
```

```
N1, N2 = 740, 900     # 防止每次输出结果会变化，设定初始值

data = data.drop(0).reset_index(drop=True)  # 除去无用的第 0 行，方便画图

print(data)

# 画出 CO2 level in ppm(buff）的图
plt.figure(figsize=(10, 6))
plt.plot(data['Year'], data['CO2 level in ppm(buff)'], marker='o', label='CO2 level with buffer effect', color='blue')
plt.title('CO2 Concentration with Buffer Effect (1987-2004)')
plt.xlabel('Year')
plt.ylabel('CO2 Concentration (ppm)')
plt.grid(True)
plt.legend()
plt.show()
```

```
    Year  carbon emission(Pg)    mean  CO2 level in ppm(no buff)  \
0   1987                5.725  349.31                 349.476592
1   1988                5.936  351.69                 350.822203
2   1989                6.066  353.20                 352.200804
3   1990                6.074  354.45                 353.553674
4   1991                6.142  355.70                 354.915942
5   1992                6.078  356.54                 356.226925
6   1993                6.070  357.21                 357.522571
7   1994                6.174  358.96                 358.858888
8   1995                6.305  360.97                 360.243684
9   1996                6.448  362.74                 361.677174
10  1997                6.556  363.88                 363.138118
11  1998                6.576  366.84                 364.583983
12  1999                6.561  368.54                 366.003269
13  2000                6.733  369.71                 367.489651
14  2001                6.893  371.32                 369.029517
15  2002                6.994  373.45                 370.590053
16  2003                7.376  375.98                 372.303119
17  2004                7.743  377.70                 374.143051

    CO2 level in ppm(buff)
0               378.373290
1               383.446838
2               385.284891
3               387.998214
4               390.510192
5               393.049909
6               395.574713
7               398.151797
8               400.782452
9               403.473544
10              406.207532
11              408.945781
12              411.677032
13              414.489925
14              417.366138
15              420.282191
16              423.372659
17              426.611062
```



每次的结果都不太一样，不过这个结果会好一些，比较符合 1.3 的图

1.3

#将三种图结合
plt.figure(figsize=(8,6),dpi=120)
plt.plot(data['Year'],data['mean'],linewidth=0,marker='o',markersize=4,color='gray')
plt.plot(data['Year'][1:],data['CO2 level in ppm(buff)'][1:],linewidth=4,color='black')
plt.plot(data['Year'][1:],data['CO2 level in ppm(no buff)'][1:],linewidth=2,color='gray')

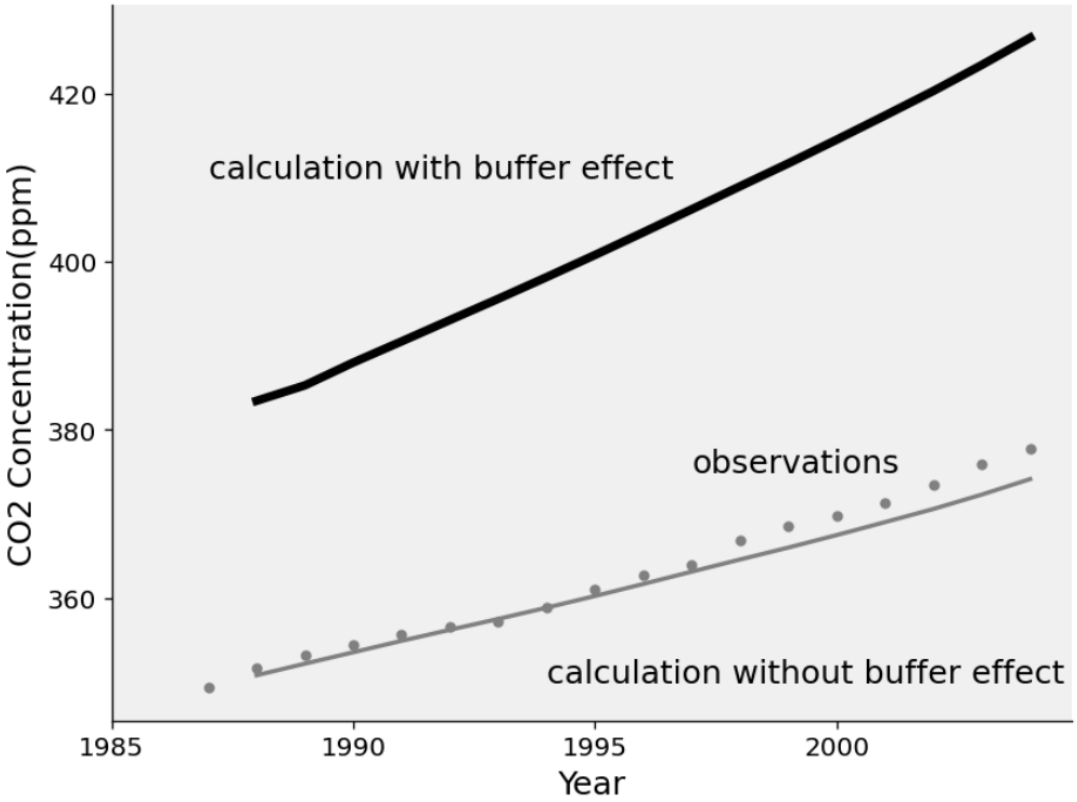
#设置标签
plt.xlabel('Year',fontsize=15)
plt.ylabel('CO2 Concentration(ppm)',fontsize=15)

# 设置 x 轴和 y 轴刻度
plt.xticks([1985, 1990, 1995, 2000], fontsize=12)
plt.yticks([360, 380, 400, 420], fontsize=12)

# 插入文本
plt.text(1994, 350, 'calculation without buffer effect', fontsize=15, color='black')
plt.text(1997, 375, 'observations', fontsize=15, color='black')
plt.text(1987, 410, 'calculation with buffer effect', fontsize=15, color='black')

# 隐藏右边和上边的边框
plt.gca().spines['right'].set_visible(False)
plt.gca().spines['top'].set_visible(False)

