

Forest Carbon Cycle Learning Modules using ForC

College Level Resources

Lesson Plans: High School to Undergraduate level

(Next Generation Science Standards)

**Using the ForC Database to Explore Carbon Cycling and Climate Change**

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| --- | --- | --- | --- |
| **Title of Unit** | Using structured, guided, and/or open inquiry and team based learning to explore a large scientific database on forest carbon cycling | **Grade Level** | Can be adjusted based on abilities of students.  Structured Inquiry lessons 9th -10th grade  Guided Inquiry lessons 11th – 12th grade  Open Inquiry 12th grade AP to undergraduate |
| **Curriculum Area** | Process of Science, Forest Ecology, Environmental Science | **Time Frame** | **Minimum**: three 45 minute lessons  **Maximum**: ten 90 minute lessons or more |
| **Next Generation Science Standards** | | | |
| HS. Matter and Energy in Organisms and Ecosystems   * **HS-LS2-4:** Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem * **HS-LS2-5:** Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere   HS. Earth’s Systems   * **HS-ESS2-6:** Develop a quantities model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.   HS. Weather and Climate   * **HS-ESS2-4**: Use a model to describe how variations in the flow of energy into and out of Earth’s systems result in changes in climate * **HS**-**ESS3-5:** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change   HS. Human Sustainability   * **HS-ESS3-6**: Use a computational representation to illustrate the relationships among Earth systems and how those relationships are modified due to human activity | | | |
| **Students will be able to…** | | **Essential Questions** | |
| * Review the process of science * Explain the structure of the forest carbon cycle and the process of carbon cycling * Explain the impacts of temperature on gross primary production * Explain how researchers study climate change and what we know and don’t know about the future of our climate * Use the process of science to explore aspects of the global forest carbon cycle * Present original research on the forest carbon cycle to their peers | | * What is the carbon cycle? * How do forests factor into the global carbon cycle? * What is the impact of temperature gross primary production? * What is the process of science and how do researches use statistical analysis to make predictions about the future? * How do you come up with an original research question? * What will happen to our global forests as a result of climate change? * What is your personal impact on the carbon cycle? | |
| **Related Misconceptions** | |
| Climate change is not real/not a big deal/not caused by humans | |

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Acknowledgements

Introduction:

Welcome to the Forest Carbon Database (ForC)’s educational outreach module, created by researchers at the Smithsonian Conservation Biology Institute (SCBI) and Forest Global Earth Observatory (ForestGEO). ForC is an open-access global database; a real scientific resource that is continually updated by researchers at SCBI and ForestGEO as new research is made available. Our goal in disseminating this curriculum is to allow students to access scientific data and potentially ask unique questions based on their interests and abilities. The modules cover a wide range in ability levels, from the structured inquiry module that slowly walks students through the process to the guided inquiry module that provides minimal guidance on a larger database to the open inquiry module that is essentially the process of science.

Forests strongly influence Earth’s climate through their role in the global carbon cycle. They sequester nearly 30% of anthropogenic carbon dioxide (CO2) emissions, and clearing just 100m2 (about a half of a school bus) of mature forest has the same climate change impact as driving most of the way around Earth’s circumference. Developing a better understanding of global forest carbon cycling and its climate sensitivity is critically important to projecting the future role of forests in Earth’s changing climate. Tens of thousands of pre-existing forest carbon measurements provide a wealth of data that could contribute to basic ecological research, ecosystem model benchmarking, and improved quantification of the climate impacts of alternative policy pathways. We want your students to be a part of this movement.

The lessons that follow can and should be adjusted based on ability level. Sections can be skipped entirely, inquiry can be purely structured, open, guided, or a mixture of all three, and students can use Excel, R, Matlab, Python, or other software to complete analyses. Our lessons assume students will be using ForC\_simplified\_edu or ForC\_GPP\_and\_temperature, rather than the much larger database ForC, but any of them can be used. This curriculum focuses on the process of science, climate change, and carbon cycling all while using real scientific data from an accredited research institution.

