Lesson 6 Assessment Scoring Guidance

Performance expectation being assessed: 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.

This assessment does not address the following DCI, which is secondary to this performance expectation:

- **ESS1.B: Earth and the Solar System.** Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. (secondary)

In addition, this assessment only partially addresses the following DCI associated with this performance expectation:

- **ESS2.A: Earth Materials and Systems.** The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.

Both of these DCIs are central to the OpenSciEd chemistry unit *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and are formatively assessed there. However, students have not had the opportunity to completely figure out the science ideas related to the final DCI associated with this performance expectation:

- **ESS2.D: Weather and Climate.** The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, ~~and redistribution among the atmosphere, ocean, and land systems,~~ and this energy's re-radiation into space.

In *Polar Ice Unit*, *electromagnetic* is crossed out because students do not yet have the understanding they need in order to explain interactions with matter at different wavelengths. This assessment is designed to give students the opportunity to apply new ideas from this unit to their understanding of climate phenomena from previous courses, to fill in the gaps in their understanding.

In addition to the SEP, CCC, and DCI associated with this PE, this assessment addresses one other DCI element and one other CCC element, as described below:

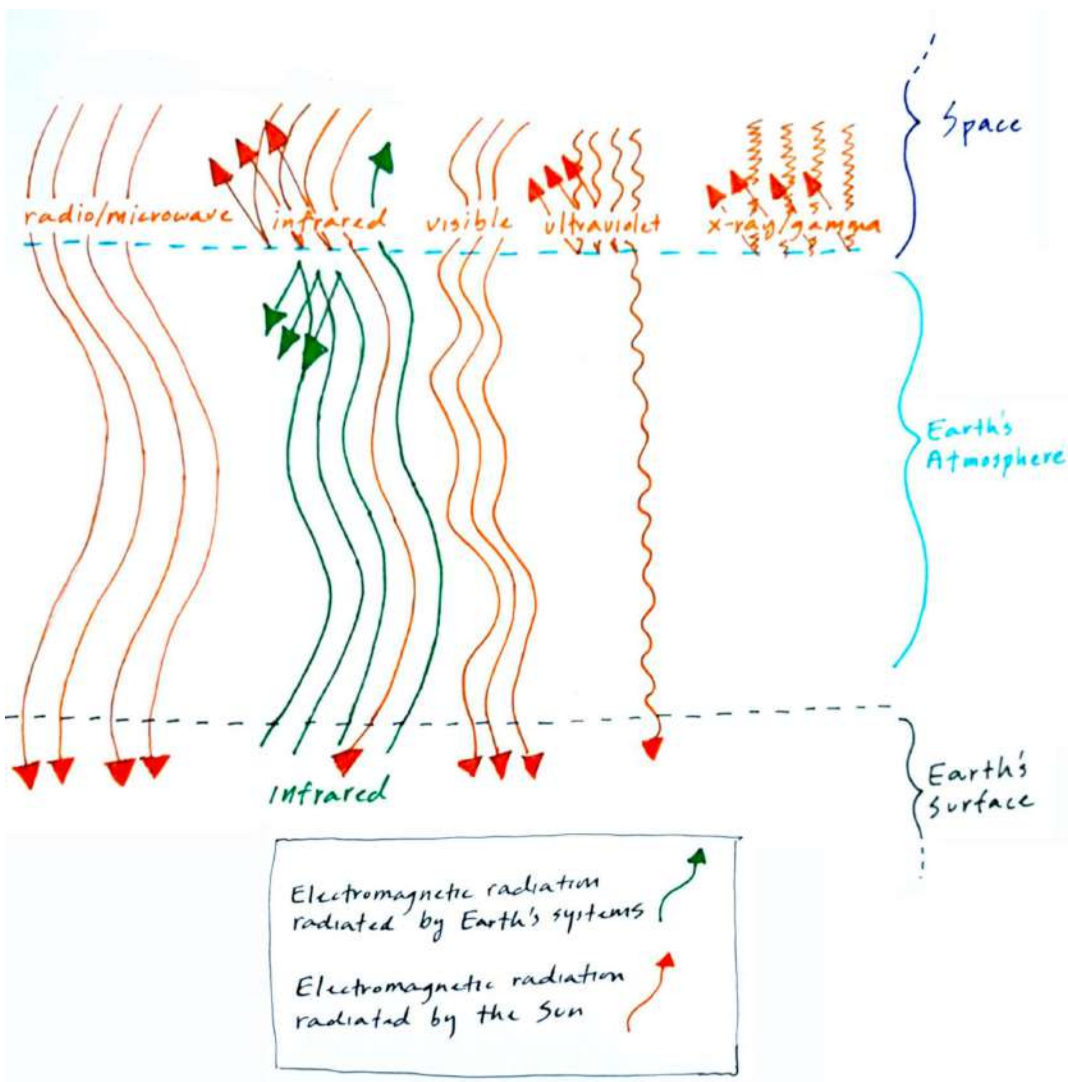
3D Elements Addressed in this Assessment	Q1	Q2	Q3
2.4 Developing and using models. Use a model to provide mechanistic accounts of phenomena.	X		X
5.2 Energy and Matter: Flows, Cycles, and Conservation Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.		X	X
2.1 Cause and Effect Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.			X
ESS2.D.1 Weather and Climate The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage~~, and redistribution among the atmosphere, ocean, and land systems,~~ and this energy's re-radiation into space.	X	X	X
ESS2.A.3: Earth Materials and Systems The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output ~~or Earth's orbit, tectonic events, ocean~~		X	X

circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (See above for explanation of partial coverage.)			
PS4.B.2 When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat).		X	X

Question 1

Almost all of the energy entering Earth's systems comes from the Sun. That energy travels through empty space in the form of *electromagnetic radiation*. Look at the model of Earth's atmosphere below. Much like the door of a microwave oven, the atmosphere allows almost all of the visible light from the Sun to transmit into Earth's systems, but reflects or absorbs some radiation with longer and shorter wavelengths, preventing it from reaching Earth's surface. The electromagnetic radiation that is transmitted through the atmosphere will mostly be absorbed by air, plants, rock, and water. Earth's systems together absorb about 71% of incoming solar radiation.

Model of Matter-Energy Interactions in Earth's Atmosphere



1a. Use the *Model of Matter-Energy Interactions in Earth's Atmosphere* above to fill in the first column of the table below, to show which types of electromagnetic radiation are radiated by the Sun toward Earth.

1b. Use the *Model of Matter-Energy Interactions in Earth's Atmosphere* to fill in the second column of the table below, to show which types of incoming electromagnetic radiation are mostly reflected back into space or absorbed by matter in Earth's atmosphere.

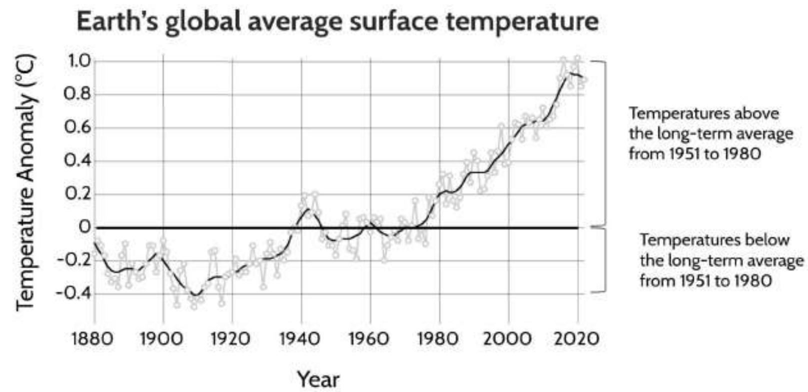
1c. Use the *Model of Matter-Energy Interactions in Earth's Atmosphere* to fill in the third column of the table below, to show which types of incoming electromagnetic radiation are mostly transmitted to the surface by matter in Earth's atmosphere.

1d. After absorbing different types of electromagnetic radiation from the Sun, Earth's systems also radiate electromagnetic radiation. But unlike the Sun, which is very hot, Earth's systems radiate only certain wavelengths of electromagnetic radiation. Use the *Model of Matter-Energy Interactions in Earth's Atmosphere* to fill in the last column of the table below to show which types of electromagnetic radiation are radiated back out by Earth's systems.

Energy input to Earth's systems	a. Radiated by the Sun toward Earth	b. Mostly reflected or absorbed by matter in Earth's atmosphere	c. Mostly transmitted by matter in Earth's atmosphere	d. Radiated by Earth's systems
Radio waves/microwave radiation	X		X	
Infrared radiation	X	X		X
Visible light	X		X	
Ultraviolet radiation	X	X		
X-rays/gamma rays	X	X		

