Simple Climate Modeling:

PART 1: Exploring the AMS Conceptual Climate Energy Model (AMS CCEM)

How does energy enter, flow through, and exit Earth’s climate system?

To consider Earth’s climate as an energy-driven physical system. To investigate fundamental concepts embodied in considering Earth’s climate from a dynamic perspective and through the use of models

Objectives:
The flows of energy from space to Earth and from Earth to space set the stage for climate, climate variability, and climate change. After completing this investigation, you should be able to describe fundamental understandings concerning:

• The global-scale flow of energy between Earth and space.
• The impact of the atmosphere on the flow of energy to space.
• The effect of incoming solar radiation on Earth’s energy budget.
• The likely effects of energy concentrations and flows on Earth system temperatures.

Earth’s climate is a dynamic energy-driven system. The radiant energy received from space and that lost to space on a global basis determine whether Earth is in a steady-state condition, cooling, or warming. A balance between incoming and outgoing radiation produces a steady-state and stable climate. Lack of a balance between incoming and outgoing radiation implies a net loss or gain of radiant energy to Earth’s climate system. One result of such an energy imbalance is climate change.

Earth’s climate evolves under the influence of its own internal dynamics and because of changes in external factors that perturb the planet’s energy balance with surrounding space. As stated by the Intergovernmental Panel on Climate Change, Working Group 1, 4th Assessment Report (IPCC, WG1-AR4), there are three fundamental ways in which the radiation balance of the Earth can be changed:

1) Change in the incoming solar radiation (e.g., changes in Earth’s orbit or Sun’s output)
2) Change in the fraction of solar radiation that is reflected (called ‘albedo’; e.g., by changes in cloud cover, atmospheric particles or surface conditions such as vegetation)
3) Alteration of the longwave radiation from Earth towards space (e.g., by changing atmospheric composition, especially greenhouse gas concentrations)

Climate responds directly to these changes, and indirectly through numerous feedback mechanisms. Solar radiation intercepted and absorbed by Earth drives our planet’s climate system. Earth responds to this acquired energy through the emission of long-wave infrared radiation (IR) as its climate system adjusts towards achieving global radiative equilibrium with

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space. Because the amounts of solar energy intercepted by Earth and IR emitted to space can be determined with great accuracy by instruments onboard Earth-orbiting satellites, the stage is set for the development of climate models with the potential of predicting future states of Earth’s global-scale climate system. In addition to predicting future climate, these climate models can be manipulated quantitatively (e.g., changing the atmospheric concentrations of heat-trapping gases) to provide insight into the probable consequences of various human activities (e.g., combustion of fossil fuels, land clearing).

In this activity, the AMS Conceptual Climate Energy Model (AMS CCEM) will be employed to investigate basic concepts underlying the global-scale flows of energy to and from Earth.

Via the AMS CCEM, [https://www.ametsoc.org/amsedu/ecs/CCEM/amsccem.html](https://www.ametsoc.org/amsedu/ecs/CCEM/amsccem.html) this investigation explores energy flow in a highly simplified representation of an imaginary planet and the space environment above it. The purpose is to provide insight into the impacts of physical processes that operate in the real world. This investigation follows the flow of energy as it enters, resides in, and exits a planetary system model, as shown in Figure 1. As seen in Figure 1 (a), short-wave solar energy is intercepted by a planet with no atmosphere and absorbed at its surface. In Figure 1 (b), the solar-heated surface emits long-wave infrared radiation upwards. In the absence of an atmosphere, the upward-directed radiation is immediately lost to space. With a clear, cloud-free atmosphere added to the planet, as in Figure 1 (c), some of the upward-directed radiating energy is absorbed by molecules of heat-trapping greenhouse gases (primarily H$_2$O and CO$_2$). The absorbed energy subsequently radiates from these atmospheric molecules to their surroundings randomly in all directions, with half of the emissions exhibiting a downward component and half an upward component. While upward emissions can escape to space, the energy directed downward can return to the planet’s surface and increase the amount of energy contained in the planetary climate system, resulting in a warmer planet.

