Modeling Blue Carbon in Salt Marshes

STUDENT PAGES

Exercise 1: Classroom Data Interpretation Activity
Exercise 2: Gathering Your Own Data in the Field

Key Questions

1. *How do salt marsh systems take carbon dioxide (CO_2) from the air and store it in soils?*
2. *How much carbon dioxide and methane (CH_4) is stored in or emitted per unit area in a New England or mid-Atlantic tidal salt marsh?*
3. *What factors have the strongest influence on the rate of carbon flow and storage?*
4. *How might the increased temperatures and faster rate of sea level rise associated with climate change affect the rates at which carbon is stored or emitted?*

Dr. Omar Abdul-Aziz and Mohammed Zaki at work on the Coastal Greenhouse Gas Model.

Background

Have you heard the term "blue carbon?" It refers to carbon that is stored by plants, algae, and phytoplankton in coastal and marine ecosystems, such as salt marshes, seagrass beds, and mangrove forests.

Salt marshes provide many valuable ecosystem services: they create barriers to prevent coastal erosion, reduce wave energy, and limit the impacts of storm surges and flooding events. They also serve as natural filters of some pollutants, and they take up nitrogen from water flowing to coastal areas, decreasing over-enrichment of estuaries. Salt marsh systems provide essential habitat for fish and food for migratory water birds, and they support complex food webs with terrestrial and marine species. Salt marshes are valuable to humans as sources of food, especially shellfish, and as places for recreation.

The Bringing Wetlands to Market (BWM) project was a collaborative research project carried out from 2011 – 2019, led by Waquoit Bay National Estuarine Research Reserve (WBNERR) with the main study sites located at South Cape Beach in Mashpee, State Game Farm in Sandwich, Bass Creek in Yarmouth, Quivett Creek in Dennis, and Stony Brook in Brewster on Cape Cod in Massachusetts. Through collaborations with other wetland scientists, more data was collected from study sites in salt marshes along the mid-Atlantic coast. Data from 26 salt marshes along the mid-Atlantic and New England Coasts were incorporated in total. This project examined the relationship between salt marshes, climate change, and nitrogen pollution with a goal of helping coastal managers improve and enhance wetland management, restoration, and conservation. Many ongoing studies continue work on related research.

Scientists in the "Bringing Wetlands to Market" project made observations that can help to determine the economic value of salt marshes as carbon sinks, places that take carbon dioxide from the air and store it in the soil. The research team examined how salt marshes may be impacted by climate change and nitrogen pollution. Through data collection, computer modeling, and many discussions with stakeholders (individuals and organizations with an interest in the project), the team generated information and tools that coastal decision makers can use to design effective wetlands protection and restoration projects and create economic incentives to reduce greenhouse gas emissions.

Research in the Bringing Wetlands to Market project demonstrated that in addition to their many ecosystem services, salt marshes are also extremely effective at sequestering, or taking up and storing, carbon from the air through photosynthesis, which can help to reduce high levels of carbon dioxide in the atmosphere.

During photosynthesis, salt marsh plants take carbon dioxide from the air and store the carbon in aboveground biomass such as stems and leaves, and belowground biomass such as roots, which can gradually become part of the soil, as illustrated in Figure 1 on next page. In these coastal salt marsh systems, carbon can be taken from the atmosphere and stored as a carbon pool. Since the major driver of climate change is increased carbon dioxide (CO_2) in the atmosphere, blue carbon ecosystems (tidal salt marshes, mangroves, and seagrasses) can help reduce the impacts of climate change by removing a lot of carbon dioxide from the atmosphere and sequestering, or storing it for up to thousands of years.

Aboveground and Belowground Biomass in a Salt Marsh

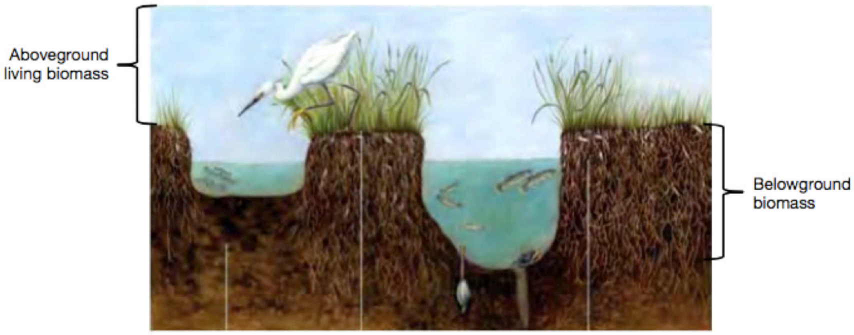


Figure 1: Aboveground and belowground biomass in a salt marsh. *Source: Fourqurean et al., 2014*

However, climate change, development, and other environmental pressures can cause salt marshes and other coastal wetlands to release the carbon that was stored in the soil in the form of carbon dioxide (CO_2) and methane (CH_4). These two greenhouse gases trap heat and act to increase temperature in the atmosphere.

As in terrestrial, or land-based, ecosystems, carbon in coastal ecosystems is only sequestered in the living plant biomass for a relatively short time - years to decades. The soils of blue carbon systems, however, can take up and hold a great deal of carbon, as shown in Figure 2, and the carbon can remain trapped for centuries to thousands of years.

