ModSim Project 2 - Sea Level Rise

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Questions

What is the effect of reducing global carbon emission on sea level rise by the year 2050?

This is an explanatory question. It explains the relationship between reducing carbon emissions now and the resulting sea level in 2050. This is an important question to ask because when sea levels rise, many cities will flood, resulting in the displacement of millions. Being able to predict both how much we need to cut carbon emission now and how much sea levels will rise in the future is vital in planning for the future. By asking the question, we will infrom people about how their current actions will affect their future way of life.

Modeling

To answer our proposed question, we are going to run a simulation that models how future sea levels rise in response to the quantity of CO2 in the atmosphere. We will run a sweepseries that uses a range of possible future CO2 emisssions that correspond to the varrying amounts we could start reducing our carbon emissions. The results of this sweep series will show how different commitments to reducing carbon emissions will result in varying amounts of sea level rise in the year 2050.

We are making a variety of assumptions in our model. Firstly, we are assuming that sea level rise is due to only the expansion of water in response to warming oceans and ice sheet melting. We made these assumptions because we concluded that these two sources were the primary causes of sea level rise, and trying to model in other causes would not make any significant differece. Furthermore, we assumed that the melting of iceburgs and glaciers would not change sea levels enough to warrent modeling. After looking at how much of the worlds ice is stored in icebergs compared to ice sheets, we felt that not including them would fall within an acceptable range of error. We also make the assumption that the primary cause of the earth energy imballnce is an incrase in carbon dioxide in the atmosphere. We further assumed that there is a direct causality between an increase in carbon dioxide and an increase in energy accumulation. Lastly, we assumed that the water and ice have no salinity, that they are pure water and therefore their densities are the same.

In our model, we have the following stocks: carbon dioxide quantity, global ice sheet mass, global ocean mass, global ocean temp, and global ocean volume. We technically only have one flow: mass flow from melted ice into water. We do, however, have many relationships between the stocks such as heat transfer into ocean temp, water temp in to water volume, carbon dioxide into heat transfer.

In [8]:
```
# Configure Jupyter so figures appear in the notebook
%matplotlib inline

# import functions from the modsim.py module
from modsim import *

# for csv reading
import pandas as pd
```

Important Constants to know:

- Water Specific Heat (c) = 4186 J/kg °C
- Water Heat of Fusion at 0 °C = 334 J/g = 334000 J/kg
- Water Volumetric Expansion Coefficient (β) = 0.000207 per degree Celsius 1/°C
- **Solar input (IUCN Report) = 340 W/m^2 = 340 J/s/m^2
- **Approximate Surface Area of Earth = 5.101*10^14 m^2
- Water absorbs about 93% of the energy imbalance of earth
- **Ice absorbs about 4% of the energy imbalance of earth

In [35]:
```
# sea water vs. ocean water vs. ice water have different density/beta/c? changes wi
th salinity? start with plain water and edit later.

def make_system(water_mass, ice_mass, water_temp, water_volume, coeff, coeffMelt, t
_0, t_end):
    df = pd.read_csv("CO2 Emissions.csv")
    co2 = df["CO2 (kg)"]
    startYear = 1970

    init = State(WM=water_mass, IM=ice_mass, WV=water_volume, WT = water_temp, WE=
0)
    return System(init=init, t_0=t_0-startYear, t_end=t_end-startYear, gg=co2, coef
f=coeff, coeffMelt=coeffMelt, c=4.186, beta=0.000207, water_sink=0.93, startYear=st
artYear)
```

In [36]:
```
def round_sig(f, p):
    return float(('%.' + str(p) + 'e') % f)
```

In [52]:
```
def update_func(state, t, system):
    wm, im, wv, wt, we = state
    gg = system.gg[t]
    co = system.coeff
    coMelt = system.coeffMelt

    # energy added
    delta_energy = (co[0]/10**18 + co[1]/10**18*gg) *10**18 # linear best fit of en
ergy trapped/year vs. co2/year
    we += delta_energy

    # distribute energy into ice and water
    delta_water_energy = system.water_sink * delta_energy # [%] * [J] = [J]

    # ice melted to water at 0*C right below freezing
    delta_mass = (coMelt[0] + coMelt[1]*gg) # linear best fit of ice melt/year vs.
co2/year

    # updating water volume and temp
    wt = wm*wt / (delta_mass + wm)
    wv *= (1+system.beta*wt)*(delta_mass+wm)/wm

    # moving ice mass to water
    wm += delta_mass
    im -= delta_mass

    r = 4
    print('t', t+system.startYear, '\twm', round_sig(wm, r), '\tim', round_sig(im,
r), '\twv', round_sig(wv, r), '\twt', round_sig(wt, r), '\tice melt', round_sig(del
ta_mass, r), '\tenergy', round_sig(we, r), '\tgg', round_sig(gg, r), )
    return State(WM=wm, IM=im, WV=wv, WT=wt, WE=we)
```