The lessons outlined here are suitable for a wide range of lessons, from three 45 minute lessons (one engagement module + one background module & one engagement + structured inquiry, simple) to seven 90 minute modules or more (background & structured Inquiry, complex & Open Inquiry and Team Based Learning & Carbon footprint). We suggest you take the time to read the instructions carefully to decide how deeply you want to take the analysis. We hope these resources will be of use in your classroom to help your students gain a deeper understanding of the process of science, carbon cycling, and climate change.

**Note to College Professors**: The majority of the education modules are aimed at a high school audience, but many are easily adaptable to an undergraduate class. A competent graduate class can easily use the database website alone for an introduction (<https://forc-db.github.io/>), visualization ( <https://forc.shinyapps.io/global_data_visualization/>), and direct link to complete data base (<https://github.com/forc-db/ForC>). ForC is a living database that can be freely accessed and utilized by researchers of any level. It is possible to use ForC for publications as long as it is properly cited as described on the database website (<https://forc-db.github.io/>). We suggest the following procedures for an undergraduate class:

1. Distribute the resources folder before class
2. Engagement module (of your choice) to start class
3. Guided or Open inquiry module (depending on ability level)

**Summary of Modules**

|  |  |  |  |
| --- | --- | --- | --- |
| Title | Description | Grade Level | Time |
| **Engagement** | Simple videos and simulations to get classes started. Can be individually modified. | 9 + | 5-7 min each |
| **Background** |  |  |  |
| * Carbon Connections | Complete unit plan on carbon cycling, basic process of science, historical records, and climate change. Can be used in place of a basic unit on the carbon cycle | 9 – 12 | ≈ fifteen 30 min lessons |
| * Forest Carbon Cycling | Very quick review of forest carbon cycling. Can be modified for higher levels, can also be shortened to less than 20 minutes | 9 – 12 | 55 min |
| * ForC | Brief introduction to ForC, essential introduction for any inquiry | 9 + | 25 min |
| * ForestGEO | Brief introduction to the organization ForestGEO, staff, and research | 9 + | 15 min |
| **Structured Inquiry** | Moves very slowly. Assumes students have little to no experience in data analysis or Excel. Walks students through all steps of data processing. Uses only ForC\_simplified\_GPP\_and\_temperature | 9 – 10 | ≈ 90 min |
| **Guided Inquiry** | Assumes students have some knowledge of data analysis and Microsoft Excel. Provides potential research questions but does not provide step by step instructions. Uses ForC\_simplified\_edu | 11 + | ≈ 180 min (or more) |
| **Open Inquiry** | Assumes students have moderate to strong backgrounds in data analysis, research, and data processing. Very little instructions and directions. Recommended for advanced learners only. Can use ForC\_simplified, or the raw ForC database. | 12 + | ≈ 360 min (or more) |
| **Carbon Footprint** | Basic extension activity, students determine carbon footprints and discuss bias | 9 + | 40 min |

# **Modules**

## **Engagement**

**Note to Instructors**: The content of the engagement modules is not provided by the Smithsonian. The Introduction to Photosynthesis video is provided for free by Frank Gregorio, Plant Productivity and A Year in the Life of Earth’s CO2 were created by NASA and are publicly available for download, and Breathing Earth was created by a private developer using publicly available data. It is recommended to at least go over photosynthesis before students progress into any other lessons. Engagement activities work best in the order presented, but can be used in any order for any lessons (or skipped entirely).

**Photosynthesis** (5 minutes)

4 minutes – **engagement**: Load (or contact author for free download) <https://www.youtube.com/watch?v=qYv3tbyquWk> and have the basic formula for photosynthesis somewhere in the room or on the board

**Photosynthesis**: 6CO2 + 6H2O + sunlight 🡪 C6H12O6 + 6O2

2 minutes – **discussion**: Explain to students that we’re not *really* exploring photosynthesis, but it’s just a great video that highlights the importance of plants and photosynthesis.

Discuss the formula. Have students think back to the images of plants in the video (or point to plants outside, hold a plant, wooden ruler, etc). Ask students where the physical matter of the plant comes from? Where does most of the mass come from (a surprising number of students thinks it comes from the ground or soil, but it’s equally from water and carbon dioxide. Plants come out of the air). Discuss the process of photosynthesis and how it pulls carbon out of the air. Plants (mostly) build their bodies out of carbon dioxide and water. It is **essential** students understand this.