Comparison of Amount of Carbon Stored in Different Habitats

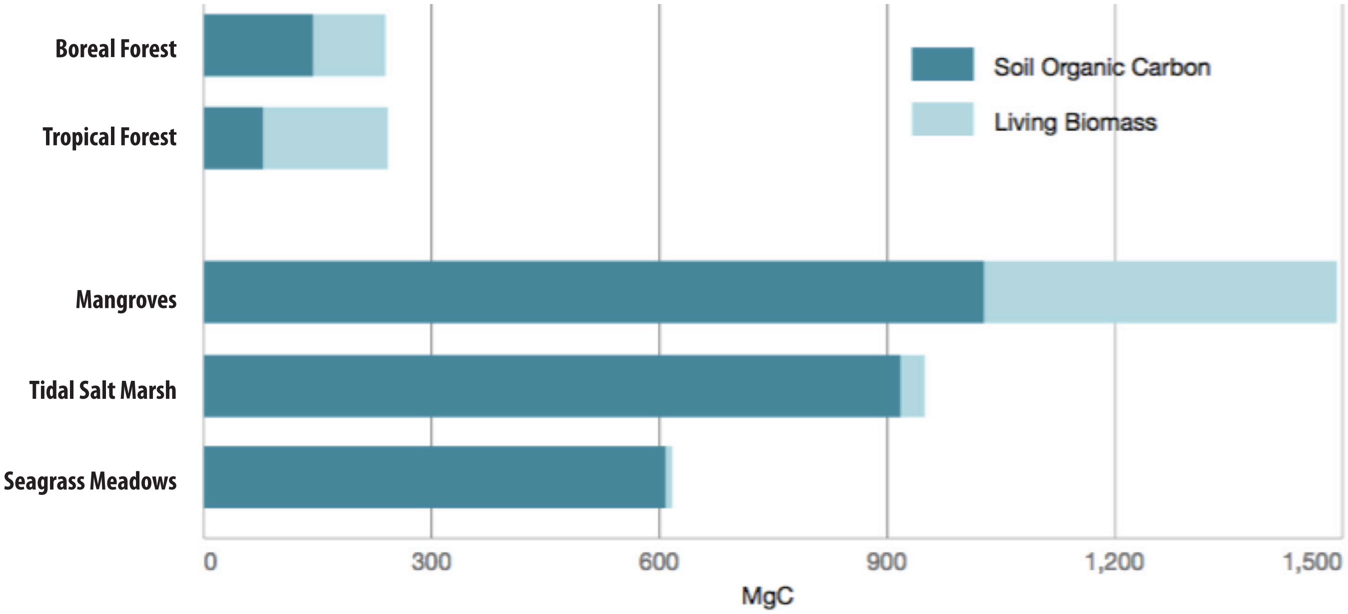


Figure 2: Mean carbon stored in vegetated habitats. Units "MgC" are milligrams of carbon per square meter surface area. Soil organic carbon is highest in coastal habitats, constituting from 50% to more than 90% of the ecosystem carbon stock. *Source: Howard et al., 2014 (Note: Boreal forests grow in high-latitude environments where freezing temperatures occur for 6 or more months a year.)*

Wetland vegetation is highly efficient in trapping sediment as it moves through the system, which aids in the continuous vertical build-up, or "accretion" of sediments. However, for the Coastal Wetland Greenhouse Gas Model 2.0 (CWGM 2.0), only the carbon entering or leaving via the atmosphere (through photosynthesis, respiration, and decomposition, as illustrated in figure 3) is considered. Therefore, the model predicts Net Atmospheric Carbon Removal (NACR) by a coastal salt marsh based on input data on light (PAR), soil temperature, and soil porewater salinity (the water trapped in the spaces between the particles of soil/sand in the ground). NACR refers to the potential (i.e., maximum) wetland carbon storage. To get a fully accurate accounting of carbon storage in the marsh, it would be necessary to measure the amount of carbon that is removed by the process called "lateral flux," or sideways flow, for example, tides or storms.