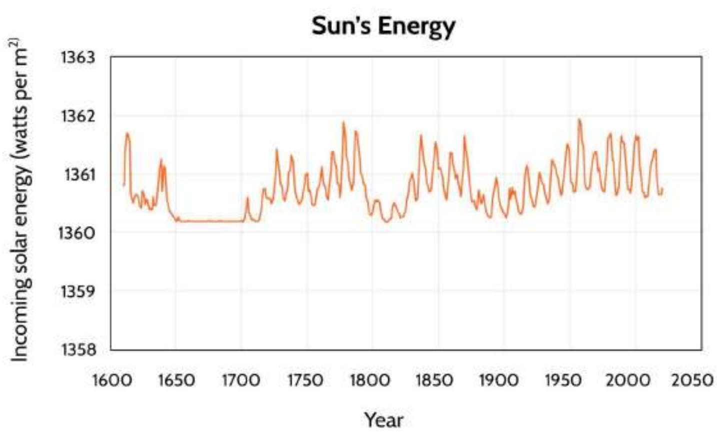
Question 2

The amount of energy in a system is determined by the *energy inputs* (how much energy is transferred into the system), minus the *energy outputs* (how much energy is transferred out of the system). The graph below shows changes in temperatures near Earth's surface over the past 150 years. The rise in temperature indicates an imbalance in the system's energy inputs and outputs.



Data Source: NASA/GISS

Although there have been natural variations in the Sun's energy over the past few hundred years, data show that there has **not** been a significant increase in energy inputs to Earth's system, as shown in the graph below.



Adapted from NOAA Climate.gov, (2016)

2a. Do the data in the graphs above indicate that electromagnetic radiation leaving Earth's systems (output) has been increasing, decreasing, or staying the same? Over what time scale, and how do you know?

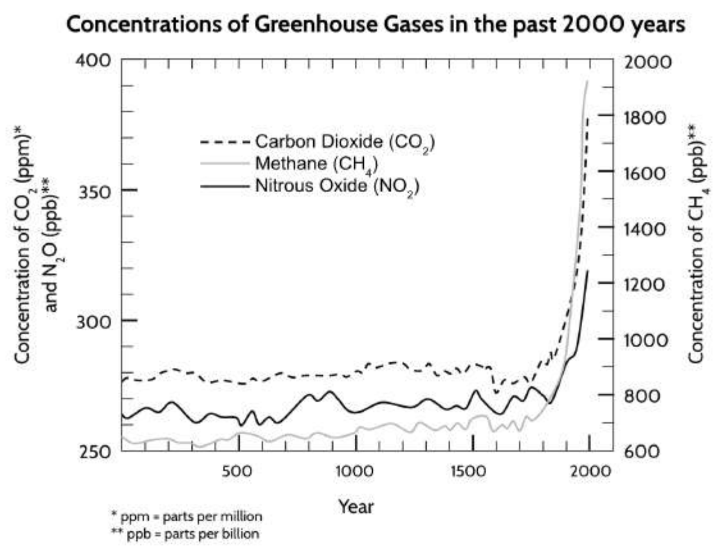
The data show temperatures rising for about the past 100 years. This indicates that output has been decreasing, because input has stayed the same.

2b. What matter-energy interactions in Earth's atmosphere could explain what is happening to the electromagnetic radiation that should be transmitted back out into space? How do you know?

Electromagnetic radiation is being absorbed or reflected more by matter in the atmosphere, and not being transmitted out. I know some of it is being absorbed because when matter absorbs electromagnetic radiation, it heats up, like the food in the microwave oven, and the temperatures are going up in the atmosphere.

Question 3

Greenhouse gases are compounds that absorb infrared radiation, preventing it from leaving Earth's atmosphere. Concentrations of greenhouse gases in our atmosphere have been increasing drastically over the past few hundred years due to human industry, as shown in the graph below.



Data Source: Forster et al. (2007)

The data table to the right provides *residence data* for greenhouse gases in our atmosphere. Residence data show how long the gases that are released into the atmosphere will stay there before they transition into a different Earth system, such as the *biosphere* (life), *geosphere* (crust), or the *hydrosphere* (oceans and other water).

Greenhouse Residence	
Greenhouse Gas	**Lifetime in Earth's Atmosphere**
Carbon Dioxide	300-1000 years
Methane	12 years
Nitrous Oxide	114 years
Water	4-10 days

3a. Scientists are concerned about the impact of greenhouse gases on global temperatures. They argue that if we fail to reduce the emission of these gases by 2030, it will become increasingly challenging for future generations to reduce their effects on global temperature. Based on the data in the graph and the table above, explain which greenhouse gas will have the greatest effect on future generations, and why.

Carbon dioxide stays in Earth's atmosphere for so long. So even if we stop emitting as much, the carbon dioxide will stay in the atmosphere and warm the planet more.

3b. Using the *Model of Matter-Energy Interactions in Earth's Atmosphere*, develop an explanation for how interactions between electromagnetic radiation and greenhouse gases could cause an increase in Earth's temperature.

