Lesson Plan: Create Your Climate Model- Earth's Energy Balance using Python

This lesson plan was developed by Tatsam Garg, Ashoka University

As an Undergraduate teacher of Earth Sciences or Physics or Math, you can teach how to build a mathematical model of the Earth's climate system using Python. This lesson plan includes discussions, activities, and a detailed guide of how to create a computational model of Earth's energy balance to understand its role in determining the surface temperature of the planet.

This lesson plan uses resources developed by Prof. David Archer from the University of Chicago. Specifically, it focuses on the "Time dependent Energy-Balance Model for the Earth" that includes fundamental **thermodynamics** concepts such as **blackbody radiation** and **heat capacities**. The model applies these concepts to study how the energy balance between the incident solar radiation and the outgoing terrestrial radiation governs the surface temperature of the planet, and consequently, how it evolves over time. The activity section of this lesson plan includes a detailed instruction manual that serves as a step-by-step guide to conceptualize David Archer's model in numerical and algorithmic terms, eventually developing a computational model using Python programming.

Thus, the use of this lesson plan allows you to integrate the teaching of a climate science topic with a core topic in **Math, Earth Sciences** and **Physics**.

Use this lesson plan to help your students find answers to:

1. What is a Blackbody?
2. What determines the average surface temperature of planet Earth?
3. How do you use a mathematical model to build a computational model?
4. How do you write a simple computational model in Python?

About the Lesson Plan

Grade Level	Undergraduate
Discipline	Mathematics, Earth Sciences, Physics
Topic(s) in Discipline	Thermodynamics, Blackbody Radiation Heat Capacity, Computational Modelling with Python
Climate Topic	Planetary Energy Balance, Planetary Climate Climate Variability Record
Location	Global
Access	Online
Language(s)	English
Approximate Time Required	2-3 hours

Contents

1	Video Lecture (45 min)	A video lecture by Prof David Archer that explains electromagnetic radiation, the concept of blackbodies and blackbody Radiation. This video also includes discussions on the use of these concepts to explain a basic climate model for determining the surface temperature of a planet. This can be accessed at: http://mindonline.uchicago.edu/media/psd/geophys/PHSC_13400_fall2009/lecture4.mp4
2	Teaching Module (45 min)	A set of tutorials to learn basic syntax in Python: 'Introduction to Python: Beginners Guide and Tutorials' This can be accessed at: https://wiki.python.org/moin/BeginnersGuide/Programmers
3	Classroom/Laboratory Activity (60 min)	A programming activity with a detailed step-by-step guide to building the computational time-dependent energy balance model for Earth using Python based on the schematics explained in the video lecture. The guide for this activity is provided with this Lesson Plan.
4	Suggested questions/ assignments for learning evaluation	1. Use the Python program to find out how do the initial conditions affect late-time behavior of the system. 2. What does each parameter mean physically? By changing various parameters of the system, how does it evolve? What is the physical significance of this evolution? 3. Modify the Python Program that we have built to incorporate higher levels of complexity, for instance, an atmosphere.

Step-by-step User Guide

(Here is a step-by-step guide to using this lesson plan in the classroom/laboratory. We have suggested these steps as a possible plan of action. You may customize the lesson plan according to your preferences and requirements.)

1	Introduction to the Time-Dependent Energy Balance	1. Play the video lecture, 'Our first Climate Model', by Prof David Archer, University of Chicago, to enable your students to understand the scientific background and the schematics of the climate model. 2. Emphasize the following topics from the video lecture: Incident Solar Energy, the Solar Constant, behavior of a Blackbody, the Stephan-Boltzmann Law, heat capacities, and the heat capacity of water.

	Model for the Earth	3. Discuss what every parameter in the model means physically. 4. Remind your students about the units of each quantity that would be required to verify dimensionally correct equations. This resource can be accessed at: http://mindonline.uchicago.edu/media/psd/geophys/PHSC_13400_fall2009/lecture4.mp4
2	Prepare for Python Programming: By installing Jupyter Notebooks	1. Ask your students to install a Python programming environment on their computers. 2. For beginners, we recommend using Jupyter Notebooks. This environment allows you to access tutorials and a programming space where students can simultaneously read instructions and try their hands at programming. 3. To access Jupyter Notebooks, install the 'Anaconda-Navigator' using this link. 4. Once it is successfully installed on your computer, navigate to the homepage of the software, and click on 'Install' in the 'Jupyter Notebook' tab. 5. Once installed, launch the notebook- the 'Jupyter notebook Homepage' will open as a webpage. 6. Open a new 'Python 3' file to begin coding.
3	Introduction to Programming with Python	Use the link to the Python tutorial database to teach the basics of Python programming such as printing text, defining variables, simple arithmetic operations, import and use of the 'numpy' and 'matplotlib' libraries, defining arrays and lists, using indices with arrays and lists, and loops (specifically 'for' loops). These introductory skills will be required for the ensuing classroom/laboratory activity. The Python tutorial database can be accessed at: https://wiki.python.org/moin/BeginnersGuide/Programmers
4	Classroom/Laboratory Activity	Begin by recalling the Time-Dependent Energy Balance Model described in the first resource. Inform your students that this classroom activity involves developing the climate model using Python. This exercise has been adopted from Prof David Archer's course titled "Global Warming II: Create your own models in python", available on Coursera at https://www.coursera.org/learn/global-warming-model/home/welcome A detailed step-by-step guide for this activity is provided with this Lesson Plan. 1. Share the instruction manual for the exercise with each student. The manual is in the format of a Jupyter Notebook and walks you through the entire process of developing the model on Python. 2. Download the notebook using the links provided. 3. To open it, launch Jupyter notebook from the Anaconda-Navigator. 4. From the homepage, go to 'downloads' folder from the directory and search for the manual.

		5. If you want the students to work their way through the exercise themselves, you may avoid sharing the manual with them. Instead, use it to motivate them in the right direction with hints.
5	Questions/Assignments	1. Use the Python program to find out how do the initial conditions affect late-time behavior of the system. 2. What does each parameter mean physically? By changing various parameters of the system, how does it evolve? What is the physical significance of this evolution? 3. Modify the Python Program that we have built to incorporate higher levels of complexity, for instance, an atmosphere.

Learning Outcomes

The tools in this lesson plan will enable students to:

1. learn about incident solar energy on Earth, Blackbody Radiation, Heat capacity, Climate Modelling, Planetary Surface Temperatures and building mathematical Models.
2. understand how the surface temperature of a planet evolves with time
3. use algorithmic thinking to translate a mathematical model into writing a computational version of it.
4. use Python to create computational models.

Additional Resources

If you or your students would like to explore the topic further, this additional resource will be useful.

1	Teaching Module; 'Coursera- Global Warming II: Create Your Own Models in Python'	A complete course in Climate Modelling in Python by Prof David Archer, University of Chicago This can be accessed at: https://www.coursera.org/learn/global-warming-model/home/welcome

Credits/Copyrights

1	Video Lecture; "Our first Climate Model"	Presented by Prof David Archer, University of Chicago
2	Teaching Module; Database for Python Tutorials	Developed by Python.org
3	Teaching Module; 'Tutorial- The Time Dependent Energy Balance Model for Earth'	Developed by Tatsam Garg, Ashoka University

4	Additional Resources	Presented by Prof David Archer, University of Chicago for Coursera