Carbon Uptake and Sequestration in Coastal Wetland Habitats

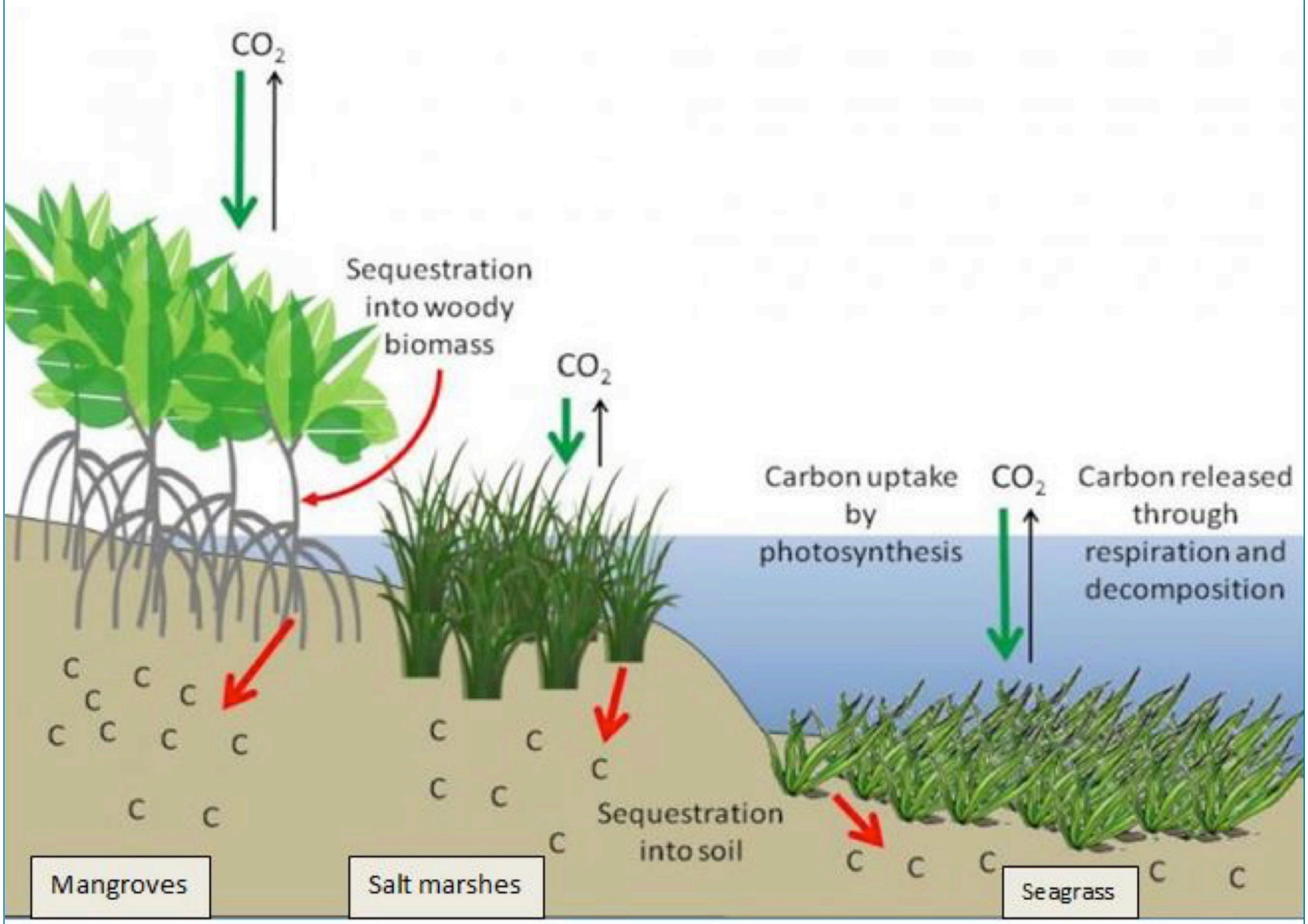


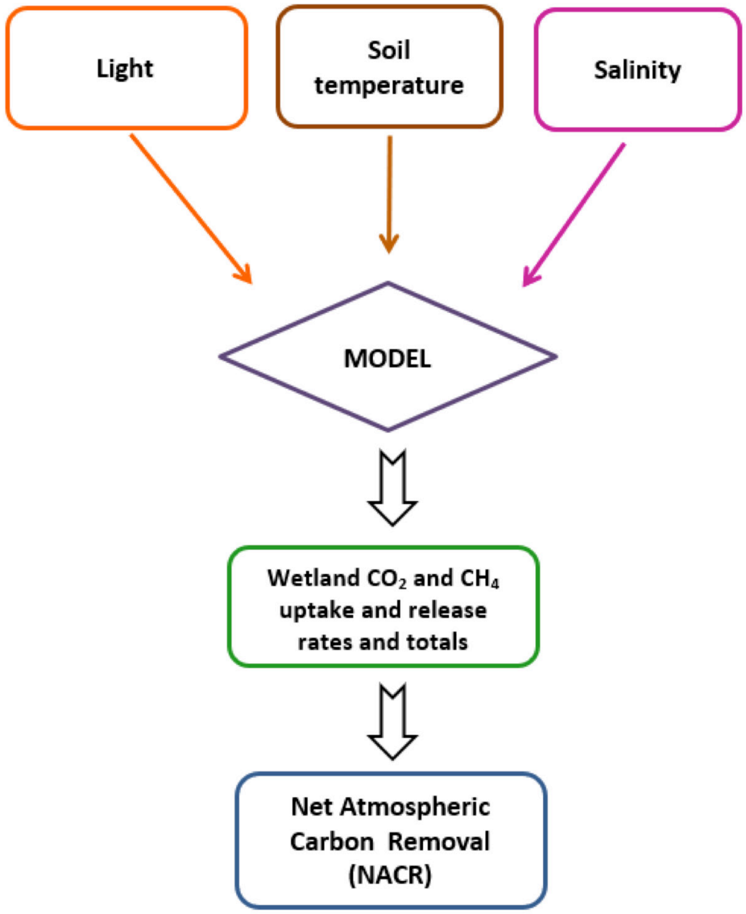
Figure 3: Carbon Uptake and Sequestration in Coastal Wetland Habitats. *Source: Howard et al., 2017*

The storage of carbon in the soil in terrestrial ecosystems is reduced when wetland soils and sediments are exposed to air and oxygen is readily available. In aerobic (high oxygen) conditions, soil bacteria release carbon back to the atmosphere through the process of decomposition, where some of the carbon binds with the oxygen in the air to form carbon dioxide (CO_2). In blue carbon systems, shown in Figure 3, the soil is saturated with water, creating an anaerobic state (low to no oxygen) in which bacteria do not release carbon dioxide, so more carbon is stored in these wet soils.

