In [1]:
```
import numpy as np
import xarray as xr
import pandas as pd
import matplotlib.pyplot as plt
import cartopy.crs as ccrs
import cartopy.feature as cfeature
import netCDF4 as nc
from sklearn.linear_model import LinearRegression
import matplotlib.ticker as ticker
```

In [2]:
```
data = pd.read_csv("global.1751_2014.csv")
data_conv = data.iloc[:, :2]
data_conv_dr = data_conv.drop(0)
data_conv_dr
```

Out[2]:

	Year	Total carbon emissions from fossil fuel consumption and cement production (million metric tons of C)
1	1751	3
2	1752	3
3	1753	3
4	1754	3
5	1755	3
...	...	...
260	2010	9128
261	2011	9503
262	2012	9673
263	2013	9773
264	2014	9855

264 rows × 2 columns

In [3]:
```
# 1.1
# I've got great help from my friend yuguang Zhu.

# Make sure the emission column is of floating point type and direc
data_conv_dr['PGC'] = data_conv_dr['Total carbon emissions from fos

# Create a new DataFrame containing a specific row
ppm_df = data_conv_dr[['Year', 'PGC']].loc[237:254]


ppm_df
```

Out[3]:

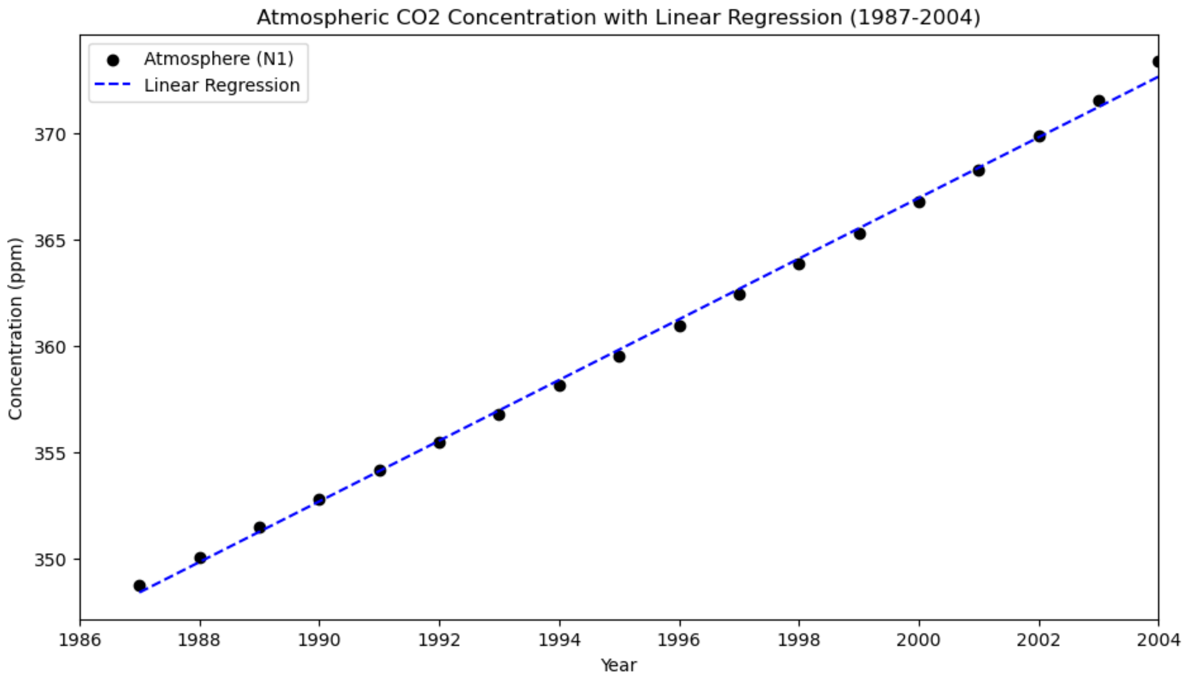
	Year	PGC
237	1987	5.725
238	1988	5.936
239	1989	6.066
240	1990	6.074
241	1991	6.142
242	1992	6.078
243	1993	6.070
244	1994	6.174
245	1995	6.305
246	1996	6.448
247	1997	6.556