**Plant Productivity in a Warming World** (7 minutes)

1 minute – **Preparation**: Load PPT to slide 3 (Plant Productivity) and have students copy down questions or write them on the board/ white board for them to see during the video: (<https://svs.gsfc.nasa.gov/vis/a010000/a010600/a010630/index.html>)

**Questions** (also available on the PPT):

1. (Before showing the video) the video even begins What impacts (positive or negative) would a warming world have on plant production? Write down some predictions. write some predictions on what impacts a warming world might have on plant production. (wide range of potential answers)When did instrumental measurements begin? (1880’s)
2. What happens to plant growth as temperatures begin to rise? (this is actually super complex! Increase under some situations, decrease under others)
3. What is primary plant production? (sequestration of CO2 into plant matter)
4. Where in the world was there a net increase in primary production? A net decrease? (increase in north, decrease in south)
5. What happened to the plant primary production globally from 2000-2009? Why? (decreased, many possible reasons why)

4 minutes – **Engagement**: Load <https://svs.gsfc.nasa.gov/vis/a010000/a010600/a010630/index.html> or download the video beforehand. Make sure to play the narrated version. Play video pausing when necessary (1:57 – 2:16 is a good section to replay)

2 minutes – **Discussion**: Ask first about question 1, how close were students? Was anything surprising? 2 – 4 are simple questions and 5 and 6 could cause potential discussions. Also possible to bring up what impacts this means for different parts of the globe, food systems, human populations, species distribution, etc.

**A Year in the Life of Earth’s CO2** (7 minutes)

1 minute – Preparation: Load PPT to Load PPT to slide 4 (Earth’s CO2) and have students copy down questions or write them on the board/ white board for them to see during the video. (<https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11719>)

Make sure students watch the dates progressing and concentration of CO2.

**Questions** (also available on the PPT):

1. Before the video begins predict what will happen to Earth’s carbon dioxide concentrations over the course of a year. (wide range of answers)
2. What happens to the carbon dioxide emitted from fossil fuel combustion (roughly half remains in atmosphere, half is absorbed)
3. Watch the video carefully and write down quick notes on what you’re seeing as the year progresses. Note months with high and low concentrations. Write down as many observations as you can. Be sure to write down any major changes or anything you hear that is surprising.
4. What is happening to the concentrations of carbon dioxide in the air?

4 minutes – **Engagement**: Load <https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11719> or download the video beforehand. Play video pausing when necessary or revisiting different seasons.

2 minutes – **Discussion:** Ask about question 1, what were some predictions? What really seemed to be happening? Go over question 2 and discuss observations for question 3. Discuss seasonal changes in CO2 and what is driving those changes (plant photosynthesis or lack of it). Discuss question 4 and how we know CO2concentrations are increasing and what this implies for global warming.

**Breathing Earth** (5 minutes)

2 minutes – **Engagement**: Load <http://breathingearth.net/> Adobe Flash required) and ask students to make observations (in notebooks or handouts). Breathing Earth (best to mute it after a few seconds) is a simulation displays the CO2 emissions and birth and death rates of every country in the world (currently based on 2015 emissions, be sure to check for updates). Use a computer mouse to hover over various countries. Students write down or call out simple observations and discuss what the carbon emissions mean. Potentially discuss the emissions of different countries. Can be done with a PPT question or verbally. Clicking the “?” in the upper left corner of the simulation provides further tips. To reset Breathing Earth, you must close the browser and re-open the link.

3 minutes – **Discussion**: Discuss student observations. Ask students about which countries might be the biggest emitters and discuss CO2 emitted per person vs CO2 emitted by country (example, China is a more rapid emitted of CO2 overall, but US is much higher per person meaning as a society we emit less carbon than China, but individually we emit much more). You may leave the simulation going until the end of class (be sure to mute it) or exit out. If you leave it running to the end of class be sure to bring it up again with the students. You could also have students write down predictions as to how much CO2 will be release globally during class. If you are doing this after the “Year in the Life” model you can discuss what will happen to the CO2(will it be sequestered? Will it be lost in the atmosphere?