![Diagram of energy flow](https://www.ametsoc.org/amsedu/ecs/CCEM/amsccem.html)
Figure 1. (a) Sunlight heats the surface of the planet. (b) In absence of an atmosphere, the surface emits infrared radiation to space. (c) If there is an atmosphere, greenhouse gases absorb infrared radiation emitted from the planet’s surface and then radiate the energy in all directions, with half directed downward and half upward.

The AMS Conceptual Climate Energy Model (AMS CCEM) (https://www.ametsoc.org/amsedu/ecs/CCEM/amsenergy2.html) is a computer simulation designed to enable you to track the paths that units of energy might follow as they enter, move through, and exit an imaginary planetary system according to simple rules applied to different scenarios. For simplicity, consider units of energy to be equivalent bundles or parcels of energy. As shown in Figure 2, the AMS CCEM is presented as a landscape view of a planetary surface, with the Sun depicted in the upper right corner. The AMS CCEM is manipulated by choosing different combinations of conditions via drop-down menus along the top of the view. Once the conditions have been set, clicking on Run activates the model.

Figure 2. Landscape view of AMS CCEM showing possible choices or settings to conduct model runs.

The AMS CCEM is already loaded with default settings, seen color-coded blue in Figure 2, as an introduction. They are “100%” under Sun’s Energy (denoting the arrival of a fresh unit of energy

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from the Sun during each cycle of play), “0%” for Albedo (indicating the percentage of incoming sunlight being directly reflected or scattered back towards space), and, “Current (1X)” under Atmospheric CO$_2$ (current concentration of CO$_2$ in the atmosphere. The values of “1 unit” under Initial Energy (energy residing in the model at the beginning) and “20 cycles” under Cycles stipulates a model run composed of 20 cycles of play. “Introductory” has been selected under Mode. Finally, click on the Run button. Because the model is in the Introductory mode, you can observe the same run repeatedly without the cycle patterns changing. You can also stop a run at any time by clicking on Pause, and then continue the run by clicking on Resume. Note that each new model run starts with the number of units of energy already at the planet’s surface indicated. The atmosphere does not absorb or scatter any of the incoming sunlight passing through it when the Albedo setting is 0%. A 0% albedo in this model indicates that all of the Sun’s energy entering the planetary system arrives at the planet’s surface and is totally absorbed.

1. Repeating or stepping through the run specified above as many times as necessary to track the first energy unit that originated from the Sun. As it arrives at the planet’s surface, the yellow energy unit changes to [(green)(blue)(red)]. This signifies its transition from sunlight to heat energy as it is absorbed into the planet’s climate system.

In the AMS CCEM, a cycle of play refers to a sequence of moves in which every energy unit in the planet system is subjected to one vertical move. A model run is composed of a specified number of cycles of play (i.e., 20, 50, 200). For example, a 20-cycle run of the model indicates that whatever energy there is in the planetary climate system at the beginning of each of the 20 cycles of play is subjected to one vertical-motion play during the individual cycle.

Once an energy unit is in the planet system, three rules govern its stepwise flow through the planet system during each run of the AMS CCEM:

Rule 1. During each cycle of play, any energy unit at the planet’s surface will have an equal chance of staying at the planet’s surface or moving upward.

Rule 2. Energy units leaving the planet’s surface as infrared radiation (IR) will be absorbed in the atmosphere if it contains IR-absorbing molecules (e.g., CO$_2$). If not, the energy units will escape directly to space.

Rule 3. During each cycle, any energy unit residing in the atmosphere will have an equal chance of moving downward or upward.

These rules are primarily based on the fact that regardless of the original direction from which an IR energy unit comes when it is absorbed by a radiatively-active atmospheric molecule (e.g., CO$_2$), the energy emitted from the gas molecule can radiate in any direction. Consequently, half the emitted radiation will be directed downward, and half will be directed upward.
2. An energy unit absorbed into the planet system turns red, signifying its change to heat energy. It remains red when radiated to indicate infrared radiation (IR) is emitted. It continues to be in play in every remaining cycle in the run until it is lost to space. Follow the same first energy unit that arrived from the Sun. In the cycle immediately following its initial absorption at the planet’s surface, the energy unit [(stays at the planet’s surface)(moves up into the atmosphere)]. [You can replay the run as many times as you wish, and step through the run by alternately clicking on Pause and Resume.]