- Be sure to explain what is causing these interactions to shift over the past few hundred years, and how evidence (from the data included in this assessment or from our experiments with the microwave oven) supports your explanation.
- Use any combination of words, diagrams, and symbols in your explanation.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	**Look for:** Students describe a connection between human-generated greenhouse gases (the cause) and rising global temperatures (the effect) but do not use model ideas or evidence to support it. (SEP: 2.4; CCC: 2.1; DCI: ESS2.A.3, PS4.B.2) OR Students use ideas from the model about absorption, transmission, and reflection of EM radiation in Earth's atmosphere and energy inputs/outputs but do not link these ideas to support an explanation. (SEP: 2.4; CCC: 5.2; DCI: ESS2.D.1)	**Look for:** Students describe a connection between human-generated greenhouse gases over the past 100 years (the cause) and rising global temperatures (the effect). (SEP: 2.4; CCC: 2.1; DCI: ESS2.A.3, PS4.B.2) AND EITHER Students use ideas from the model about absorption, transmission, and reflection of EM radiation in Earth's atmosphere and energy inputs/outputs to develop their explanation. (SEP: 2.4; CCC: 5.2; DCI: ESS2.D.1) OR Students use empirical data, either provided in the assessment or from experiments we have done in class, to support their cause-effect explanations. (CCC: 2.1).	**Look for:** Students describe a connection between human-generated greenhouse gases over the past 100 years (the cause) and rising global temperatures (the effect). (SEP: 2.4; CCC: 2.1; DCI: ESS2.A.3, PS4.B.2) AND Students use ideas from the model about absorption, transmission, and reflection of EM radiation in Earth's atmosphere and energy inputs/outputs to develop their explanation. (SEP: 2.4; CCC: 5.2; DCI: ESS2.D.1) AND Students use empirical data, either provided in the assessment or from experiments we have done in class, to support their cause-effect explanations. (CCC: 2.1).
Example	We can see that the changes in global temperature and the changes in some greenhouse gases follow similar trends over time. OR The more greenhouse gases in the atmosphere, the more EM radiation is absorbed, and the more increases in temperature we will see.	The EM radiation coming into the atmosphere is mostly visible light and radio waves. But Earth radiates infrared back out, which is not transmitted back out into space. Instead, it is absorbed by greenhouse gases. The more greenhouse gases in the atmosphere, the more radiation from the Sun and Earth's surface is absorbed. This results in an increase in global temperature.	The EM radiation coming into the atmosphere is mostly visible light and radio waves. But Earth radiates infrared back out. A lot of the infrared radiation that is leaving Earth gets absorbed by greenhouse gases in the atmosphere. Remember when we tested the microwave oven and saw how reflection can change the flow of radiation and make other stuff hotter? Well, it's the same deal here. There has been an increase in greenhouse gases since the 1800s, meaning more radiation is getting absorbed by Earth's surface and atmosphere, and less radiation is being transmitted

			back to space, which makes things hotter all over the world, as shown in the global temperature graph.
Feedback	*To revise toward linking:* Instruct students to integrate evidence about absorption, reflection, and transmission in their explanation. Ask, *What happens with the electromagnetic radiation that is not absorbed?*	*To revise toward organizing:* Encourage students to draw on evidence, either from the data included in the assessment or from our own investigations with the microwave oven.	*To extend:* Focus students on thinking not only about how they can explain what is happening to Earth's temperature in the graphs, but also to make predictions about what will happen over the next several hundred years. Point them to the residency data to emphasize how long it will take to stabilize energy inputs and outputs, even if we reduce emissions.

	Foundational Understanding	Linked Understanding	Organized Understanding
Suggestions for instruction	If the majority of the class demonstrates a foundational understanding, ask students to go back to their *Progress Tracker* and look at their models of the microwave oven. Reinforce the metaphor of the oven door, which allows some types of electromagnetic radiation through but blocks others. Ask students to create an analogy map between the microwave oven system and Earth's atmosphere.	If the majority of the class demonstrates a linked understanding, ask students to work with a partner to discuss the data sources in the assessment, and figure out how they support their explanations. Then bring the class together to discuss their ideas, and review some of the investigations we have done and how they relate. Have them rewrite their explanations afterward with additional evidence.	If the majority of the class demonstrates an organized understanding, challenge students by asking them to think about design solutions that might change the balance of energy inputs and outputs in Earth's atmosphere.

References

- Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., ... & Whorf, T. (2007). Changes in atmospheric constituents and in radiative forcing. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change*.
- Coddington, O., Lean, J. L., Pilewskie, P., Snow, M., and Lindholm, D. (2016). A Solar Irradiance Climate Data Record, *Bull. Amer. Meteorol. Soc, 97,* 1265–1282.
- Vital signs: Global Temperature. (2022). Retrieved February 10, 2023, from https://climate.nasa.gov/vital-signs/global-temperature/