In [4]:
```
# Initialize the variable to store the result
calculation_without_buffer = []


N1 = 740  # Carbon concentration in the atmosphere
N2 = 900  # Carbon concentration at the ocean surface
k12 = 105 / 740  # Atmosphere-to-ocean transfer coefficient
k21 = 102 / 900  # Ocean-to-atmosphere transfer coefficient
# I wonder the coefficient is a fixed value or it changes with the 


# Ensure that the length of years matches the number of lines in ppi
num_years = len(ppm_df)


for i in range(num_years):
    year = ppm_df['Year'].iloc[i]
    gamma = ppm_df['PGC'].iloc[i]

    dN1_dt = -k12 * N1 + k21 * N2 + gamma
```

```
    dN2_dt = k12 * N1 - k21 * N2

    dt = 1
    N1 += dN1_dt * dt
    N2 += dN2_dt * dt

    calculation_without_buffer.append(N1 / 2.13)

    print(f"Year: {year}, Atmospheric CO2 concentration: {N1 / 2.13
```

```
Year: 1987, Atmospheric CO2 concentration: 348.70 ppm
Year: 1988, Atmospheric CO2 concentration: 350.05 ppm
Year: 1989, Atmospheric CO2 concentration: 351.44 ppm
Year: 1990, Atmospheric CO2 concentration: 352.80 ppm
Year: 1991, Atmospheric CO2 concentration: 354.17 ppm
Year: 1992, Atmospheric CO2 concentration: 355.48 ppm
Year: 1993, Atmospheric CO2 concentration: 356.78 ppm
Year: 1994, Atmospheric CO2 concentration: 358.12 ppm
Year: 1995, Atmospheric CO2 concentration: 359.51 ppm
Year: 1996, Atmospheric CO2 concentration: 360.95 ppm
Year: 1997, Atmospheric CO2 concentration: 362.41 ppm
Year: 1998, Atmospheric CO2 concentration: 363.86 ppm
Year: 1999, Atmospheric CO2 concentration: 365.28 ppm
Year: 2000, Atmospheric CO2 concentration: 366.77 ppm
Year: 2001, Atmospheric CO2 concentration: 368.31 ppm
Year: 2002, Atmospheric CO2 concentration: 369.87 ppm
Year: 2003, Atmospheric CO2 concentration: 371.59 ppm
Year: 2004, Atmospheric CO2 concentration: 373.43 ppm
```

In [14]:
```
years = np.arange(1987, 2005, 1)

co2_concentration = np.array(calculation_without_buffer).reshape(-1

# Convert year and CO2 concentration data into NumPy arrays for lin
X = years.reshape(-1, 1)  # Convert to a two-dimensional array to f
y = co2_concentration


regressor = LinearRegression()
regressor.fit(X, y)


predicted_co2 = regressor.predict(X)


plt.figure(figsize=(11, 6))
plt.scatter(X, y, label='Atmosphere (N1)',color='black')
plt.plot(X, predicted_co2, color='blue', linestyle='--', label='Lin
plt.xlabel('Year')
plt.ylabel('Concentration (ppm)')
plt.xlim(1986, 2004)
plt.title('Atmospheric CO2 Concentration with Linear Regression (19
plt.legend()
plt.show()
```