[stays at the planet’s surface] [(moves up into the atmosphere]

3. Eventually, the same energy unit [(moves up into the atmosphere)(moves directly from the planet’s surface to space)].

[moves up into the atmosphere] [moves directly from the planet’s surface to space]

4. The planet’s climate system in the AMS CCEM includes the surface and any existing atmosphere. Follow the same first energy unit from the Sun through the 20 cycles. By the end of the 20-cycle run, it [(is still in the planet system)(was lost to space)].

[is still in the planet system] [was lost to space]

5. The default setting shows a planet having a concentration of atmospheric CO₂ equivalent to the current Earth value and an initial energy content of one unit. After its 20 cycles of play, this particular run shows the planet system (surface and atmosphere) ending up with [(1)(2)(4)(6)] units of energy.


Running this and other simulations in the model’s Introductory Mode always produces the same result from the same model setting. This is because in the Introductory Mode all energy unit movements are determined by a fixed set of “random numbers” essentially frozen for the purposes of demonstrating how the model works. Random numbers are employed in AMS CLEM to assure that energy-unit movements are determined purely by chance. [In the model’s Random Mode, a unique sequence of random numbers is generated with every run, so it is extremely unlikely any two runs can be exactly alike and no run can be repeated.]

6. We introduced the AMS CCEM in 20-cycle runs to see what happens in slow motion. Now change the number of Cycles to “50” while otherwise keeping the other default settings including the Introductory Mode. This speeds up the model as well as increasing the size of the run. Click on the Run button, and watch the model operate. Run the model, noting that after 50 cycles there are 5 energy units left in the planet’s climate system (3 in the surface and 2 in the atmosphere). Now, change the model from the Introductory Mode to Random Mode, and run the model several times. With the random setting, different runs of the model almost always produce [(different)the

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same] results in terms of the numbers of energy units residing in the surface and atmospheric components of the planet system at the end of each model run.

different] [the same]

The AMS CCEM allows you to investigate numerous questions, such as, “What impact does atmospheric CO₂ have on the amount of energy retained in the system?” You can explore this question by starting with the default settings except for setting Cycles to “50” and changing the Atmospheric CO₂ value to “None” (And, be sure the Mode is “Introductory”).

7. You have now changed the AMS CCEM to evaluate a computer simulation of a planet with no radiatively active gas (e.g., CO₂) in its atmosphere. Click on the Run button and watch the model go through a 50-cycle run. Next, change the Mode to “Random” and make several model runs. Compare the results with those of your earlier 50-cycle runs when the Atmospheric CO₂ setting was set a “Current (1x)”. Comparison of several runs of the simulations with and without atmospheric CO₂, reveals the generalization that more energy is retained in the planet system that [has[does not have]] atmospheric CO₂.

[has] [does not have]

8. Stated another way, comparing the two simulations (with and without atmospheric CO2) shows that the addition of IR-absorbing atmospheric molecules, causes the amount of energy retained in the planet’s climate system to [(increase)(remain the same) (decrease)]. Congratulations, you have just modeled the fundamental physical basis of the greenhouse effect.

[increase] [remain the same] [decrease]

Below the AMS CCEM landscape view is a graph which displays the amount of energy in the planetary system after each cycle. With the AMS CCEM settings at: 100% Sun’s Energy, 0% Albedo, Current (1x) Atmospheric CO₂, 1-unit Initial Energy, 20 Cycles, and Introductory Mode, click on the Run button to review the 20-cycle run. Then, sequentially, choose “50”, “100”, and “200” cycles and run the model. Since the model is running in the Introductory mode, each subsequent higher-cycle run embodies the previous lower-cycle runs.