## **Background**

**Note to Instructors**: Content in the Carbon Connections Module is provided by Carbon Connections, through the science education nonprofit Biological Sciences Curriculum Study (BSCS) that received funding by Oregon Public Broadcasting (OPB) and NASA. The carbon connections module goes into some detail. If you plan on using it we recommend signing up and using only select lessons. The Forest Carbon Cycling lesson might be too complex or vague depending on the class and it can be skipped, skimmed through, or assigned as homework (after simple modifications) depending on what you have already covered. We **strongly** suggest completing the ForestGEO and ForC background modules. All lessons can be completed digitally or through paper handouts and a PPT.

**Carbon Connections** (fifteen 30 minute lessons)

**Objectives**:

1. Students will be able to explain the process of carbon cycling
2. Students will be able to explain the impacts of past carbon cycling and how current climate signals can be interpreted
3. Students will be able to explain the future of climate change and the carbon cycle
4. Students will be able to explain how researchers study climate change and what we know and don’t know about the future of our climate

**Materials**: Internet connection, PPT (provided by Carbon Connections), worksheets (provided by Carbon Connections), student and instructor login for <http://carbonconnections.bscs.org/curriculum/>.

**\*NOTE\*** many lessons require extra materials while others rely on videos and clips only. If you plan on using Carbon Connections it is a good idea to familiarize yourself with the website and lessons. You can make a login for free and access all PPT, answer keys, student worksheets, and all lesson plan materials for free.

**Procedure**: (varies depending on lesson. Create a login [http://carbonconnectionsinstructorpage.bscs.org/](http://carbonconnectionsteacherpage.bscs.org/) to get access to all lessons).

**Forest Carbon Cycling** (55 minutes)

**Objectives**:

1. Students will be able to review the process of science and statistical analysis
2. Students will be able to explain the basic structure of the forest carbon cycle

**Materials**: ForC\_PPT, Handout\_Forest\_Carbon (one per student or one per group, to be turned in), digital copies or color prints of all diagrams (one per group or pair, reusable), Background\_Forest\_Carbon (one per student or group, reusable), Background\_cheat\_sheet (one per student or group, reusable)

**Procedure**:

10 minutes – **lecture**: handout Handout\_Forest\_Carbon\_handout then load ForC\_PPT, go to Carbon Cycle (slide 6) and begin. Notes are included in the PPT and the handouts have instructions. Students follow along with the slides

20 minutes – **reading**: handout one copy per (group/pair) of the Forest\_Carbon\_background handout. Students follow directions on handouts and use resources to answer questions. As students finish early begin passing out the diagrams to different groups

20 minutes – **diagram activity**: After each group has a diagram they will use it to answer questions on their handouts. Students are required to find several other diagrams so make sure you have passed out sufficient copies (there are 8 unique diagrams and all are necessary). Students may walk around the classroom as a group or individually to get information. They can split up the tasks many different ways.

5 minutes – **wrap-up**: go over the discussion questions at the end of the handout as a class and discuss the process of forest carbon cycling.

**ForC** (15 minutes)

**Objective**: Students will be able to explore a visual representation of the ForC database and gain exposure to scientific data and forest carbon cycling

**Materials**: ForC\_PPT, Handout\_ForestGEO\_ForC (one per student or pair), internet connection, personal or group/pair laptops, Forest\_Carbon\_Background (one per student or group, re-usable) Background\_cheat\_sheet (reusable)

**Procedures**:

2 minutes – **Introduction**: Pass out Handout\_ForestGEO\_ForC (digitally or print). Load the ForC\_PPT, go to section “ForC Introduction” (slide 17) and complete a brief lecture. Students follow along and answer questions.

10 minutes – **Reading**: Pass out ForC\_Intro\_reading (one per group/pair/individual). Students work quietly alone or in small groups answering questions based on the reading. Circulate around the classroom.

3 minutes – **Discussion**: When time is running out make sure to call the class back together and go over the discussion questions on the ForC\_PPT.