Factors that can cause sediments to become exposed to air include land-use change, such as draining tidal marshes, or erosion from accelerated sea-level rise. To promote conservation and restoration of these important ecosystems, it is important to understand how climate change or direct degradation of the systems will affect carbon sequestration and storage.

The Coastal Wetland Greenhouse Gas Model 2.0 (CWGM 2.0)

As part of the Bringing Wetlands to Market project, a user-friendly computer model was developed to predict the rate of Net Atmospheric Carbon Removal (NACR) in salt marshes using measurements that are easy to make. The model is a generalization of a previous model developed for four salt marshes of Waquoit Bay. The CWGM 2.0 incorporated data from 26 salt marshes along the mid-Atlantic and northeast coasts of USA. NACR refers to the potential (i.e., maximum) wetland carbon storage. Users would need to subtract the net lateral flux of carbon (to the ocean) from NACR to compute the net ecosystem carbon balance (NECB) in a salt marsh. This model can help coastal managers determine how much carbon a salt marsh will store in a season, and credit for the stored carbon can be considered when calculating the economic value of wetlands.


Schematic of Computer Model to Calculate Net Atmospheric Carbon Removal

The computer model requires users to measure and input observations of three relatively easily measured factors:

- **Photosynthetically active radiation, PAR** (units: micromoles/m^2/sec)
- **Soil temperature** (units: degrees Celsius)
- **Salinity of marsh sediment** (units: parts per thousand, ppt)

PAR or photosynthetically active radiation refers to the components of sunlight that have a wavelength from 400 to 700 nanometers. These wavelengths are in the range necessary for plants to use in the process of photosynthesis. In general, with higher levels of PAR, more carbon can be taken in through photosynthesis and stored in the marsh soil.

Soil temperature: Respiration by plants and metabolism by soil microorganisms both produce CO_2 and are strongly dependent on soil temperature. As temperature increases, in general the marsh soil tends to give off more carbon dioxide and store less carbon due to a higher rate of metabolism by bacteria which increases decomposition. However, at very high temperatures less carbon dioxide is emitted.

Soil porewater salinity affects rates of greenhouse gas fluxes and wetland carbon storage. Soil porewater salinity is related to the frequency and duration of coverage of a marsh by salty tides. Marshes that are inundated by salty tides tend to release less carbon dioxide and methane than drier soils or soils with fresher water.

The computer model was designed to run using inputs of measurements made over the period of a growing season (May-October; productive period for coastal salt marshes in this region) in coastal salt marshes along the mid-Atlantic and northeast coasts of USA. The model calculates the potential maximum possible uptake of carbon dioxide (CO_2) and methane (CH_4) by the salt marsh plants over the course of the growing season, and the emissions of those greenhouse gases back to the atmosphere due to respiration and decomposition, to determine the Net Atmospheric Carbon Removal (NACR) for that particular area. **A negative NACR number indicates more carbon is being taken up and potentially stored than emitted.**

Vocabulary

Aerobic: High availability of oxygen

Anaerobic: Low to no oxygen

Biomass: the living material in a specific area or habitat.

Blue carbon: The carbon stored in mangroves, tidal salt marshes, and seagrass meadows within the soil, the living biomass aboveground (leaves, branches, stems), the living biomass belowground (roots), and the non-living biomass (litter and dead wood).

Carbon dioxide (CO_2): Carbon dioxide is a gas in the Earth's atmosphere. It occurs naturally and is also a by-product of human activities such as burning fossil fuels. It is the principal greenhouse gas (heat-trapping gas) produced by human activity.

Carbon pool: Any place where carbon is stored, such as plants, the atmosphere, the ocean, or soil. Carbon pools can also be called stocks or reservoirs.

Carbon sink: A place that is actively taking carbon from the atmosphere or soil and storing it for a long or short period.

Decomposition: the breakdown of dead matter into simpler forms. Organisms in the soil, such as bacteria and fungi, help carry out the process of decomposition.

Degradation: The condition or process of disturbing or decreasing the quality of an ecosystem.

Emission: Carbon that is released back to the atmosphere, often in the form of carbon dioxide or methane due to respiration or oxidation as a result of land-use or climate changes.

Flux: The magnitude and direction of flow of a substance.

Greenhouse Gas (GHG): Gases that trap heat in the Earth's atmosphere. This is essential to maintain a livable temperature on the earth but the addition of too much greenhouse gas to the atmosphere is causing the earth to warm. The most abundant greenhouse gases in the atmosphere are water vapor, carbon dioxide, and methane.

Global warming potential (GWP): A relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas to the amount of heat trapped by a similar mass of carbon dioxide. Although the figures are different depending on the length of time that is being considered, the recommended GWP of methane in the model is 34 (100 year time span is considered).

Mangroves: Several species of salt-tolerant trees and shrubs that live in the coastal intertidal zone in areas where winter temperatures do not go much below 20° C (68° F).

Marine: Related to the ocean; for example, marine plants are those that can grow in saltwater.

Methane (CH_4): The second most prevalent greenhouse gas (heat-trapping gas) emitted in the United States from human activities. It's a very potent greenhouse gas (34 times the effect, or global warming potential, of CO_2 over a 100-year span).

