**Question 1**: What performance expectations are related and can be included in instruction within the lessons/unit? (Cluster PEs)

The following are from the HS.ESS Weather and Climate

**HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth 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 and associated future impacts to Earth systems.**

The following are from the HS.ESS Earth Systems

**HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems.**

**HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.**

The following are from the HS.ESS Human Impacts

**HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.**

**HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.\***

**HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.\***

COMMENT: While this topic is called Weather and Climate, it really is about global climate change. The two performance expectations center on that topic and have little to do with weather. Topics of weather are set in middle school. The topic of global climate change is well suited for the integration of ideas about Earth systems and human impact. In fact, the very existence of the Earth systems paradigm came about as scientist began to study global change and found a need for the a cross disciplinary systems perspective.

**Question 2**: What are the performance expectations, clarification statements, and assessment boundaries and how are they related in terms of instructional practices?

**HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth systems result in changes in climate.**

[Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.]

**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 and associated future impacts to Earth systems.**

[Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]

The following are from the HS.ES Earth Systems

**HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems.**

[Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth’s surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

**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.]

The following are from the HS.ES Human Impact Topics

**HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.**

[Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

**HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.\***

[Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

**HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.\***

[Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]

COMMENT: These performance expectations are broad but interrelated endeavors which will be held together instructionally by organizing them under a unit on global climate change. To achieve these expectations students need mastery in five key areas: 1) the physical science of the greenhouse effect, energy transference and the cycling of matter, 2) famous and seminal climatic data sets, 3) use of paleoclimatology to understand interactions in the earth systems, 4) use of models to test ideas and make predictions on future climate and human activity and 5) global change that is observable and predictable. These five areas will anchor the performances in a deep and comprehensive sense of evidence and the scientific approaches central to climate change science.

**Question 3**: What are the disciplinary core idea(s), practices, and crosscutting concepts coded to the performance expectations and how will they drive instruction?

**Disciplinary Core Ideas**

**ESS1.B:** Earth and the Solar System

**ESS2.A:** Earth Materials and Systems

**ESS2.D:** Weather and Climate

**ESS3.D:** Global Climate Change

The aspects of these DCI’s that drive instruction include ideas that relate to the interactions within Earth systems. Energy from the sun drives the dynamics of climate. Natural process and cycles respond to natural and human induced forcings.

**Science and Engineering Practices**

Developing and Using Models

Planning and Carrying Out Investigations

Analyzing and Interpreting Data

Using Mathematics and Computational Thinking

Constructing Explanations and Designing Solutions

**Engaging in Argument from Evidence**

Scientists use data from direct and indirect measures to understand how natural processes and cycles of mater and energy drive change over time. They create and use conceptual and quantitative models to test assumptions and make predictions. Models and predictions convey constraints that can guide mitigation and engineering solutions.

**Cross-Cutting Concepts**

Cause and Effect

Systems and System Models

Energy and Matter: Flows, Cycles and Conservation

Structure and Function

Stability and Change

Deep study of Earth systems involves modeling where **cause and effect** are described as positive (reinforcing) and negative (counteracting) forcings. Stable elements may be recognized or assumed to evaluate changes imparted on other elements of the system. Changes within Earth systems involved flows and cycles. Clearly any analysis of geoscience data as directed by HS-ESS3-5 involves *Patterns* and *Scale, Proportion, and Quantity*.

**Question 4**: What understandings need to be developed for students to be successful in the performance expectation(s)? What content ideas will they need to know and what skills will they need to learn?

Concepts to understand:

* Middle school concepts on earth’s climatic systems (i.e., sun’s uneven heating, atmospheric and oceanic circulation, regional climatology)
* How certain gases in the atmosphere trap heat
* How atmospheric concentrations of gases and global temperature have changed over the past century, during the Pleistocene, and in general over the Phanerozoic.
* How to analyze cause and effect, cycles and feedbacks operate among Earth systems, (especially the carbon cycle)
* How human industrial and land use practices impact Earth’s atmosphere
* Key chemical reactions central to the carbon cycle (e.g., formation of carbonic acid in oceans, release of carbon dioxide in the lime production and combustion of fossil fuels)
* Details of two or three examples of how paleoclimatic research is conducted (e.g., microfossils, ice cores, tree rings)
* How climate models are constructed and used
* How to analyze prominent examples of the evidence of global change (e.g., melting glaciers, rising sea level, changes in climate and extreme weather, ocean acidification, melting permafrost, biome migration)

**Question 5**: What Science and Engineering Practices are appropriate with the instruction of the disciplinary core ideas? (See Appendix F for description of Practices for high school).

**Practice 1**: Asking questions (for science) and defining problems (for engineering) – Students will make observations of evidence and ask questions on how phenomena impact Earth systems. They will also compare mitigation solutions using a design process.

**Practice 2:** Developing and using models – Quantitative models developed in a spreadsheet and computer simulators are tools students use to test mitigation ideas and make predictions.

**Practice 3**: Planning and carrying out investigations – Students will plan and carry out investigations on physical science phenomena, paleoclimatology and predictive modeling.

**Practice 4**: Analyzing and interpreting data – Students will analyze graphical and spatial data using spreadsheets, online analyzers, GIS software and image analysis software.

**Practice 5**: Using mathematics and computational thinking – Students apply mathematics to investigations of Earth systems interactions, global change and predictive modeling.