```
# 调整背景灰度
plt.gca().set_facecolor('#F0F0F0')  # 设置为浅灰色

plt.show()
```




```
#bonus
#solve this problem with help from malinqiang

# 重新导入数据，之前的数据处理过，重新导入避免麻烦
data = pd.read_csv('global.1751_2014.csv')
observation = pd.read_csv('trends-in-atmospheric-carbon-dioxide-concentration.csv')
delta = pd.read_excel('Global_land-use_flux-1850_2005.xls')

# 数据处理过程
observation = observation[(observation['Category'] >= 1750) & (observation['Category'] <= 2000)] #仅保留在 1750 到 2000 之间的数据
data = data.iloc[1:, 0:2]
data['Year'] = data['Year'].astype(int)  #改变 year 的数据类型
data.loc[-1] = [1750, 3] #插入一行数据到索引 -1
data = data.sort_values('Year').reset_index(drop=True)
data = data[(data['Year'] >= 1750) & (data['Year'] <= 2000)].reset_index(drop=True)
data['Total carbon emission in pg'] = data['Total carbon emissions from fossil fuel
```

```
consumption and cement production (million metric tons of C)'].astype(int) / 1000
data['Emission from land use change'] = delta['Global in pg']
data['CO2 level in ppm(0.38)'] = 289
data['CO2 level in ppm(0.5)'] = 289

# 定义 beta 值的列表
beta_values = [0.38, 0.50]
#循环遍历每个 beta 值。
for beta in beta_values:
    k12, k21, k23, k24, k32, k34, k43, k45, k51, k67, k71 = 60/615, 60/842, 9/842, 43/842, 52/9744, 162/9744, 205/26280, 0.20/26280, 0.2/90000000, 62/731, 62/1328
    n0 = 740 * 10**21 / 12 / 347
    N1, N2, N3, N4, N5, N6, N7 = 615, 842, 9744, 26280, 90000000, 731, 1328
    N20 = 842
    f0, P0 = 62, 289
    gamma = data['Total carbon emission in pg']
    delta = data['Emission from land use change']
    data[f'CO2 level in ppm({beta})'] = 289    #在内部使用 for 循环迭代模型的每一年，从 1751 年到 2000 年。

    for year in range(1751, 2001):
        ksi = 3.69 + 1.86 * 10**(-2) * data[f'CO2 level in ppm({beta})'][year-1751] - 1.8 * 10**(-6) * data[f'CO2 level in ppm({beta})'][year-1751]**2
        f = f0 * (1 + beta * math.log(data[f'CO2 level in ppm({beta})'][year-1751] / P0))
        dN1 = -k12 * N1 + k21 * (N20 + ksi * (N2 - N20)) + gamma[year-1750] - f + delta[year-1750] + k71 * N7 + k51 * N5
        dN2 = k12 * N1 - k21 * (N20 + ksi * (N2 - N20)) - k23 * N2 + k32 * N3 - k24 * N2
        dN3 = k23 * N2 - k32 * N3 - k34 * N3 + k43 * N4
        dN4 = k24 * N2 + k34 * N3 - k43 * N4 - k45 * N4
        dN5 = k45 * N4 - k51 * N5
        dN6 = f - k67 * N6 - 2 * delta[year-1750]
        dN7 = k67 * N6 - k71 * N7 + delta[year-1750]
        N1 += dN1
        N2 += dN2
        N3 += dN3
        N4 += dN4
        N5 += dN5
        N6 += dN6
        N7 += dN7    #这部分代码执行了模型的迭代计算，计算每一年各个组分的变化，其中包括 CO2 浓度在大气和海洋中的变化。
        data[f'CO2 level in ppm({beta})'][year-1750] = N1 * 10**21 / 12 / n0

plt.figure(figsize=(10, 6), dpi=120)
plt.plot(observation['Category'], observation['Ice Core & Mouna Loa'], linewidth=0,
```

```
marker='o', markersize=4, color='black')
for beta in beta_values:
    plt.plot(data['Year'][1:], data[f'CO2 level in ppm({beta})'][1:], label=f'β={beta}')

plt.xlabel('Year', fontsize=15, labelpad=10)
plt.ylabel('CO$_2$ Concentration(ppm)', fontsize=15, labelpad=10)
plt.xticks(np.arange(1750, 2001, 10), [str(t) if t in np.arange(1800, 2001, 100) else '' for t in np.arange(1750, 2001, 10)], fontsize=15)
plt.yticks(np.arange(280, 375, 5), [str(t) if t in np.arange(280, 361, 20) else '' for t in np.arange(280, 375, 5)], fontsize=15)
plt.xlim([1750, 2009])
plt.ylim([275, 375])
plt.tick_params(axis='both', bottom=True, top=False, direction='in', which='major')

plt.text(1900, 285, 'Observation', fontsize=15, color='black')
plt.text(1825, 300, 'Calculation', fontsize=15, color='black')
for beta in beta_values:
    plt.text(2000, data[f'CO2 level in ppm({beta})'][2000-1750], f'β={beta}', fontsize=15)

# 去除上面和右边框
plt.gca().spines['top'].set_visible(False)
plt.gca().spines['right'].set_visible(False)

plt.show()
```