



**Satellites, Weather and Climate
Lesson plan summary: Modeling the Water
Cycle, Carbon Cycle and Associated
Feedback**

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Grade Level: 9

Curriculum Target Benchmarks: HS-ESS2-6, HS-LS2-5

Subject keywords: Water Cycle, Carbon Cycle, Solar Radiation

Title: Modeling the Water Cycle, Carbon Cycle, and Associated Feedback Loops to Gain a Basic Understanding of the Global Climate System

I have chosen to create a unit of study that highlights the interconnectedness and complexity of the climate system. Throughout this course we looked closely at the many drivers that effect climate, the associated radiative forcing, and the ways in which they interact to create feedback loops. My hope is that with this unit students will:

- Understand that natural and anthropogenic sources of carbon dioxide act as a driver for climate change (*Shindell, 2013 and Schmidt, 2014*)
 - Important concepts that I plan cover will include are that there are natural components that effect the levels of carbon dioxide and other greenhouse gases in the atmosphere. CO₂ and greenhouse gases effects the movement of solar radiation into and out of the atmosphere. There are also anthropogenic contributions that are throwing this system out of balance, leading to a net gain or absorption of 0.9W/m² that leads to an increase in global temperature. (*Global Energy Flows diagram and Radiative Forcing diagram*)
- Understand that CO₂ has a positive radiative forcing ($\approx 1.6\text{W/m}^2$) which would lead to an increase in global temperature. (*Global Energy Flows diagram, Radiative Forcing diagram, and Mathez, 2013*)
 - Important concepts that I plan cover will include the concept of carbon reservoirs on earth and that there is large amount of carbon stored in rocks and the world oceans, the concept of short-term carbon cycling of photosynthesis and respiration, and how carbon is cycled between short term cycles and the long term storage. I will also discuss how humans are influencing this balance through actions such as burning of fossil fuels and how this takes stored carbon and adds it to the atmosphere. This is a serious problem because we are removing stored carbon faster than we are sequester carbon back into long term storage. This effect acidity levels in the ocean which further decreases the addition to stored carbon reservoirs

because organisms that use calcium carbonate as a shell cannot trap as much carbon thus further exacerbating the problem (positive feedback loop) (Mathez, 2013).

- Understand that water vapor is a driver for climate change
 - Water vapor is added and removed from the atmosphere through the natural water cycle (although it can be added to the atmosphere at a greater rate if global temperature rises, thus increasing evaporation, as a result of less radiation escaping)
 - Water vapor can also come from the degradation of atmospheric methane (positive radiative forcing of $\approx 0.1 \text{ W/m}^2$) which leads to an increase in global temperature (*Global Energy Flows diagram and Radiative Forcing diagram*)
- Understand that water vapor varies dramatically by region
- Understand incoming solar radiation (341.3 W/m^2) and outgoing solar radiation are not in equilibrium (Net absorbed 0.9 W/m^2). This will result in a rise in global temperature of an estimated 2°C - 5°C in the next 50-100 years. (*Global Energy Flows diagram and Radiative Forcing diagram*)
 - Important concepts that I plan to cover will include what components of the atmosphere cause this system to be out of equilibrium. I will teach how long-lived greenhouse gases, CO_2 , N_2O , and CH_4 , trap long-wave radiation that is emitted or reflected from the surface of the earth or other components of the atmosphere. I will teach about the differences between stratospheric and tropospheric ozone with an emphasis on how stratospheric ozone acts as a negative driver and thus reduces the overall energy reaching the surface of the earth, and tropospheric ozone which acts as a positive driver and forces an increase in the energy within the system. I will teach about albedo of surfaces and how they differ and can change over time. I will emphasize the major differences in albedo of earth versus snow and discuss how snow that has a layer of black carbon particulate matter on top can drastically lower its albedo and lead to melting events. While talking about albedo I also plan to discuss the positive feedback loop that is associated with melting events and the changing of the albedo of the surface as it changes from high albedo snow or ice to low albedo dirt, rock, or vegetation. Lastly I will discuss with students how aerosols in the atmosphere are a negative driver for climate change and act to cool that atmosphere by creating more cloud condensation nuclei for which water vapor can attach to which leads to an increase in cloud cover and more reflection of solar radiation off the high albedo tops of clouds. (*Global Energy Flows diagram, Radiative Forcing diagram, Geerts, 2000 and Aerosols and climate*)