Set the model to 200 cycles and click on the Run button. While it is running, note the curve being drawn on the graph directly below the landscape view. This part of the model is reporting the number of energy units in the planet system cycle-by-cycle as the run progresses. This, in effect, reports the variability in the state of the planetary climate system. Also, for runs of 100 cycles or more, a mean value of energy units in the system at the end of each cycle and the standard deviation of the number of units is shown above the graph. The mean and standard deviation are only calculated from the number of units beyond the initial 50 cycles to avoid the fluctuations imposed by the choice of initial energy value. Extensive experience with the model

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shows an initial “spin up” occurs over ten to twenty cycles before it appears to suggest the model has achieved a relatively stable operating condition.

9. Directly above the graph, the model reports that for the 200-cycle run, the mean (average) number of energy units in the planet system after each cycle beyond the initial 50 cycles was [(3.0)(4.3)(5.3)(7.2)].

   [3.0]  [4.3]  [5.3]  [7.2]

10. After the initial 50-cycle “spin up” of the model, according to the graphed data, the number of energy units in the planet system during the Introductory-mode 200-cycle run ranged between [(0)(1)(2)(3)] and 9.

   [0]  [1]  [2]  [3]

11. Even with the model settings being the same throughout the 200-cycle run, the energy-content curve displays variability about the mean. The overall pattern of the curve suggests that the planet’s climate system (i.e., energy content) appears relatively stable. Assuming such a “steady state” condition was achieved, it can be expected that the rate at which energy is leaving the system to space would be [(less than)(equal to)(more than)] the rate of incoming energy from space.

   [less than]  [equal to]  [more than]

Keeping other settings the same, switch to the Random mode. Try several runs of the model to see differences and similarities in results. Since the settings were kept the same, the differences you observe, that is, differences in the means and departures from the means, must be due exclusively to chance within the model’s operation. These can be referred to as examples of natural variability as they cannot be attributed to any change in the system settings (because there were no changes). That is, they were due to the inherent randomness built into the rules on which the model is based and any internal feedbacks that might exist.

We will return to the AMS CCEM in future investigations to follow the flow of energy through Earth’s climate system in different simulations under different sets of conditions. We will then use the model to objectively evaluate evidence of climate change.

Figure 3 schematically depicts the components, or sub-systems, of Earth’s climate system (atmosphere, ocean, terrestrial and marine biospheres, cryosphere, and land surface) that must be considered in advanced computer climate models. These major components interact with each other through flows of energy in various forms, exchanges of water, the transfer of greenhouse gases (e.g., carbon dioxide, methane), and the cycling of nutrients. Solar energy is the originating source of the driving force for the motion of the atmosphere and ocean, heat transport, cycling of water, and biological activity.
Figure 3. Schematic view of the components of Earth’s climate system, their processes and interactions. [IPCC AR4 WG1 faq-1-2-fig-1]

12. The arrows in the figure identify the processes and interactions with and between the major components of Earth’s climate system. The double-headed arrows show that [(almost all) (about half) (few)] of the processes and interactions between climate system components (e.g., precipitation-evaporation, land-atmosphere) involve bi-directional (upward/downward) flows.

    [almost all]  [about half]  [few]

13. Six of the interactions depicted in Figure 3 are specifically labeled “Changes in ...” “Changes” imply forcing that results in climate change. While the human impact that most affects global climate is Changes in the Atmosphere, the human impact that is likely to be most directly observable in altering the local or regional climate is the one concerning the changes in the [(ocean) (hydrological cycle) (cryosphere) (land surface)].

    [ocean]  [hydrological cycle]  [cryosphere]  [land surface]

Summary:

This Investigation has presented the AMS CCEM, a simple conceptual model that demonstrates Adapted from AMS Climate Studies eManual 2015
climate as a planet system’s response to external forcing (radiant energy from the Sun) and the amount of energy that is held in the system. It embodies some basic elements of computer-based climate models which are representations of the climate system based on the mathematical equations governing the behavior of the various components of the system, including treatments of key physical processes, interactions, and feedback phenomena.

**PART 2: Understanding Climate Variability and Climate Change**

We will use the term climate variability to describe the variations of the climate system around a mean state (e.g., average temperature of a single month compared to the average monthly temperature for that month as determined from several decades of observations). Typically, the term is used when examining departures from a mean state determined by time scales from several decades to millennia or longer.