Net Atmospheric Carbon Removal (NACR): The potential (i.e., maximum) carbon storage in a wetland. The carbon removed from the atmosphere by net CO_2 uptake minus net carbon (CO_2 and CH_4) emissions in the salt marshes.

Net Ecosystem Carbon Balance (NECB): The amount of carbon stored in a wetland when the amount of carbon removed and added by the tides or stormwater is taken into effect. NECB = NACR - lateral carbon flux (the amount of carbon brought in or out by the tides or stormwater).

PAR (Photosynthetically active radiation): represents the fraction of sunlight with a wavelength from 400 to 700 nanometers, the range necessary for plants to photosynthesize.

Phytoplankton: Microscopic organisms in the ocean that use photosynthesis for energy.

Salt marshes: coastal wetland areas that are regularly flooded by saltwater brought in by the tides; salt marshes mainly contain grasses and herbs, not woody plants.

Seagrass beds: Seagrasses are flowering plants that grow underwater in marine, fully saline environments. Examples include eel grass and turtle grass.

Sequestration: The process by which carbon dioxide in the atmosphere or oceans is removed by plants during photosynthesis or by physical processes such as through tides and runoff from the land, and stored in biomass or soil.

Terrestrial: Land-based or referring to land, not ocean.

Water vapor: Water vapor traps heat in the atmosphere, so it is considered a greenhouse gas, but the amount of water vapor in the atmosphere is not directly controlled by humans. Warmer air can hold more water vapor, so as CO_2 levels increase in the atmosphere, air temperature increases, and the levels of water vapor may also increase.

Student Pages

Exercise 1: Student Data Analysis Web-based Activity

How Will Climate Change Affect Carbon Storage in a Salt Marsh?

In this activity, you will investigate the factors that influence the flux (direction and quantity of flow) of carbon and methane in a wetland using sample data. You will also examine the effect of potential climate change impacts on the overall flux and balance of carbon.

Using data from the Bringing Wetlands to Market project, a computer model was developed to predict the Net Atmospheric Carbon Removal in mid-Atlantic and northeast coast tidal wetlands of USA. This model can help coastal managers determine how much carbon a salt marsh will store in a season, and credit for the stored carbon can be sold in carbon markets.

Scientists took many types of measurements to find out which parameters (factors) had the greatest effect on the amount of carbon that was stored. In order to make the model practical for coastal managers to use, only the most important parameters are included in the final model.

Model Assumptions and Boundaries:

1. Coastal salt marshes are productive mainly during the extended growing season (e.g., May to October). However, users can decide what time period to use in the model. For New England, you can use any range from one day to about 183 days. The model is not accurate for winter season measurements.
2. This model was designed for New England and Mid-Atlantic salt marshes. However, the model can be extended to other tidal wetlands given similar wetland conditions.
3. The Net Atmospheric Carbon Removal (NACR) represents the amount of carbon removed from the atmosphere by CO_2 uptake (through photosynthesis), after subtracting net carbon CO_2 and CH_4 emissions in the salt marshes (from respiration and decomposition).

NACR represents the potential maximum possible carbon storage in that salt marsh, but the actual value would need to include the amount of stored carbon lost to erosion and tidal processes (lateral flux).

The model was designed to use observations made over the course of a growing season and assumes that the growing season is May-October. For the most valid results, the input data should include observations made at different times in the growing season, to yield a result representing the beginning, midpoint, and end of the growing season.

It is possible to run the model using only one set of observations. However, it is preferable to use three sets of observations representing beginning (e.g., May), middle (e.g., August), and end (e.g., October) of the growing season. If more measurements are made over the course of the growing season, the model outcomes are more valid. Data loggers may be used to collect data over one or more days and can provide additional data to enter into the model.

For this model, input measurements can be made at any time of day, in any tidal conditions and anywhere within the salt marsh. However, the measurements for each set of three factors (PAR, soil temp, and salinity) should be taken in the same area, then the next set of observations can be made at a different area and/or time. This will yield an output that is valid for that general location.

Procedure

1. Make sure you have the program Microsoft Excel on your computer.
2. Open the spreadsheet for the Coastal Wetland Greenhouse Gas Model 2.0 (CWGM 2.0) at this link and download it as an Excel file. http://waquoitbayreserve.org/research-monitoring/salt-marsh-carbon-project/expanding-blue-carbon-phase-2/model/.
3. If using Excel, enable macros in your Excel file. If your version of the Excel software does not have macros enabled already, you should be asked to enable macros when you open this file. Then save this Excel file as an "Excel Macro-Enabled Workbook."
4. The information in the "read me" section of the file is somewhat technical, so it has been simplified and included in the information above. Note: NEE stands for Net Ecosystem Exchange.
5. The table A1 (included below) provides example observations with the necessary input data for the model. The data in the examples represents averages of actual observed data from Cape Cod salt marshes.
6. Input each line of the data into the spreadsheet and hit run. Input 183 for the number of days in growing season. In the space for "CO_2 equivalent Global Warming Potential of CH_4 (methane)" input 34 because methane has 34 times the global warming potential of CO_2 over 100 years. This will calculate the warming due to methane over 100 years, expressed in units relating it to CO_2. You can also enter 1.0 from the dropdown menu to estimate the CH_4 emission and NACR without considering any GWP, or enter 86 to estimate the 20 year CO_2 equivalent global warming potential (GWP) of CH_4 (methane).
7. Click "RUN." Enter the output data into the table (Predicted daytime and nighttime CO_2 flux, Predicted CH_4 flux, Net Atmospheric Carbon Removal (NACR).
8. The Excel spreadsheet model will produce the following outputs:
    - Predicted daytime and nighttime CO_2, and CH_4 fluxes
    - Net Atmospheric Carbon Removal (NACR) in units of gC/m^2 (grams of carbon per square meter of salt marsh area)
    - A negative number indicates carbon has been taken out of the atmosphere over the course of the growing season of the year, a positive number means it is being emitted.
9. Interpreting your results: Record the Net Atmospheric Carbon Removal (NACR) in grams of carbon per square meter (gC/m^2). Net Atmospheric Carbon Removal represents the maximum potential amount of carbon removed from the atmosphere through photosynthesis by salt marsh plants, after correcting for loss of carbon back to the atmosphere from plant respiration and decomposition.