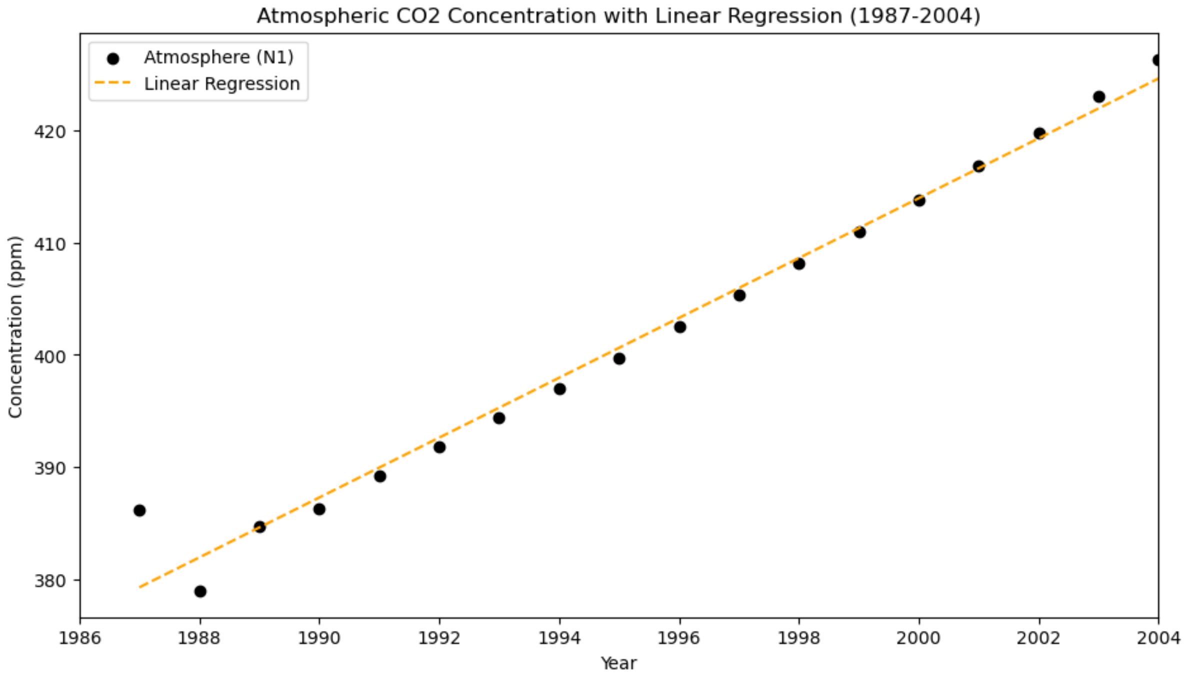


In [6]:
```
# 1.2

calculation_with_buffer = []

N1 = 740
```

```python
N2 = 900
k12 = 105 / 740
k21 = 102 / 900
N20 = 821  # The balance of ocean surface carbon


for i in range(num_years):
    year = ppm_df['Year'].iloc[i]
    gama = ppm_df['PGC'].iloc[i]
    z = N1 / 2.13  # Atmospheric CO2 concentration in parts per mil

    # Calculate the buffer factor
    xi = 3.69 + 1.86 * 10**(-2) * z - 1.80 * 10**(-6) * z**2

    dN1_dt = -k12 * N1 + k21 * (N20 + xi * (N2 - N20)) + gama
    dN2_dt = k12 * N1 - k21 * (N20 + xi * (N2 - N20))


    dt = 1
    N1 += dN1_dt * dt
    N2 += dN2_dt * dt


    calculation_with_buffer.append(N1 / 2.13)


    print(f"Year: {year}, Atmospheric CO2 concentration: {N1 / 2.13
```