**ForestGEO** (15 minutes)

**Objective**: Students will be able to explain what kind of data is entered into ForC using ForestGEO as an example

**Materials**: ForC\_PPT, Handout\_ForestGEO\_ForC (one per student or pair), internet connection

**Procedures**:

2 minutes – **Introduction**: Pass out handouts (digitally on print). Load ForC\_PPT go to section “ForestGEO” (slide 18) and complete a brief introduction on ForestGEO, students follow along with PPT and answer questions

7 minutes – **video**: Load <https://www.youtube.com/watch?v=02UTPPmiKyM&feature=youtu.be> , students answer questions and follow along

3 minutes – **Featured researcher:** follow PPT (slide 19), students read alone or quick class lecture

3 minutes – **discussion**: The video might move a bit fast for some, it is up to you if you would like to pause along the way or wait until the video is done and discuss it. The main goal here is to expose students to ForestGEO and the standard methods researchers employ and to get them thinking about the ForC database and carbon cycling. It is best to at least go over the discussion question at the end of the forestGEO secion of the handout.

## **Structured Inquiry** (two 45 minute lessons or one 90 minute lesson)

**Note to Instructors**: There are two sections in structured inquiry. The “simple” section requires minimal knowledge of Excel and data analysis while the “complex” section involves a more detailed analysis using Excel, R, or MATLAB. We suggest completing one or the other (since both are asking the same question). The “simple” section could be used as transition into guided or open inquiry or it could act as the culmination of the inquiry section. The “complex” structured inquiry section is intended to be used in lieu of the guided or open inquiry sections.

**Objective**: Students will be able to explain the impacts of temperature on gross primary production (GPP) and gain exposure to the process of science and data analysis

**Materials**: ForC\_PPT, Handout\_structured (one per student or group), internet connection, group or individual access to computers with Microsoft Excel and an internet connection

**Procedures**:

2 minutes – **Introduction**: Pass out Handout\_structured (digitally or handout) and load ForC\_PPT to the “Process of science” (slide 5) section and complete a brief lecture on the process of science. Then skip to the “Structured Inquiry” section (slide 20) and review the basic outline of what students will be doing

3 minutes – **Discussion**: (Skip if unnecessary), discuss any homework and briefly review the purpose of ForestGEO and the ForC database

20 minutes – **Review**: Review the process of science (forest carbon cycle using ForC\_PPT) paying special attention to GPP since it is the factor students are focusing on this lesson. Students take notes on handouts and follow along with the PPT

25 minutes – **Data Processing**: Students continue the handout following along with the step-by step PPT (or you can just have them follow along with you as you complete it). Students follow directions in Handout\_structured and answer questions together or alone. We suggest having students work in small groups or pairs if they have little experience in data analysis or Excel.

(links: <https://github.com/forc-db/ForC/blob/master/educational%20resources/ForC_GPP_and_temperature.csv>)

20 minutes (or more) – **Data Analysis**: Students complete the data analysis and conclusion sections. Circulate around the classroom. As students complete the data analysis section they can continue to the extension sections (or it can be assigned as homework). Make sure the “Data Analysis” slide is left up as reference while students work and that students have access to text books or other references.

15 minutes – **Extension**: Students answer and discuss more difficult discussion questions (or can be assigned for homework)

5 minutes – **Discussion**: When class is drawing to a close to be sure to at least go over the “big idea” discussion question to ensure students understand their analysis and the importance of GPP.

## **Guided Inquiry and Team Based Learning** (3-4 days or more 45 minutes each day)

**Note to Instructors:** This module is designed for students and educators that have moderate experience in Microsoft Excel and data analysis. The instructions we have provided are designed to walk you and your students through the basic procedure of data analysis using Microsoft Excel, but you are also able to use any other statistical analysis software (such as R or MATLAB) to complete your analysis. Since students will be asking their own questions and working in groups they will also have a chance to briefly present their findings to the classroom.