11. Use the data in the tables provided to you and your results to answer the questions on the Interpreting the Results page.

Table A1: Example Data Table for the Coastal Wetland Greenhouse Gas Model 2.0 (CWGM 2.0)

Units are:

- **Light:** PAR (Photosynthetically Active Radiation): micromoles per square meter per second
- **Soil temp:** degrees C
- **Soil salinity:** parts per thousand
- **Predicted daytime and nighttime carbon dioxide (CO_2) flux (uptake or release) and methane (CH_4) flux:** grams carbon per square meter; **negative numbers represent uptake or storage and positive numbers represent release or carbon emissions.**

EXAMPLE DATA TABLE	DATE	INPUT	INPUT	INPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT
		Light PAR (micro-mole/ m^2/s)	Avg. Soil Temp (C)	Soil Salinity (ppt)	Predicted daytime net uptake fluxes of CO_2, (micromole/ m^2/s)	Predicted nighttime net emission fluxes of CO_2, (micromole/ m^2/s)	Predicted anytime net emission fluxes of CH_4, (nanomole/ m^2/s)	Net CO_2 (uptake minus emission) (gC/m^2)	Net CH_4 emission (gC/m^2)	Net atmospheric carbon removal NACR (gC/m^2)
Date 1 Early in season	5/16/16	1431.54	13.91	20.00						
Date 2 Mid-season	8/23/16	1673.10	20.30	23.59						
Date 3 Late in season	10/14/16	993.77	14.46	25.57						

Table A2: How Will Climate Change Affect Carbon Sequestration Rates?

The table below provides an example comparing daily values of carbon uptake for present conditions and anticipated future conditions with climate change. How do the inputs and results differ in the future scenario?

DATE	INPUT	INPUT	INPUT	OUTPUT	OUTPUT	OUTPUT
	Light PAR (micro-mole/ m^2/s)	Avg. Soil Temp (C)	Soil Salinity (ppt)	Predicted CO_2 Flux (uptake minus emission) (gC/m^2)	Net CH_4 emission (gC/m^2)	Net atmospheric carbon balance (gC/m^2)
23 Aug 2016	1673.10	20.30	23.59			
Future scenario						
15 July 2030	1673.10	21.30	26			

Table A1

1) Examine the input values from the data collected from Cape Cod salt marshes in Table A1 and the Model Example Data table. What trends do you observe in the input variables over the growing season?

2) What difference do you observe in the value of the Net Atmospheric Carbon Removal output over the course of the season in Table A1?

3) What relationship, if any, can you observe between temperature and carbon uptake (or storage) and release (or emissions)? Look at the columns for uptake and emissions.

4) Suggest some reasons for the pattern of carbon uptake.

Table A2

5) What changes did you notice in the input data in the climate change scenarios in table A2? How are they related to climate change?

6) What happened to the Net Atmospheric Carbon Removal in the Table A-2 climate change scenario when compared to the 2016 rates? Remember, negative numbers indicate more uptake or storage and positive numbers indicate carbon is being emitted or released into the atmosphere.

7) What practical applications does this model have in understanding the relationship between climate change and greenhouse gas fluxes (direction and amount of flow)?

Model Example Data from Cape Cod Salt Marshes

Enter the number of days for which you want to estimate NACR --->	183	Enter CO_2 equivalent global warming potential (GWP) for CH_4 ----->	34