I have chosen to focus on these three main topics for several reasons. First I plan on implementing this material into an integrated science course. This course already has units and lessons planned that look at the water cycle, the carbon cycle (with a focus on how life interacts with it, photosynthesis and cellular respiration), and electromagnetic spectrum of radiation. It is my hope to build on the prior knowledge by creating a project that asks students to apply their knowledge to the greater climate system. While I think

the math behind why/how some of the driver effect climate change is important to fully understand the system and its problems, I have chosen not to take a mathematical approach to this project. I have chosen to do this because I teach mostly 9th grade students with a diverse array of learning styles and abilities. I did not want to create a project in which I would get bogged down in the math behind this problem, rather I want to be able to focus my student's effort on understanding the complexity of the system and the basics of climate change. When they leave my course I want them to be able to say "increasing CO₂ in the atmosphere will lead to an increase in global temperatures and here is why..." and while I think it would be amazing if a student was able to elaborate on say why volcanic aerosols have a cooling effect on the environment, I want them to leave my class with a basic understanding of climate change.

Learners

The students that will be conducting this lesson are 9th grade students in an integrated science classroom. The learners are a heterogeneous group of different learning styles, learning preferences; they come from a range of racial and socio-economic backgrounds. For this lesson students will be instructed in a whole group setting, but students will be asked to complete an individual project and turn in their own work, not as a group.

Standards

Next Generation Science Standard: HS-ESS2-6

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

Next Generation Science Standard: 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. [Clarification Statement: Examples of models could include simulations and mathematical models.] [Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.]

Topic

- Water Cycle
 - Students will use their prior knowledge of the water cycle and connect it to the climate system. Prior to this project students will have worked with the water cycle and learned about how water cycles between the atmosphere, surface of the earth, and below Earth's surface. Emphasis will be placed on water vapor as a driver for climate change, and ice and its albedo as a driver.
- Carbon cycle
 - Prior to this project students will have learned about the interaction

between life and carbon, specifically the reactions for photosynthesis and cellular respiration. Students will build on this knowledge and look at CO₂ as a driver for climate change. They will identify natural and anthropogenic sources of that CO₂ and connect that to the rate at which solar radiation is transmitted/emitted through our atmosphere.

- Solar Radiation
 - Prior to this project students will have learned about the electromagnetic spectrum of light. Students will use this knowledge and apply it to our atmosphere by looking at which wavelengths of light penetrate our atmosphere, which wavelengths of light are trapped by CO₂, water vapor, and other greenhouse gases, and they will learn about the overall net radiative forcing that is the result of these components interacting.

Curriculum Links

What comes before this project?

- Students will have completed a unit on the hydrosphere. In this unit students will gain an understanding of:
 - Reservoirs of water on Earth
 - How water is moved from one reservoir to another
 - The energy required to move water from one reservoir to another (including latent heat)
 - The physical characteristics of water and why they are important to life
 - Freezing temperature
 - Evaporation temperature
 - Structure of water as a liquid, solid, and vapor
 - Variability of water vapor levels (humidity) in the atmosphere and how they correlate to dew point and cloud formation.
 - Density of solids, liquids, and gases and how salinity affects these aspects
- Students will have completed a unit on the carbon cycle. In this unit students will gain an understanding of:
 - How organisms cycle carbon through life processes
 - Products and reactants for the chemical reactions of photosynthesis
 - Products and reactants for the chemical reactions of cellular respiration
 - The required components for combustion
 - Chemical reactions for combustion
 - Ways in which we can trap/sequester carbon dioxide from the atmosphere
- Students will have completed a unit on the electromagnetic spectrum of light. In this unit students will gain an understanding of:
 - Wavelengths of light and their associated energy
 - Ways in which energy is transmitted (Conduction, convection, radiation)
 - Which wavelengths of light the sun emits and which wavelengths of light can penetrate the Earth's atmosphere.

How will it connect to their prior knowledge?

Students will their prior knowledge on the subject of the water cycle, the cycling of carbon, and the flow of energy into and out of the atmosphere to build a model of the complex system that is created by the interaction between these three components. Students will be able to model the cycles they learned about previously and apply their knowledge to a new system based approach to looking at the aspects that affect the global climate system.

What comes after this lesson (what is the link)?