The **AMS CCEM** can be employed to illustrate climate variability. Go to the “AMS Conceptual Climate Energy Model” ([https://www.ametsoc.org/amsedu/ecs/CCEM/amsccem.html](https://www.ametsoc.org/amsedu/ecs/CCEM/amsccem.html)). Then click Run the AMS CCEM ([https://www.ametsoc.org/amsedu/ecs/CCEM/amsenergy2.html](https://www.ametsoc.org/amsedu/ecs/CCEM/amsenergy2.html)). Set the model for **Sun’s Energy: 100%, Albedo: 0%, Atmospheric CO₂: Current (1x), Initial Energy: 1 unit, Cycles: 200, and Mode: Introductory**, and click “Run”. The graph displays a curve drawn to report numbers of energy units in the planetary system at the end of each cycle.

14. According to the CCEM depicting the planet’s climate system and space above, at the end of the 200th cycle there are \([4, 6, 8, 10]\) energy units residing in the climate system. Note that this is the same value for the 200th cycle as depicted in the graph below the window.


Figure 1 is an abridged version of the graph portion of the on-screen image that displays the jagged curve reporting the number of energy units in the planetary climate system at the end of each cycle.

Note in Figure 1 that well before the 50th cycle the curve appears relatively stable with about as many ups as downs. To be sure of being beyond the model’s spin-up period, statistical data are based on values generated from the 51st cycle onward. The on-screen visualization includes, immediately above the graph, the Mean and Standard Deviation of energy units residing in the imaginary planet’s climate system (surface and atmosphere) from the 51st cycle onward.
According to Figure 1 (or the printed copy of the on-screen view), the number of energy units residing in the planetary climate system at the end of each cycle from the 51st cycle to the 200th cycle rose and fell between [1 and 7] [1 and 8] [2 and 9]. The difference between these largest and the smallest values, called the range, was 7. Range is one measure of variability.

The mean number of energy units in the planetary climate system for the 150 cycles from Cycle 51 to 200 is reported above the graph as [1.7] [3.2] [5.3]. Draw on the printed graph a solid horizontal straight line from Cycle 51 onward to represent the mean ($M$).

Shade with colored pencils the areas between the line depicting the mean and the jagged curve from Cycle 51 to Cycle 200. Color those areas above the mean red and those below the mean blue. Visually, it should be apparent that the total shaded area above the mean line is approximately equal to the total shaded area below the mean line. The departures of the jagged curve from the mean line represent the energy-unit variability of the system for that particular run. Another statistical measure of the magnitude of this variability is standard deviation (SD). The greater the spread of observed values from the mean, the greater the SD. According to the on-screen image, this run exhibited a SD of [(1.4)(3.2)(4.7)].
18. Draw on the Figure 1 graph horizontal dashed lines representing +1 SD (mean plus SD value = 6.7) and –1 SD (mean minus SD value = 3.9) from the mean from Cycle 51 onward. Figure 2 shows a plot of a normal distribution by SD (or σ). [A normal distribution is a frequency graph of a set of values, usually represented by a bell-shaped curve symmetrical about the mean (μ).] According to the Figure 2 graph, \([4.1\%](68.2\%)(95.4\%)] of the observed values fall between +1 SD and –1SD of the mean. On Figure 1, compare the areas you shaded between the +1 SD and –1 SD lines you drew with the total area you shaded to confirm that this appears to be correct.

\([4.1\%]\quad [68.2\%]\quad [95.4\%]\)

![Figure 2. Normal Distribution by Standard Deviation (SD or σ – Greek letter sigma)](image)

19. On Figure 1, draw horizontal dashed lines representing +2 SD (mean plus 2 SD = 8.1) and –2 SD (mean minus 2 SD = 2.5) from the mean from Cycle 51 onward. Figure 2 shows that \([4.1\%](68.2\%)(95.4\%)] of observed values can be expected to fall between +2 SD and –2SD. On Figure 1, compare the shaded areas you drew between +2 SD and –2 SD with the total shaded area to confirm that this appears to be correct.