	Inputs			Outputs for each date			Result over entire study period		
Date	Photosynthetically active radiation, PAR (micro-mole/m^2/s)	Soil temperature, ST (°C)	Porewater salinity, SS (ppt)	Predicted daytime net uptake fluxes of CO_2 micromole/m^2/s	Predicted nighttime net emission fluxes of CO_2 micromole/m^2/s	Predicted anytime net emission fluxes of CH_4 nanomole/m^2/s	Net CO_2 (uptake minus emission) over the user defined period gC/m^2	Net CH_4 emission over the user defined period by considering a GWP gC/m^2	Net atmospheric carbon removal over the user defined period, NACR gC/m^2
5/16/2016	1431.54	13.91	20.00	-5.65	1.46	0.65	-598.83	28.89	-569.94
5/19/2016	2102.75	13.19	20.00	-6.79	1.35	0.51			
6/9/2016	1485.60	17.08	21.00	-7.25	1.99	1.54			
6/14/2016	1607.49	18.48	16.78	-10.61	2.24	9.35			
6/15/2016	888.71	17.76	22.00	-5.19	2.11	1.73			
7/13/2016	1608.03	19.60	19.36	-9.95	2.45	3.19			
7/14/2016	777.59	22.32	20.55	-6.90	2.97	5.29			
7/20/2016	1476.74	22.38	20.15	-10.78	2.98	5.49			
7/21/2016	1486.01	21.67	18.55	-11.27	2.84	5.31			
8/8/2016	1696.12	21.70	19.70	-11.60	2.85	4.92			
8/9/2016	1126.83	20.97	20.16	-8.27	2.71	4.09			
8/18/2016	1262.07	21.78	20.00	-9.45	2.86	4.91			
8/23/2016	1673.10	20.30	23.59	-8.78	2.58	2.87			
8/24/2016	1657.80	19.81	20.00	-9.97	2.49	3.20			
10/3/2016	1558.14	16.09	19.00	-7.64	1.82	1.35			
10/13/2016	1025.13	13.44	22.97	-3.77	1.39	0.47			
10/14/2016	993.77	14.46	25.57	-3.66	1.55	0.56			
5/4/2017	1608.73	12.23	20.55	-5.01	1.20	0.35			
6/14/2017	1796.23	21.19	18.00	-12.77	2.75	15.77			
6/21/2017	2004.37	18.97	17.58	-12.14	2.33	9.90			
7/10/2017	1653.41	20.73	17.59	-12.02	2.66	14.73			
8/21/2017	1342.30	21.42	18.60	-10.35	2.79	5.01			
9/11/2017	1395.45	17.29	19.18	-7.74	2.03	1.83			

Exercise 2: Students Field Study Activity

Taking Model Measurements in the Marsh

If you have the opportunity to visit a salt marsh, you can take your own measurements and input them into the model. Although it may not be possible to visit the marsh multiple times and make a series of data observations over a growing season to provide the optimal data input for the model, it is still beneficial to perform the model input measurements as a stand-alone exercise so students can learn about what factors affect the amount of carbon a wetland can store.

The Coastal Wetland Greenhouse Gas Model (CWGM 2.0) was developed based on data from different tidal wetlands along the mid-Atlantic and northeast coasts of USA representing biogeochemical and ecological gradients. A robust data analysis framework was used to select the most important variables as model inputs. The model can be used without requiring much input data.

Model Assumptions and Boundaries:

1. Coastal salt marshes are productive mainly during the extended growing season (May to October).
2. The model was designed especially for the tidal salt marshes in mid-Atlantic and northeast coasts of USA. However, the model can be extended to other tidal wetlands given similar wetland conditions.
3. The Net Atmospheric Carbon Removal (NACR) represents the difference between carbon removed from the atmosphere by CO_2 uptake and net carbon (CO_2 and CH_4) emissions to atmosphere from the salt marshes.

The model was designed to use daytime and nighttime averages over the course of a growing season and assumes that the growing season is May-October. For the most valid results, the input data should include at least three data entries taken at different times in the growing season to yield an acceptable average representing the beginning (e.g., May), midpoint (e.g., August), and end (e.g., October) of the growing season, but students can gain valuable field study experience even with one field visit. If more measurements are made over the course of the growing season, the model outcomes are more valid.

For this model, daytime is defined as any time of the day that has visible sunlight. Input measurements can be made at any time of day, in any tidal conditions and anywhere within the low marsh. However, the temperature, salinity, and PAR for each set of observations should be taken at about the same time of day and within the same area.

Materials

- Marsh soil water "Sipper" (handmade with tubing and a syringe – see photo or you can order on line)
- Metal rod or ¼ inch Dowel (at least 20 cm long)
- Hammer
- Coffee filter
- Meter stick
- Thermometer
- Refractometer
- Photosynthetic Light Sensor (for example, Onset HOBO data logger), software, and computer or Vernier PAR sensor, or similar sensor for measuring PAR

Procedure:

1. Measuring PAR (Photosynthetically Active Radiation, part of the spectrum of sunlight)

a. Activate or program the HOBO data logger to collect data while you are collecting the temperature and salinity data.

b. Place the HOBO data logger in a sunny area.

c. Follow the instructions for using the software for finding PAR data.

d. If you use a Vernier PAR or other sensor, follow the manufacturer's directions.

e. You can also find PAR for the last 24 hours at Waquoit Bay at this SWMP link http://cdmo.baruch.sc.edu/dges/. You will need to do a conversion: **SWMP PAR (mmol/m^2) x 1.11 = blue carbon model value (umol/m^2/sec).**

For example: If Total PAR from the SWMP website is 702.0 mmol/m2/15 minutes, multiply that by 1.1 to get 772.2 umol/m2/sec to enter into the model spreadsheet. (702 x 1.1=772.2)

f. If not using SWMP data, you may need to convert the PAR measurements to micromoles per square meter per second, **µmol/m^2/sec** which are the units used in the model.

The Hobo data loggers read in lumens per square foot

1 lumen/ft^2 = 10.7639 lux

1 lux = 0.0185 PAR

You can also use this page to calculate the conversion. http://www.egc.com/useful_info_lighting.php Choose radiation source "sunlight" and conversion "lux to photons".