This lesson will serve as a culminating project to the atmosphere section of the course. After this lesson the course will proceed to a unit on the geosphere of the earth. In this unit students will learn about rock cycle in great detail and it is the intention that students will use their understanding of the water and carbon cycles and apply them to the weathering of rocks and creation of new rocks as they pertain to the sequestration and release of CO₂ from the atmosphere. After the geosphere unit students will complete a unit on the biosphere, in this unit students will again revisit the carbon cycle as it pertains to life on earth. At the end of the biosphere unit their will be project that will serve as the capstone to the course and will ask students to apply their knowledge from the year and look at how human actions are affecting the world around them and what we can do to mitigate those effects.

Objectives

- Students will be able to model a positive and negative feedback loop that relates to the carbon cycle and connect these to human activities on earth.
- Students will be able to develop a model to describe the cycling of water among the hydrosphere, atmosphere, geosphere, and biosphere.
- Students will be able to develop a model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

Materials

Students will need access to:

- A computer or iPad (Computer is preferred as the software is more easily manipulated using a computer)
- Access to ise systems STELLA modeling Software (<http://www.iseesystems.com/software/Education/StellaSoftware.aspx>)
- Access to a cloud based document saving platform – this will allow teacher to assess student’s work without having to print off models, which can be rather large.

Teachers will need access to:

- A computer or iPad (Computer is preferred as the software is more easily manipulated using a computer)
- Access to ise systems STELLA modeling Software

(<http://www.iseesystems.com/software/Education/StellaSoftware.aspx>)

- Access to a cloud based document saving platform – this will allow teacher to assess student’s work without having to print off models, which can be rather large.
- SMART Board, white/chalk board, overhead projector, or other way of displaying information to the entire class.

Time

This project should take five 80-minute class periods

Scope and Sequence

Day One:

What I will teach:

- I will introduce the modeling software (STELLA) by doing a short demonstration while students follow along with the Introduction to STELLA Modeling software (Activity), this will include a classroom discussion about what stocks, flows and converters are.
- I will tell students that the components that we will be focusing on will be the water cycle (done in a previous unit), solar radiation balance (done electromagnetic spectrum prior to this unit), and carbon cycling (done prior to this unit)

Interactive/Multi Media needed.

- Overhead projector and computer to introduce STELLA modeling software.
- Classroom display of Global Energy Flows diagram
- Copies of Pre-20th-Century Drivers of Climate Change, by Dr. Schmidt and Drivers of 20th-Century Climate Change, by Dr. Shindell.

Activities Students Will Undertake

- Students will read Pre-20th-Century Drivers of Climate Change, by Dr. Schmidt and Drivers of 20th-Century Climate Change, by Dr. Shindell. While students are reading I want will ask them to keep a list of drivers that they need to include in their model.
- Students will identify stocks and flows in the carbon and water cycle.
- Students will begin with initial sketches of which components they want to include in their model.

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- Initial list of stocks and flows that are involved in the water and carbon cycle

Homework or additional readings

- Students will read The Carbon Cycle and How It Influences Climate, by Dr. Mathez

Day Two:

What I will teach:

- I will provide initial feedback on student’s identification of stocks and flows to correct any misconceptions or misidentifications.

- I will review the toolbar in the STELLA modeling software so students may begin work on their model.

Interactive/Multi Media needed.

- Overhead projector to refresh and remind students about how to use STELLA
- Copies of Energy Balance and the Greenhouse Effect by Dr. Shindell

Activities Students Will Undertake

- Students will read Energy Balance and the Greenhouse Effect by Dr. Shindell
- Students will explore the Global Energy Flows diagram and record the ways solar radiation is allocated within our atmosphere, how much comes in and escapes to space.
- Students will begin work on their STELLA models. Emphasis will be placed on trying to build a draft of one component (water cycle, or carbon cycle) during today's class period.

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- Draft one of one component of their STELLA model, saved as PDF in shared folder with teacher.

Homework or additional readings

- Students will re-read Energy Balance and the Greenhouse Effect by Dr. Shindell and identify how energy flows around our atmosphere and places where energy is transferred and stored in the atmosphere.

Day Three:

What I will teach:

- I will provide initial feedback on student's draft one of a single component of the STELLA model.
- I will provide one-on-one instruction to correct mistakes and misconceptions during today's work time.

Interactive/Multi Media needed.

- Overhead projector to display needed STELLA materials

Activities Students Will Undertake

- Students will continue work on their STELLA models. Emphasis will be placed on trying to build a draft of the other components (water cycle, carbon cycle, energy balance) during today's class period.