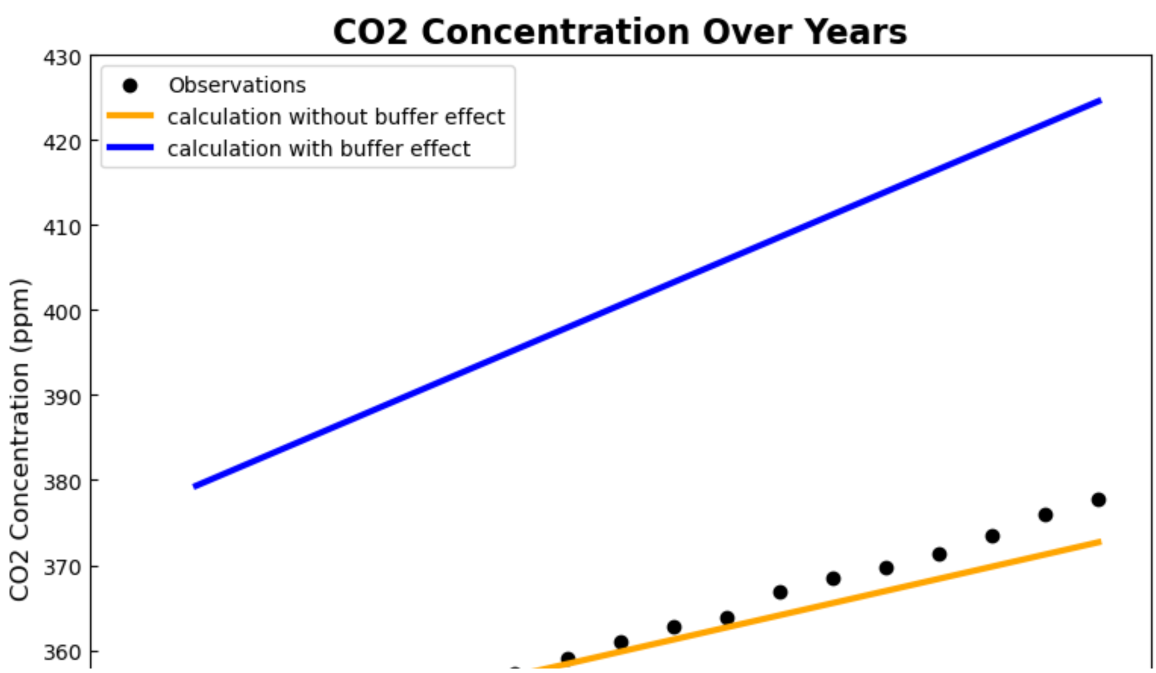
```
Year: 1987, Atmospheric CO2 concentration: 386.25 ppm
Year: 1988, Atmospheric CO2 concentration: 379.05 ppm
Year: 1989, Atmospheric CO2 concentration: 384.78 ppm
Year: 1990, Atmospheric CO2 concentration: 386.37 ppm
Year: 1991, Atmospheric CO2 concentration: 389.31 ppm
Year: 1992, Atmospheric CO2 concentration: 391.79 ppm
Year: 1993, Atmospheric CO2 concentration: 394.41 ppm
Year: 1994, Atmospheric CO2 concentration: 397.03 ppm
Year: 1995, Atmospheric CO2 concentration: 399.73 ppm
Year: 1996, Atmospheric CO2 concentration: 402.49 ppm
Year: 1997, Atmospheric CO2 concentration: 405.30 ppm
Year: 1998, Atmospheric CO2 concentration: 408.11 ppm
Year: 1999, Atmospheric CO2 concentration: 410.92 ppm
Year: 2000, Atmospheric CO2 concentration: 413.81 ppm
Year: 2001, Atmospheric CO2 concentration: 416.77 ppm
Year: 2002, Atmospheric CO2 concentration: 419.77 ppm
Year: 2003, Atmospheric CO2 concentration: 422.95 ppm
Year: 2004, Atmospheric CO2 concentration: 426.29 ppm
```

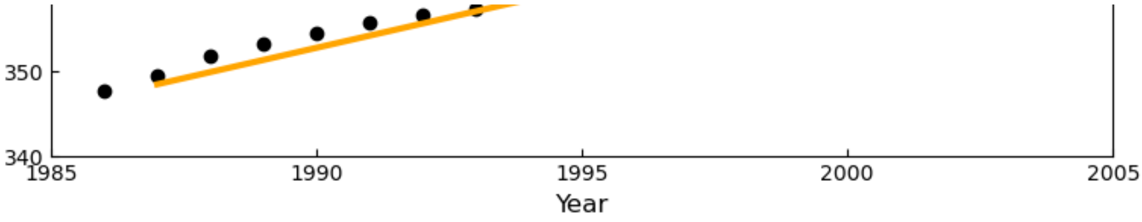
In [15]:
```
years = np.arange(1987, 2005, 1)


co2_concentration_2 = np.array(calculation_with_buffer).reshape(-1,


X_2 = years.reshape(-1, 1)
y_2 = co2_concentration_2


regressor = LinearRegression()
regressor.fit(X_2, y_2)


predicted_co2_2 = regressor.predict(X_2)


plt.figure(figsize=(11, 6))
plt.scatter(X_2, y_2, label='Atmosphere (N1)',color='black')
plt.plot(X_2, predicted_co2_2, color='orange', linestyle='--', labe
plt.xlabel('Year')
plt.ylabel('Concentration (ppm)')
plt.xlim(1986, 2004)
plt.title('Atmospheric CO2 Concentration with Linear Regression (19
plt.legend()
plt.show()
```