**Objectives**:

1. Students will be able to use statistical analysis in order to answer question of their choosing concerning forest carbon cycling
2. Students will gain hands on experience in the process of science and statistical data analysis
3. Students will be able to present their findings to the class and review the carbon cycle

**Materials**: ForC\_PPT, Handout\_guided (one per student or group), Background\_cheat\_sheet (one per group/pair), group or individual access to computers with Microsoft Excel and an internet connection,

**Optional**: handout\_asking\_your\_question (only for those who wish to choose open inquiry), color diagrams

**Procedures**:

Day 1: **Exploring the data** (45 minutes)

2 minutes – **Introduction**: Pass out Handout\_guided, Background\_cheat\_sheet (digitally or handout) and load ForC\_PPT to the “Guided Inquiry” section. Complete a brief lecture on the process of science and the basic outline of what students will be doing

3 minutes – **Discussion**: (Skip if unnecessary), discuss any homework and briefly review the purpose of ForestGEO and the ForC database

2 minutes – **Review**: Briefly review the forest carbon cycle and process of science (using ForC\_PPT)

5 minutes – **Groups**: Assign students to small groups (preferably no more than 4). Students determine their roles and assign work (instructions are in Handout\_guided handout)

20 minutes – **Exploring the data**: Students follow the instructions in the Handout\_guided handout, alternatively you may want to walk the students through the complex structured inquiry procedure. This is done to ensure students understand the basic process of data analysis and are able to access, download, and process data on their own (or in groups). Students may access the shiny app (<https://forc.shinyapps.io/global_data_visualization/>) to get an idea of what some of the questions might look like.

10 minutes – **selecting your question, starting analysis**: Load the “Questions” slide in the ForC\_PPT. Students may choose from any question but each group must choose their own question. Make sure to strike out selected questions. Alternatively students may choose their own question (we suggest passing out the handout\_asking\_your\_question handout)

3 minutes – **discussion**: Bring class together after each question has been asked and briefly review the carbon cycle and what is expected of students over the next several days (data analysis followed by presentations)

Day 2 – 3: **Data analysis** and **presentation preparation** (45 minutes each day)

45 minutes – **Data analysis**: Students work in pairs or small groups analyzing data. Make sure to circulate around the classroom. This may take more time depending on how detailed you would like their analysis to be. We provide the outline for a basic analysis, but you are welcome to add to it.

45 minutes – **Presentation preparation**: As student groups finish working on analysis they should begin to put together brief presentations (5 minutes each or more) that focus on their question, methods, conclusions, and how it links to the carbon cycle. Instructions are provided in Handout\_guided

Day 4: **Presentations** (45 minutes or more)

2 minutes – **Introduction**: Load ForC\_PPT to welcome students to the day of presentation and select the order of presentations.

40 minutes (or more) – **Student presentations**: Students present their research as students seated go over the answers to the questions.

3 minutes – **Conclusion**: Discuss the carbon cycle and aspects that were studied by students. Collect handouts (if applicable) and preview final lesson on carbon footprints (if applicable).

**Open Inquiry** (4-6 days or more 45 minutes each day)

**Note to Instructors**: This module follows a similar pattern to the guided inquiry module, but it assumes the students have a greater understanding of data analysis and the process of science. Students are at this point doing real science. The goal is to help students ask a unique question and explore a potential explanation using the ForC database. Depending on student ability they may use ForC\_simplified\_edu (<https://github.com/forc-db/ForC/blob/master/educational%20resources/ForC_simplified_edu.csv>) which is ForC\_simplified but ONLY including mature, undisturbed, unmanaged forests. This is the easiest data set to use, but we have taken away some potentially interesting analyses that could be completed in ForC\_simplified (<https://github.com/forc-db/ForC/tree/master/ForC_simplified)>, which condenses the most relevant information within ForC into a single spreadsheet. Students may also use the complete ForC database <https://github.com/forc-db/ForC> , but the information contained here and not in ForC\_simplified would typically only be of interest to specialists, and use should only be attempted by students with substantial data analysis skills (advanced undergraduate or graduate students).