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- Draft one of all three component of their STELLA model

Homework or additional readings

- Students will read Climate Feedback and Processes by Dr. Shindell

Day Four:

What I will teach:

- I will provide initial feedback on student's draft one of their three component of the STELLA model.
- I will provide one-on-one instruction to correct mistakes and misconceptions during today's work time.

- I will teach about feedback loops with an initial introduction of feedback loops using the Lorax, by Dr. Seuss as a model.

Interactive/Multi Media needed.

- Overhead projector to display needed STELLA materials
- Copy of The Lorax, by Dr. Seuss.

Activities Students Will Undertake

- Students will work to make corrections to their STELLA models.
- Students will complete the What are feedback loops (LORAX activity)

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- Draft two of all three component of their STELLA model
- Students will print off a copy of their model to use for homework

Homework or additional readings

- Students will work to apply their knowledge of feedback loops to ID a positive and negative feedback loop in their model and identify one of each for homework

Day Five:

What I will teach:

- I will provide final feedback on student's drafts of their three component of the STELLA model.
- I will provide one-on-one instruction to correct mistakes and misconceptions during today's work time about the feedback loops they identified for homework.

Interactive/Multi Media needed.

- Overhead projector to display needed STELLA materials

Activities Students Will Undertake

- Prior to meeting one-on-one with the teacher, students will conference in small groups, 2-3 individuals, to discuss their positive and negative feedback and provide suggestions for improvement for each other. This will also serve to allow students to see multiple positive and negative feedback loops within the greater system.
- Students will work to make final corrections to their STELLA models.

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- Final draft of students STELLA models.

Homework or additional readings

- Prior to next class students will complete the following for the positive and negative feedback loops.
 - Identify within the STELLA model a positive and negative feedback loop that relates to the Carbon Cycle.
 - Explain in a short paragraph why the loop they chose is a positive feedback loop and will explain each flow and connector in terms of the loop as a whole and the carbon cycle.
 - Explain in a short paragraph why the loop they chose is a negative feedback loop and will explain each flow and connector in terms of the loop as a whole and the carbon cycle.

End product delivered at the end of unit:

- Completed Model of Incoming/outgoing Radiation, Water Cycle and Carbon

- Cycle (Bonus: Include a other greenhouse gas emissions)
- Completed identification and explanation of positive and negative feedback loops

Supplementary Materials

- Introduction to STELLA Modeling software (Activity)
 - This document will introduce students to the concepts of stocks, flows and converters. This is necessary for the understanding and use of the STELLA modeling software. My idea is to make a connection to the English curriculum at this point: Stocks (Nouns) – A thing that accumulates over time. Flows (Verbs) – activities that changes that amount of stock (*add or subtract*), Converters (Adverbs and adjectives) do not change the meaning of the stock or flow, but can effect or be effected by the stock or flow. Connectors would be showing which converters go to which stocks/flows, similar to the English language in that the phrase “He walked quickly” we know that quickly is modifying the speed at which the person walks, not modifying the subject (he). In the climate modeling software there is no logical order in which things need to be laid out, like reading left to right, so therefore we must use arrows to tell which things are being modified by the converter.
 - Tutorial videos may also be used to help familiarize students with the program and its use. A list can be found at: <http://www.iseesystems.com/community/downloads/tutorials/ModelBuilding.aspx>
- Intro to project: Identification of stocks and flows in Incoming/outgoing Radiation, Water Cycle and Carbon Cycle subsystems (Activity/Worksheet)
 - This document will allow students to map out which things are stocks, flows, and converters in each subsystem. This activity can be completed in small groups, but it is important that prior to construction of their models that students receive some sort of direct instruction or feedback on which aspects they identified as stocks, flows and converters. (*Example: Water cycle, atmosphere water is a stock, evaporation is a flow, Incoming solar radiation is a converter*)
 - Radiation diagram will be based on the Global Energy Budget handout from week 1 of the Climate Course. http://amnh.mrooms.net/pluginfile.php/50125/block_html/content/W1D1.pdf
 - Water cycle: I use this diagram for the basis of a paper model for the water cycle. They will have learned this prior to this project but will need to refer to it for this project. http://www.education.noaa.gov/Freshwater/Water_Cycle.html
- What are feedback loops (Activity)
 - This activity is a way to get students to see feedback loops outside of the climate system in hopes that they will apply their knowledge to the climate system after completion.
 - Students will read *The Lorax*, by Dr. Seuss and will try to identify the