2. Measuring soil salinity with a refractometer

a. Insert the metal rod or dowel 15 centimeters into the marsh surface.

b. Remove the dowel and insert the tube from the sipper.

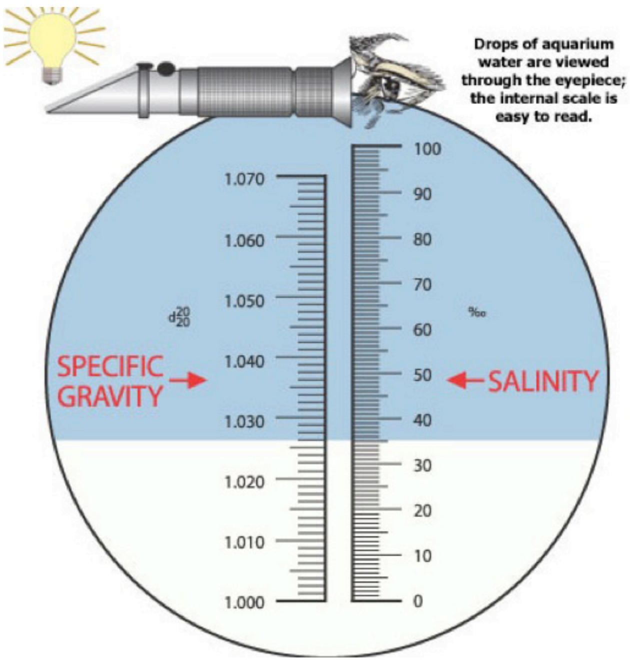
c. Take up a small amount of water by pulling up the syringe.

d. Open the clear plate of the refractometer to expose the prism.

e. Before adding a few drops of water to the prism, remove any sediments taken up by the sipper by straining the water though the coffee filter.

f. Wring out the coffee filter over the prism of the refractometer and close the clear plate. The sample should make a thin film over the entire surface of the prism.

g. Look through the eyepiece. Focus the scale until it is sharp to your eyes by gently turning the eyepiece. The upper field of view appears blue and the lower field will be white. The reading is taken at the line where the blue and white fields meet. For salinity, read the scale on the right side. It is marked as a "0/00". This is read as "parts per thousand".


Drops of aquarium water are viewed through the eyepiece; the internal scale is easy to read.

3. Measuring soil temperature

a. Insert the thermometer into the hole made by the dowel.

b. Leave in place for three minutes.

c. After three minutes, read the thermometer in Celsius.

Data Sheet for Field Measurements to Use with Coastal Wetland Greenhouse Gas Model

Name ______________________ Date ____________ Location ______________________

MARK SITE LOCATIONS ON A MAP	TIME	LIGHT PAR (MICROMOLE/M^2/S)	SOIL TEMP (C)	SALINITY (PPT)	NOTES
Sample site 1					
Sample site 2					
Sample site 3					
Sample site 4					

Enter Your Own Field Data and Results Below

DATE	INPUT	INPUT	INPUT	INPUT	INPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT	OUTPUT
Date or Time	Light PAR (micromole/ m^2/s)	Soil Temp (C)	Soil Salinity (ppt)	Number of days in growing season	Global warming potential	Predicted daytime net uptake fluxes of CO_2, (micromole/ m^2/s)	Predicted nighttime net emission fluxes of CO_2, (micromole/ m^2/s)	Predicted anytime net emission fluxes of CH_4, (nanomole/ m^2/s)	Net CO_2 (uptake minus emission) (gC/m^2)	Net CH_4 emission (gC/m^2)	Net atmospheric carbon removal NACR (gC/m^2)

Exercise 2:

Field Study: Running the Computer Model

Follow the steps outlined in exercise 1 to enter your own data into the Net Atmospheric Carbon Removal (NACR) Model. You may use the data provided in Exercise 1 to compare with your data.

Interpreting Your Results

1) **Examine the input values from the data you collected and compare them with the data on the "example" tab in the model or the simplified Model Example Data table provided in your packet. What dates have observations that most closely match your data?**

2) **How does the value of the Net Atmospheric Carbon Removal (NACR) output vary with different input observations? Describe the pattern.**

   a. Light (PAR):

   b. Soil temperature:

   c. Soil Porewater Salinity:

3) **Propose an explanation for the patterns of carbon storage you find in the example data. (for example, during different seasons or with different salinity or temperature values). Use the data to support your claim.**

4) **If you could sample at different times of year, how might you expect this to affect the rate of carbon uptake?**

Going Further

5) **The results of the Net Atmospheric Carbon Removal model represent the maximum potential amount of carbon removed from the atmosphere through photosynthesis by salt marsh plants, after correcting for loss of carbon back to the atmosphere from plant respiration and decomposition. What other factors would affect how much carbon is stored in a marsh? How might you go about measuring these?**

6) **Please explain any insights this exercise gave you into the difficulties developing mathematic models for ecological problems.**

Salt Marsh Study Data Form

Name(s)____ **Date**______________________

Location _______________________________________ **Time** ________________ **AM/PM**

Tide **low** **mid-tide** **high**

Air temperature _____________________ **°C** **Water temperature**______________ **°C**

Cloud cover__________________________**%** **Salinity of water** ______________ **ppt**

Plants, algae, and animals observed where sample was taken

Evidence of human activities

Additional notes

Sketch a map of the study area and mark the locations where you took your measurements.