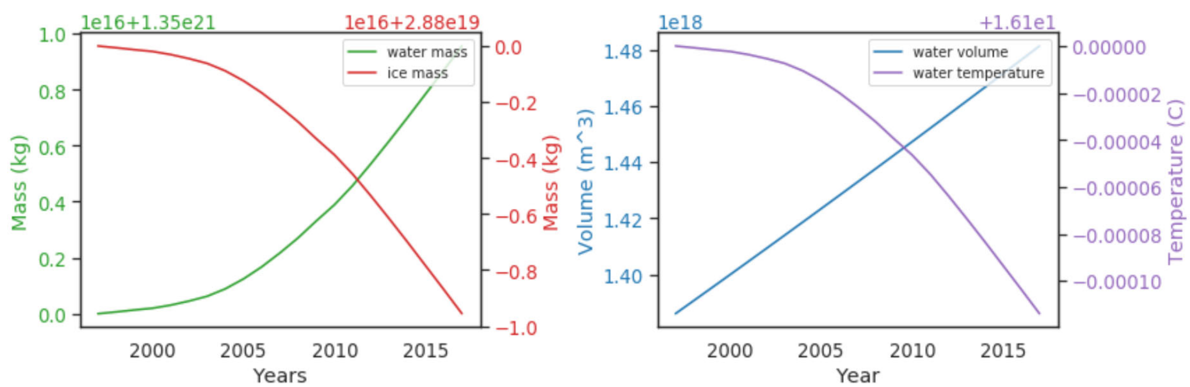
In [53]:
```
def plot_results(results, t_0):
    fig, (pl1, pl2) = plt.subplots(1, 2, figsize=(12, 4))
    time = [i+t_0 for i in range(len(results.WM))]

    color = 'tab:green'
    pl1.set_xlabel('Years')
    pl1.set_ylabel('Mass (kg)', color=color)
    cells, = pl1.plot(time, results.WM, color=color)
    pl1.tick_params(axis='y', labelcolor=color)

    ax1 = pl1.twinx()
    color = 'tab:red'
    ax1.set_ylabel('Mass (kg)', color=color)
    cells1, = ax1.plot(time, results.IM, color=color)
    ax1.tick_params(axis='y', labelcolor=color)

    color = 'tab:blue'
    pl2.set_xlabel('Year')
    pl2.set_ylabel('Volume (m^3)', color=color)
    cells2, = pl2.plot(time, results.WV, color=color)
    pl2.tick_params(axis='y', labelcolor=color)

    ax2 = pl2.twinx()
    color = 'tab:purple'
    ax2.set_ylabel('Temperature (C)', color=color)
    cells3, = ax2.plot(time, results.WT, color=color)
    ax2.tick_params(axis='y', labelcolor=color)

    pl1.legend((cells, cells1), ('water mass', 'ice mass'), fontsize=10, loc='upper
right')
    pl2.legend((cells2, cells3), ('water volume', 'water temperature'), fontsize=1
0, loc='upper right')
    fig.tight_layout()
```

In [54]:
```
def run_simulation(system, update_func):
    """Runs a simulation of the system.
    Adds a TimeFrame to the System: results

    system: System object
    update_func: function that updates state
    """
    init = system.init
    t_0, t_end = system.t_0, system.t_end
    frame = TimeFrame(columns=init.index)
    frame.row[t_0] = init
    ts = linrange(t_0, t_end, 1)

    for t in ts:
        state = frame.row[t]
        frame.row[t+1] =  update_func(state, t, system)

    return frame
```