**Objectives**:

1. Students will be able to use statistical analysis in order to answer question of their choosing concerning forest carbon cycling
2. Students will gain hands on experience in the process of science and statistical data analysis
3. Students will be able to present their findings to the class and review the carbon cycle
4. Students will be able to ask an original question and answer it using a large database

**Materials**: ForC\_PPT, Background\_cheat\_sheet (one per group/pair, re-usable), handout\_asking\_your\_question (one per group/pair, re-usable), group or individual access to computers with Microsoft Excel (or other data processing program) and an internet connection

**Optional**: color diagrams (one per group/pair), Handout\_guided (one per student or group)

**Procedures**:

**Day 1 – 2:** Asking your question, exploring the data  
2 minutes – **Introduction**: Pass out Handout\_Open, Background\_cheat\_sheet, and handout\_asking\_your\_question (digitally or handout) and load ForC\_PPT to the “Open Inquiry” section. Complete a brief lecture on the process of science and the basic outline of what students will be doing

3 minutes – **Discussion**: (Skip if unnecessary), discuss any homework and briefly review the purpose of ForestGEO and the ForC database

2 minutes – **Review**: Briefly review the forest carbon cycle (using ForC\_PPT)

5 minutes – **Groups**: Assign students to small groups (preferably no more than 4). Students determine their roles and assign work (instructions are in Handout\_Open handout)

30 minutes – **Asking your Question**: Students read the handout\_asking\_your\_question hand out and follow the instructions in the Handout\_Open handout. Students may access the shiny app (<https://forc.shinyapps.io/global_data_visualization/>) to get an idea of what some of the questions might look like.

This section may inherently be difficult for some students and take a great deal of time to ask a suitable question. You may potentially use the questions from the “guided inquiry” module as a type of “cheat sheet” to good questions, but it is also possible that students may ask their own completely unique question. Indeed, this is the whole point of ForC.

We recommend that students use the ForC\_simplified database, although if a group is adventurous (or you require it) they may access the full database. Instructions are devised assuming students will be using Microsoft Excel, but we encourage you to look into more robust statistical analysis programs (like R or MATLAB)

3 minutes – **discussion**: Bring class together after each question has been asked and briefly review the carbon cycle and what is expected of students over the next several days (data analysis followed by presentations). Students might not have a suitable question by the end of day one. That is acceptable. In science it is generally accepted that asking the right question can be one of the most difficult things to do. Keep your students encouraged.

**Day 3 – 5**: Data analysis and presentation preparation

45 minutes – **Data analysis** (may take several days): Students work in pairs or small groups analyzing data. Make sure to circulate around the classroom. This may take more time depending on how detailed you would like their analysis to be. We provide the outline for a basic analysis, but you are welcome to add to it.

45 minutes – **Presentation preparation**: As student groups finish working on analysis they should begin to put together brief presentations (5 minutes each or more) that focus on their question, methods, conclusions, and how it links to the carbon cycle. Instructions are provided in Handout\_Open

**Day 6:** Presentation

2 minutes – **Introduction**: Load ForC\_PPT to welcome students to the day of presentation and select the order of presentations.

40 minutes (or more) – **Student presentations**: Students present their research as students seated go over the answers to the questions.

3 minutes – **Conclusion**: Discuss the carbon cycle and aspects that were studied by students. Collect handouts (if applicable) and preview final lesson on carbon footprints (if applicable).

**Carbon Footprint** (40 minutes)

**Objectives**:

1. Students will be able to explain the impacts of their choices on their carbon footprint
2. Students will be able to explore different carbon footprint calculators and discuss bias

**Materials**: ForC\_PPT, Background\_footprint (one per group/pair), computers (per student or pair/group) with internet connection

**Procedures**:

5 minutes – **Introduction/Discussion**: Load ForC\_PPT and go to the Carbon Footprint section. Spend time discussing what students have accomplished (if you are doing this lesson after the inquiry based analysis) and transition into personal carbon footprints.

Pass out Footprint handout (one per student, digitally or in print) and make sure students have access to footprint resources (preferably digital). Instructions are contained within the handout. Circulate around the classroom.

30 minutes – **Exploring Your Footprint**: Students fill out the information on their handouts based on their personal carbon footprint. They are also able to discuss with a partner or other classmates their respective footprints.

5 minutes – **Discussion**: The goal here is two-fold. First, to help students get a feel for how much their personal choices impact their carbon footprint, and second to help them understand biases. Each carbon calculator is biased in some way and some may give wildly different estimates with the same information. This is a great chance to discuss the roles scientific skepticism and analytic thinking in your everyday life.

**Acknowledgements**:

**Co-authors**: Ryan Helcoski, Kristin Black, Kristina Anderson-Teixeira

We would like to thank the following organizations for providing funding to make this endeavor possible