\([4.1\%]\quad [68.2\%]\quad [95.4\%]\)

20. Knowing what percentage of observed values can be expected to fall between +2 SD and –2 SD indicates that 4.6% of observed values can be expected to have values greater than +2 SD or lower than –2 SD from the mean. Examination of the Figure 1 jagged
curve and the +2 or –2 SD lines you drew [(does)(does not)] show there were observed values beyond +2 or –2 SDs.

[does] [does not]

Return to the AMS CCEM. Set the model with the default values of Sun’s Energy: 100%, Albedo: 0%, Atmospheric CO\textsubscript{2}: Current (1x), and Initial Energy: 1 unit. Set Cycles to 200 and change the mode to Random. Click on “Run”. These settings are all the same as those that produced Figure 1, except that each model run with the Random setting is based on a different, unique set of random numbers.

21. Run the model several times with these settings. In the Random setting, the means (Ms) and standard deviations (SDs) [(do)(do not)] vary from run to run. Because the AMS CCEM settings have been kept the same in the 200-cycle runs, whatever is observed concerning the variability of means and standard deviations is not due to a change in the system, that is, there was no change in the amount of the Sun’s energy received, albedo, or Atmospheric CO\textsubscript{2}.

[do] [do not]

**If climate is variable, how do we know when climate has changed?**

The definition of *climate change*, as used in this course, refers to any sustained change in the long-term statistics of climate elements (such as temperature, precipitation or winds) lasting over several decades or more, whether due to natural variability or as a result of human activity. This definition follows the *AMS Glossary of Meteorology, electronic edition,* ([https://glossary.ametsoc.org/wiki/Welcome](https://glossary.ametsoc.org/wiki/Welcome)), and that used by the IPCC. (While this activity employs the definition given here, keep in mind that climate change is defined by some to mean a change of climate that can be attributed directly or indirectly only to human activity. The context in which the term appears will usually inform the reader of the definition employed.)

22. Determining whether or not climate change has occurred requires comparison of [(climate means)(climate variability)(both of these)] as determined from empirically acquired climatic data for the same locality.

[climate means] [climate variability] [both of these]

23. So far, we have kept the settings on Sun’s Energy, Albedo, and Atmospheric CO\textsubscript{2}, all called *boundary conditions*, the same, as have other settings except for the mode. Consequently, it is probably safe to infer that climate change [(has)(has not)] occurred during the multiple runs of the model climate system. But, how do we know for sure?

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Based on the definition given for climate change, to be confident of change we must identify whether or not a sustained change in the long-term statistics of climate elements can be detected. The AMS CCEM demonstrates an objective test for system change. Near the bottom of the AMS CCEM webpage, (https://www.ametsoc.org/amsedu/ecs/CCEM/amsccem.html), click on “AMS CCEM Test”, (https://www.ametsoc.org/amsedu/ecs/CCEM/amsstats2.html).

The AMS CCEM Test for System Change enables you to compare the model’s different results due to one variable in the system at a time.

A test of statistical significance is a measure of the probability that something is occurring due to other than chance. It can be determined by a one-sided, paired t-test. [For t-test details, see http://en.wikipedia.org/wiki/Student%27s_t-test] In the Reference Boundary Conditions section of the AMS Test for System Change, the conditions are set with Sun’s Energy: 100 %, Albedo: 0%, Atmospheric CO$_2$: Current (1x), Initial Energy: 1 unit, and Cycles: 200. In the Modified Boundary Conditions section, the same values automatically appear. With the Number of model runs set at 200, click on “Run”, operate the Model several times, noting the unique set of conditions produces with each run.

24. Compare the Means and Standard Deviations of the multiple Model runs to confirm whether or not the variability they show is enough to demonstrate statistically significant change. According to the analysis the of the t-test score, the question, “Statistically different?” is consistently answered [(No...) (Yes!!)].

[No...] [Yes!!]

Now imagine that the Sun suddenly dimmed. While keeping the Sun’s Energy at 100% in the Reference Boundary Conditions section of the AMS Test for System Change, set the Sun’s Energy value to 50% in the Modified Boundary Conditions. Now click on “Run” to determine whether or not the change in this one variable would result in climate change. Allow time for the test to make its calculations.