**Practice 6**: Constructing explanation (for science) and designing solutions (for engineering) – Students construct explanations based on results from investigations on greenhouse gas phenomena, Earth’s climate history and predictive modeling.

**Practice 7:** Engaging in argument from evidence – Students reason with evidence to develop sound explanations of past and future climate and climate impact. They weigh tradeoffs of various solutions to the challenges presented by global climate change.

**Practice 8**: Obtaining, evaluating, and communicating information – students can analyze informational text and communicate information as well as communicate information gained from observations, data, and investigations.

**Question 6**: What are the lesson level expectations (learning performances) and how will they build to meet the performance expectations?

* For Lessons on Patterns and Trends of Global Climate
  + - Plan and carry out investigations in order to generate evidence to support explanations of how certain greenhouse gases trap heat in the atmosphere.
    - Analyze and interpret patterns in data that depict changes in atmospheric parameters (i.e., gas concentration, temperature, precipitation, climatic variability).
  + For Lessons on climate change research using approaches in paleoclimatology and climate modeling
    - Analyze and interpret paleoclimatic evidence in light of interacting earth systems and constructing an explanation of earth’s climatic history.
    - Use results from climate models to predict a future climate and the impact on Earth systems and humans.
  + For Lessons on monitoring and mitigating global change
    - Use interpretations of global change research to generate questions that can be addressed through the use of climate models.
    - Support arguments from evidence that evaluate various strategies to mitigate the magnitude and impact of global climate change.

**Question 7**: What assessment (formative and summative) will provide evidence of the understanding and/or ability to perform lesson level expectations (learning performances)?

*Student production of written explanations, oral arguments, analyses and reports will be used in formative and summative instruments to evaluate these performances:*

* For lessons on Patterns and Trends of Global Climate
  + - Students demonstrate a detailed and conceptually correct understanding of the mechanisms that cause the greenhouse effect, including how certain gases trap heat in the atmosphere.
    - Students demonstrate an ability hypothesize projected trends of climatic parameters supported by arguments that used the conceptual context of the datasets presented. Datasets could include Mauna Loa carbon dioxide vs. time, Vostok carbon dioxide and temperature vs. time, global temperatures and carbon dioxide emissions.
  + For lessons on climate change research using approaches in paleoclimatology and climate modeling
    - Students demonstrate an ability to propose a new paleoclimatic investigation given constraints such as a specific time span. Examples could include selecting a region of ocean floor and applying isotopic techniques on microfossils.
    - Students demonstrate an ability to use a climate change model given a specific goal such as the reduction of global average temperature in a given time frame.
  + For lessons on monitoring and mitigating global change
    - Student demonstrate and understanding of connections between Earth systems by proposing research questions related to a global change phenomenon, such as precipitation changes in the Great Lakes region, or impacts on a region’s biome.
    - Students propose and support an impact ranking of several mitigation strategies.

**Question 8:** What is the storyline that helps learners apply what they know, build new, sophisticated ideas from observation and evidence, and use information to solve an engineering problem?

The NGSS Earth and Space Science standards in high school are distinct from middle school and involve significant advances in sophistication. In the area of Weather and Climate, middle school builds fundamental competencies around weather and Earth’s climatic system. High school builds upon these with a comprehensive focus on global climate change, which is richly complex, highly relevant, integrating topic well suited to the vision for science education put forth by the NGSS. All the scientific practices and crosscutting concepts are necessary for mastery and the problem solving opportunities make use of the design cycle of engineering. The broad interdisciplinary paradigm of Earth System Science came to be through global change research and therefore a unit on global climate change provides the best opportunity to put it to use.

A comprehensive unit in global climate change could be designed into three cycles as demonstrated in Question 6. With this design the students explore Earth’s climatic history through an analysis of the famous and seminal datasets such as the Keeling Curve or Vostok ice core data. In doing so, they develop a fluency of the key patterns and trends that anchor the science of global climate change. They relate patterns in that data to the phenomena and climate forcings within the Earth systems starting with the sun. They develop a sophisticated and accurate understanding of greenhouse gases and the greenhouse effect and relate changes overtime to natural and human induced forcings.

Students develop proficiencies in the central approaches and scientific practice of climate change research. They do this through explorations of several paleoclimatological approaches and understand how they inform climate models. They also use models in the form of equations in spreadsheets and online simulators to test predictions based on the manipulation of climate variables and human actions. Through the manipulation of models they analyze climate forcings, feedbacks and outputs.

Students use their deep and sophisticated understanding of Earth systems, climate history and climate research approaches to analyze ongoing global change that impacts humans and the biosphere. Topics (e.g., melting glaciers, rising sea level, changes in climate and extreme weather, ocean acidification, melting permafrost, biome migration) will be selected and explored using images, spatial and numeric data and scientific reports. Students will propose mitigation strategies and model their impacts in order to evaluate most favorable approaches.

**Question 9:** How do the lessons and tasks help students move towards an understanding of the performance expectation(s)?

The lessons and task can be organized into three learning cycles: 1) Patterns and Trends of Global Climate, 2) Researching Climate Change and 3) Monitoring Global Change. The five key areas of mastering listed in question 2 are attended to within and produce the competencies described by the seven interrelated performance expectations from the topics of Weather and Climate, Earth Systems and Human Impacts.