elements of the story, and identify how those elements affect other elements in the story. (Example: As the environmental quality goes down in the story, the population of animals goes down). I hope to use and modify the activity created by Rob Quaden and Alan Ticotsky titled Studying The Lorax With Feedback Loops

http://www.clexchange.org/ftp/documents/x-curricular/CC2012_TheLorax.pdf

- Students will work to apply their knowledge of feedback loops to ID a positive and negative feedback loop in their model. Students will: (Activity/Worksheet) (Initial draft of this activity can be found here: https://docs.google.com/a/mpsvt.org/document/d/1N13Xer9A1xJDT6Fz_sySiXi_zwV1bHa-LijYzCKmmvY/edit)
 - Identify within the STELLA model a positive and negative feedback loop that relates to the Carbon Cycle.
 - Explain in a short paragraph why the loop they chose is a positive feedback loop and will explain each flow and connector in terms of the loop as a whole and the carbon cycle.
 - Explain in a short paragraph why the loop they chose is a negative feedback loop and will explain each flow and connector in terms of the loop as a whole and the carbon cycle.
- Continued revisions (Activity)
 - Students will receive feedback from the instructor about aspects of their model that are incorrect, need revisions, or are missing. Students will then implement those changes for the final draft.
- Rubric for assessment (Handout) – *See below*
 - A rubric will be created that states the necessary components that students must demonstrate an understanding of. Initial draft below.

Target	1	2	3	4
<i>Stella Model Carbon & Water Cycle</i>	I can label a diagram of the carbon cycle.	I can develop a model (ex. diagram) to describe the cycling of carbon through photosynthesis and respiration within the biosphere.	I can develop a model (ex. diagram) to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.	I can develop a model (ex. diagram) to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere and include the chemical changes that carbon experiences in the carbon cycle.
<i>Stella Model EMR into and out of Atmosphere</i>	I can describe how energy flows into and out of Earth's system (Electromagnetic radiation)	I can describe how energy flows into and out of Earth's system (Electromagnetic radiation) and connect to changes in surface temperature.	I can use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate (Ex. Changes in surface temperatures, precipitation patterns,	I can use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate and relate to feedback loops.

			glacial ice volumes, sea levels, and biosphere distribution)	
<i>Positive and Negative Feedback Loops</i>	I can define positive and negative feedback loops.	I can identify and describe an example of a positive feedback loop and an example of a negative feedback loop.	I can model a positive and negative feedback loop that relates to the carbon cycle and connect these to human activities on earth.	I can model a positive and negative feedback loop that relates to the <i>climate change</i> and connect these to human activities on earth.

Assessment of Students

Summative Assessment: Students will be graded on their completed models and their descriptions of feedback loops. They will be graded on accuracy in order to assess their understanding of the climate systems concepts covered during and prior to this project. Students will be graded using the rubric that they were given at the beginning of the project.

Formative Assessments: Students work will be given feedback throughout the five class periods. Student's work will be checked for accuracy and feedback will be given to students. The format of this project will allow the teacher to circulate the room at times and check in with students to assess progress, answer questions, correct misconceptions, and reiterate content.

Evaluation of the Lesson

Students will be able to produce a model that accurately reflect the concepts taught prior to this lesson that pertain to the water cycle, carbon cycle, the flow of energy into and out of Earth's systems. Students will be able to make accurate connections between these subsystems that show the interconnectedness between them. Students will be able to identify and explain a positive and negative feedback loop that connects to the carbon cycle and human activities on Earth

Conclusion

My hope is this project will greatly enhance the unit on the atmosphere. I plan on using it as a capstone project that will allow students to synthesize their understanding about the atmosphere and the hydrosphere and apply it to understanding the complexity of the climate system. A major concern for implementation of this project is the learning curve associated with the STELLA modeling software. I have a feeling that some students will get it right away and will run with it, but I also feel some students will not like the complexity and non-linear ways about organizing this system. While I plan on not using the mathematical component of the program I hope that some students who wish to deepen their understanding will attempt to mathematically model some of the subsystems that this project asks them to explore. I feel this unit/project will work exceptionally well at synthesizing student's knowledge of the topics we are covered prior to this unit

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