25. Run the test several times with the new settings. According to the evaluation of the of the t-test scores calculated, the question, “Statistically different?” is consistently answered [(No...) (Yes!!)].

[No...] [Yes!!]

You have just demonstrated how to use the AMS CCEM Test for System Change to objectively determine if climate change has taken place. Become acquainted with the test by changing other variables, one at a time.

Does weather determine climate or does climate produce weather?
Climate of a particular locality is commonly and traditionally described as the average of its weather plus extremes of weather observed at that location, implying that weather determines climate. But is it weather that produces climate, or is climate that constrains weather?

Stated another way, can weather, the state of the atmosphere at a particular place and time, predict climate? Or, is it the boundary conditions of climate and the dynamics of the system and feedbacks within the climate system that produce weather?

These questions can be explored with the AMS CCEM by assuming that the Initial Energy in the model is analogous to weather and the average amount of energy in the system over many cycles, along with its variability, represents its climate. A basic question to investigate is whether or not the Initial Energy in the system has any impact on the long-term state of the climate system. That is, does the initial energy (weather) in the system have predictive value in determining climate?

Return to the AMS CCEM. Adjust the Model so some settings are default values (Sun’s Energy: 100%, Albedo: 0%, Atmospheric CO₂: Current (1x), and Mode: Introductory). Set the Initial Energy value to 20 and the Cycles setting to 200.

These settings are the same as those for the AMS CCEM run that produced Figure 1, except that the Figure 1 setting for Initial Energy was 1 unit.

26. Compare the “20-unit” graph model run you just completed with the “1-unit” graph of Figure 1. Note that the curves in both graphs seem to have shed any obvious evidence of their initial energy values well within their first 50 cycles of run. Now compare the means for the two setting for their cycles 51-200 as reported on each graph. Comparison of the two means infer that the Initial Energy values [(had a substantial) (had little or no)] effect, or predictive power, on their respective long-term averages.

27. Now change the AMS CCEM settings from the Introductory to the Random mode with the otherwise same 200-cycle settings. Make Model runs alternating between the Initial Energy values of 20 and 1. While there is variability in M and SD values, the graphs generated appear to confirm that evidence of the Initial Energy (weather) in the system seems to [(persist beyond) (disappear before)] the 51st cycle.

The visual examination of graphed data seems to show that the Initial Energy (think weather) does not contribute much, if anything, to the long-term statistics of the climate system. However, the AMS CCEM Test for System Change can be applied to evaluate whether or not this is actually the case. At the bottom of the AMS Conceptual Climate Energy Model page, click on

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“AMS CCEM Test”. Retain all the default values as they are, except in the **Modified Boundary Conditions**, change the Initial Energy value to “20 units” so the comparison between “20-unit” and “1-unit” model runs can be made. Click on “Run”. Do several runs to determine if the Reference and Modified Boundary Conditions are significantly different.

28. The results [(do) (**do not**) ] show a statistically significant difference between “20-unit” and “1-unit” model runs.

   [do] [do not]

29. Assuming the weather/climate analogy as described in the *AMS CCEM* is true, the results of the *AMS CCEM Test for System Change* show that in general [(**weather determines climate**) (**climate constrains weather**) ].

   [weather determines climate] [climate constrains weather]

**Summary:**
The studies referred to in this investigation are presented to demonstrate the challenges of identifying and discriminating between climate variability and climate change. The *AMS CCEM* and its *Test for System Change* were employed to illustrate climate variability and climate change. Their use also demonstrates that while climate is often described as the average weather over a period of years, the reality is that it is the climate that constrains the weather.

If you are interested in taking a 3 graduate credit online course in Climate Studies, please be sure to check out: [https://www.ametsoc.org/ams/index.cfm/education-careers/education-program/k-12-teachers/datastreme-program/datastreme-earth-s-climate-system/](https://www.ametsoc.org/ams/index.cfm/education-careers/education-program/k-12-teachers/datastreme-program/datastreme-earth-s-climate-system/) for more information.

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