In [55]:
```
# These values are all from google for 2019, should be checked for correctness:
IM = 2.88 * 10**19
WM = 1.35 * 10**21
WT = 16.1
WV = 1.386 * 10**18

# best fit determined
t_0 = 1997
t_end = 2017
coeff = [-6.07*10**21, 6.24*10**8]
coeffMelt=[-1.56*10**15, 67.9]

# the water temperature looks too small due to assuming that ALL of the ocean heats
up, while in reality the upper layer is and lower isn't really
# ^^ this is because we are using the whole ocean's volume and mass in our starting
state.
# 0.7 km deep upper ocean layer, which stores 60% of heat according to https://www.
oceanscientists.org/index.php/topics/ocean-warming

system = make_system(WM, IM, WT, WV, coeff, coeffMelt, t_0, t_end)
results = run_simulation(system, update_func)
plot_results(results, t_0)
```

```
t 1997  wm 1.35e+21     im 2.88e+19     wv 1.3906e+18    wt 16.1         ice melt
62810000000000.0        energy 8.8436e+21       gg 23900000000000.0
t 1998  wm 1.35e+21     im 2.88e+19     wv 1.3953e+18    wt 16.1         ice melt
69600000000000.0        energy 1.775e+22        gg 24000000000000.0
t 1999  wm 1.35e+21     im 2.88e+19     wv 1.3999e+18    wt 16.1         ice melt
62810000000000.0        energy 2.6593e+22       gg 23900000000000.0
t 2000  wm 1.35e+21     im 2.88e+19     wv 1.4046e+18    wt 16.1         ice melt
110340000000000.0       energy 3.5874e+22       gg 24600000000000.0
t 2001  wm 1.35e+21     im 2.88e+19     wv 1.4093e+18    wt 16.1         ice melt
144290000000000.0       energy 4.5466e+22       gg 25100000000000.0
t 2002  wm 1.35e+21     im 2.8799e+19   wv 1.4139e+18    wt 16.1         ice melt
171450000000000.0       energy 5.5308e+22       gg 25500000000000.0
t 2003  wm 1.35e+21     im 2.8799e+19   wv 1.4187e+18    wt 16.1         ice melt
266510000000000.0       energy 6.6024e+22       gg 26900000000000.0
t 2004  wm 1.35e+21     im 2.8799e+19   wv 1.4234e+18    wt 16.1         ice melt
354780000000000.0       energy 7.755e+22        gg 28200000000000.0
t 2005  wm 1.35e+21     im 2.8798e+19   wv 1.4281e+18    wt 16.1         ice melt
429470000000000.0       energy 8.9764e+22       gg 29300000000000.0
t 2006  wm 1.35e+21     im 2.8798e+19   wv 1.4329e+18    wt 16.1         ice melt
497370000000000.0       energy 1.026e+23        gg 30300000000000.0
t 2007  wm 1.35e+21     im 2.8797e+19   wv 1.4377e+18    wt 16.1         ice melt
538110000000000.0       energy 1.1581e+23       gg 30900000000000.0
t 2008  wm 1.35e+21     im 2.8797e+19   wv 1.4425e+18    wt 16.1         ice melt
606010000000000.0       energy 1.2965e+23       gg 31900000000000.0
t 2009  wm 1.35e+21     im 2.8796e+19   wv 1.4473e+18    wt 16.1         ice melt
578850000000000.0       energy 1.4323e+23       gg 31500000000000.0
t 2010  wm 1.35e+21     im 2.8795e+19   wv 1.4521e+18    wt 16.1         ice melt
687490000000000.0       energy 1.5782e+23       gg 33100000000000.0
t 2011  wm 1.35e+21     im 2.8795e+19   wv 1.4569e+18    wt 16.1         ice melt
775760000000000.0       energy 1.7321e+23       gg 34400000000000.0
t 2012  wm 1.35e+21     im 2.8794e+19   wv 1.4618e+18    wt 16.1         ice melt
809710000000000.0       energy 1.8892e+23       gg 34900000000000.0
t 2013  wm 1.35e+21     im 2.8793e+19   wv 1.4667e+18    wt 16.1         ice melt
830080000000000.0       energy 2.0482e+23       gg 35200000000000.0
t 2014  wm 1.35e+21     im 2.8792e+19   wv 1.4716e+18    wt 16.1         ice melt
850450000000000.0       energy 2.209e+23        gg 35500000000000.0
t 2015  wm 1.35e+21     im 2.8791e+19   wv 1.4765e+18    wt 16.1         ice melt
850450000000000.0       energy 2.3698e+23       gg 35500000000000.0
t 2016  wm 1.35e+21     im 2.879e+19    wv 1.4814e+18    wt 16.1         ice melt
864030000000000.0       energy 2.5319e+23       gg 35700000000000.0
```

Out[55]:



Results

Our model still has a lot of work to go, such as converting from water volume to sea level, but it does show the basic trend of global climate change. It shows that over time, ice sheets will melt and the volume of water of water will increase.

Interpertation of Results

In [0]:

```
```