In [8]:
```
# 1.3

data = pd.read_csv('co2_annmean_mlo.csv', comment='#')

# Filter data from 1986 to 2004
filtered_data = data[(data['year'] >= 1986) & (data['year'] <= 2004
```

```
# Obtain filtered year and CO2 concentration data
years_with_1986 = filtered_data['year']
observations_with_1986 = filtered_data['mean']

plt.figure(figsize=(8, 6))
plt.scatter(years_with_1986, observations_with_1986, color='black',
plt.plot(X, predicted_co2, color='orange', linestyle='-', label='ca
plt.plot(X_2, predicted_co2_2, color='blue', linestyle='-', label='

# Set the scale to face in
plt.tick_params(axis='x', direction='in')
plt.tick_params(axis='y', direction='in', which='both')

# Set chart labels and titles
plt.xlabel('Year', fontsize=12)
plt.ylabel('CO2 Concentration (ppm)', fontsize=12)
plt.title('CO2 Concentration Over Years', fontsize=16, fontweight='

# Add grid
plt.grid(False)

# Set x-axis ticks with 5-year intervals
plt.xticks(np.arange(1985, 2006, 5))
plt.xlim(1985, 2005)
plt.ylim(340, 430)


plt.legend(fontsize=10)

plt.tight_layout()

plt.show()
```





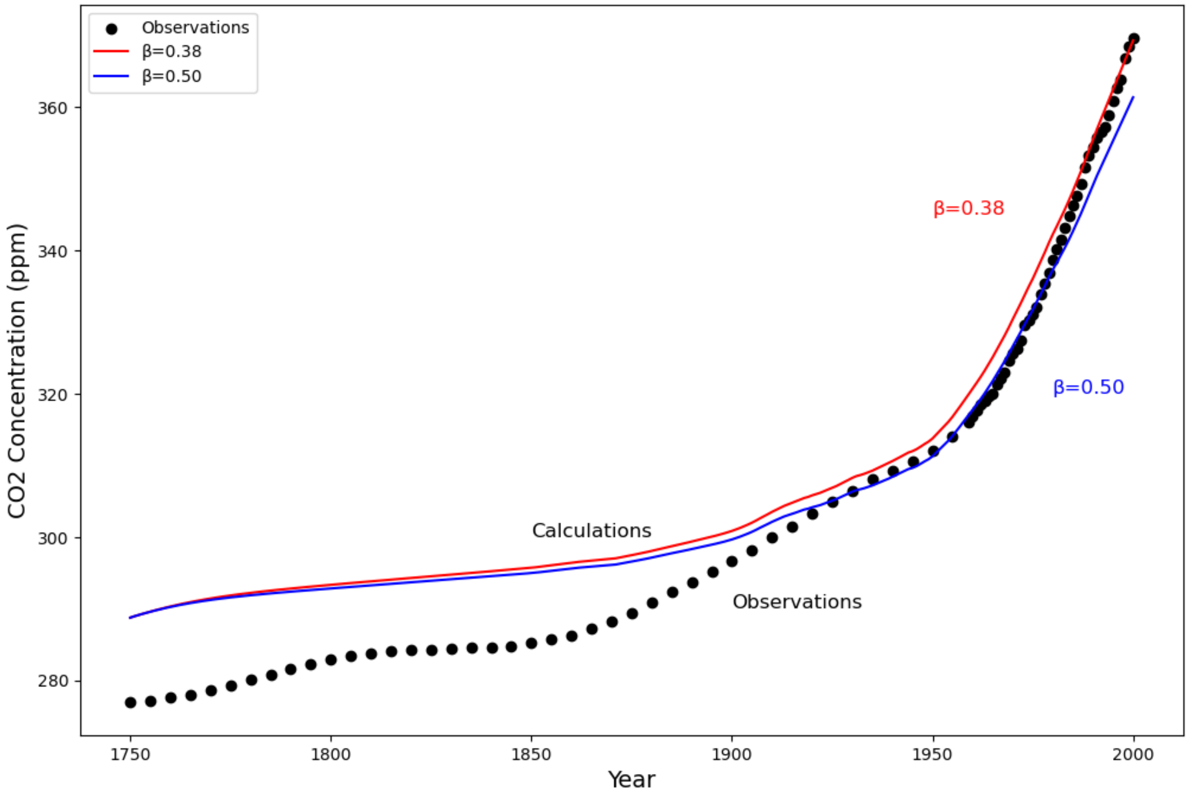
In [ ]:

In [9]:

```
# Bonus
# Again thanks to yuguang Zhu for the help.

co2_observations = pd.read_csv('1750-2000CO2.csv')
land_use_data = pd.read_excel('Global_land-use_flux-1750_2005.xls')
ff_emissions = pd.read_csv('global_1751_2016.csv')


land_use_data = land_use_data[['Year', 'Global']]
land_use_data['LandUseChange'] = land_use_data['Global'] / (1000 * 

ff_emissions = ff_emissions[['Year', 'Total carbon emissions from fo
ff_emissions['FossilFuelEmissions'] = ff_emissions.iloc[:, 1] - ff_e
ff_emissions['EmissionFactor'] = ff_emissions['FossilFuelEmissions'
```

In [10]:
```
k12, k21, k23, k24, k32, k34, k43, k45, k51, k67, k71 = [60 / 615, (
N2_0 = 842 / 2.13


initial_conditions = [615 / 2.13, 842 / 2.13, 9744 / 2.13, 26280 / 2
f0 = 62 / 2.13
P0 = 615 / 2.13

# Explore the Beta value
beta_values = [0.38, 0.5]
results = []

for beta in beta_values:

    N1, N2, N3, N4, N5, N6, N7 = initial_conditions.copy()
    atmosphere = [N1]

    for year in range(1751, 2001):
        gamma = ff_emissions[ff_emissions['Year'] == year]['Emissio
        delta = land_use_data[land_use_data['Year'] == year]['LandU

        xi = 3.69 + 0.0186 * N1 - 0.0000018 * N1**2

        f = f0 * (1 + beta * np.log(N1 / P0))

        # Calculate the rate of change for each part
        dN1_dt = -k12 * N1 + k21 * (N2_0 + xi * (N2 - N2_0)) + gamma
        dN2_dt = k12 * N1 - k21 * (N2_0 + xi * (N2 - N2_0)) - k23 *
        dN3_dt = k23 * N2 - k32 * N3 - k34 * N3 + k43 * N4
        dN4_dt = k34 * N3 - k43 * N4 + k24 * N2 - k45 * N4
        dN5_dt = k45 * N4 - k51 * N5
        dN6_dt = f - k67 * N6 - 2 * delta
        dN7_dt = k67 * N6 - k71 * N7 + delta

        # Update the values of each section
        N1 += dN1_dt
        N2 += dN2_dt
        N3 += dN3_dt
        N4 += dN4_dt
        N5 += dN5_dt
        N6 += dN6_dt
        N7 += dN7_dt

        atmosphere.append(N1)

    results.append(atmosphere)
```

In [11]:
```
plt.figure(figsize=(12, 8))

plt.scatter(co2_observations['year'], co2_observations['mean'], lab

plt.text(1850, 300, 'Calculations', fontsize=12)
plt.text(1900, 290, 'Observations', fontsize=12)
plt.text(1950, 345, 'β=0.38', fontsize=12, color='red')
plt.text(1980, 320, 'β=0.50', fontsize=12, color='blue')

# Draw the results of each beta value directly, with the colors red
plt.plot(range(1750, 2001), results[0], color='red', label='β=0.38'
plt.plot(range(1750, 2001), results[1], color='blue', label='β=0.50


plt.xlabel('Year', fontsize=14)
plt.ylabel('CO2 Concentration (ppm)', fontsize=14)

plt.legend()

plt.show()
```



In [ ]: