Atmosphere Learning Progression

Grades 9-12: GLOBE Protocols Aligned with NASA Resources and NGSS Standards

NGSS Disciplinary Core Ideas Progression of Learning: Building on the concepts developed in grades K-8, students in grades 9-12 will examine the relationship between the Sun's radiation and its interactions with the Earth system, in particular the atmosphere, recognizing the ocean and land as the foundation of the global climate system. Global climate models, developed by scientists and mathematicians, are used to predict future changes, including changes related to human impacts and natural factors. Using GLOBE and MY NASA DATA educators and students will access NASA satellite data to examine a variety of Earth system interactions.
(NASA Langley GLOBE Resource Page: www.globe.gov/web/nasa-langley-research-center/home/resources)

Atmosphere Performance Expectations: (Aligned with NASA Missions) (Note: the following Performance Expectations and 3 Dimensional Learning are aligned with GLOBE and NASA Resources and are meant to support the development of the associated content and skill development but may not lead to complete mastery)

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

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. **(PACE, ECOSTRESS, GOES-R, PREFIRE, and SMAP)**

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. **(ICESat-2, Landsat**)

Atmosphere as part of the Earth System Performance Expectations:

HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedback that causes changes to other Earth systems.

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

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 on Earth systems. **(GPM, GOES-R, PACE, PREFIRE, SAGE III, and SMAP)**

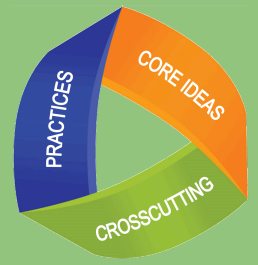
HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. (**ATom**, **TEMPO**)

HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. **(ATom, GOES-R, PACE, Landsat, SAGE III, TEMPO)**

HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Science Practices:	**Disciplinary Core Idea:**	**Crosscutting Concepts:**
Asking Questions and Defining Problems: Ask questions to identify and clarify evidence of an argument. Analyze complex real-world problems using models and simulations. (HS-ETS1-1) **Developing and Using Models**	**PS3.A Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1) **PS3.B Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) Energy cannot be created or destroyed, but it can be transported from one place to another and	**Stability and Change** Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS2-2) Change and rates of change can be quantified and modeled

Develop and use a model to describe phenomena. Use a model to provide mechanistic accounts of phenomena. (HS-ESS2-4, HS-ESS2-6) **Analyzing and Interpreting Data**: Analyze data using tools, technologies, and/or models (e.g. computational and mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-2) Analyze data using computational models in order to make valid and reliable scientific claims. (HS-ESS3-5) **Using Mathematics and Computational Thinking** Create a computational model or simulation of a phenomenon, designed device, process, or system (HS-PS3-1) Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-ESS3-6) **Constructing Explanations and Designing Solutions** Design, evaluate, and refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7) Construct an explanation based on	transferred between systems. (HS-PS3-1) The availability of energy limits what can occur in any system. (HS-PS3-1) Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1) **ESS2.A: Earth Materials and Systems:** Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-2) 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. (HS-ESS2-4) **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. (HS-ESS2-4) Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6) Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6) Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases, added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. (HS-ESS3-6) **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. **ESS3.D Global Climate Change** Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. (HS-ESS3-5) Through computer simulations and other studies, important discoveries are still being made about how the ocean, atmosphere, and biosphere interact and are modified in response to human activities. (HS-ESS3-6) **LS2.C Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment - including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change - can	over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-5) **Cause and Effect** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.(HS-ESS2-4, HS-ESS3-1) **Energy and Matter** The total amount of energy and matter in closed systems is conserved. (HS-ESS2-6) **Systems and System Models** Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1) When investigating or describing a system, the boundaries and initial conditions of the system need to be

valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-ESS3-1)	disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7) **ETS1.A Defining and Delimiting Engineering Problems** Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.B Developing Possible Solutions** When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ESS3-4)	defined and their inputs and outputs analyzed and described using models. (HS-ESS3-6) 

GLOBE Application: Environmental observations, data collection and learning activities to develop Earth science concepts.

Atmosphere Protocols:

- Air Temperature
- Aerosols
- Clouds
- Surface Temperature
- Precipitation
- Water Vapor
- Wind

Data Investigation Sheets:

- Atmosphere Investigation Integrated 1-Day
- Atmosphere Investigation Clouds 1-Day
- Atmosphere Investigation Aerosols
- Atmosphere Investigation

GLOBE Learning Activities:

1. RC2: Effects of Inputs and Outputs on a Region: To identify what enters and leaves the regional system, and how changes in the input or output of one component can affect other components (HS-ESS2-2, HS-ESS2-4)
2. Seasonal Change on Land and Water: To further students' understanding of the causes of seasonal change using visualizations to compare effects of incoming solar energy in the two hemispheres (HS-ESS2-4)
3. Calculating Relative Air Mass: To introduce students to the concept of relative air mass and demonstrate how solar elevation angle affects the intensity of sunlight that reaches an observer on the ground. (HS-ESS2-4)
4. LC5: Comparing the Study Site to One in Another Region: To deepen students understanding of the Earth as a system, and their appreciation for the value of diagrams as tools for both learning and communication, by having them work with diagrams of study sites from different regions (HS-ESS2-4)
5. GC2: Components of the Earth System Working Together: To develop familiarity with interactions among the major components of the Earth system at the global scale (HS-ESS2-2)
6. Paper Clip Simulation: A Simple System: manufacturing system, students will take part in one part of a simple system. As a result of the simulation, students will identify and analyze the basic parts of a simple system and model inputs and outputs. (HS-ESS2-6)

Guiding Question(s):

1. By merging satellite data and ground-based measurements, what insights can we gain into the interconnected trends and patterns within Earth's systems?
2. How do fluctuations in Earth's incoming and outgoing energy influence climate variability and change?
3. How does the intensity of sunlight vary across the Earth, and what factors contribute to this variation?
4. How do scientists utilize the geologic record to reconstruct and understand changes in Earth's climate over time?
5. Considering satellite evidence, what key factors appear to be driving the observed rise in global

Surface Temperature

Math Connection: LC3-Using Graphs to Show Connections (HS-ESS2-2)

GLOBE Supporting Resources:

- Systems and Modeling (All)
- Air Quality and NASA Science Missions
- GLOBE Weather Protocol Bundle
- GLOBE Weather
- UCAR SciEd Teaching Boxes
- Educator Presentations
- Earth System Science Posters

7. Carbon Cycle and Climate Change: Build knowledge around the carbon cycle, the Earth as an interconnected system, how elements move from one place to the next via different natural and man-made processes. (HS-ESS2-6)
8. Global Carbon Cycle Modeling: Students use the global carbon cycle diagram to make pencil and paper calculations of changes to carbon pools after a few years. They then explore a computer model to look at changes over hundreds of years. Students will consider the carbon cycle both pre- and post- industrial revolution and answer basic questions by observing model output. (HS-ESS2-6, HS-ESS3-5)
9. Global Carbon Cycle Modeling with Feedbacks: The Global Carbon Model with Feedbacks builds on the Simple Carbon Cycle Model by including processes (feedbacks) in the global carbon cycle that modify the movement of carbon into and out of the atmosphere. These added processes allow students to better understand the consequences of human activities in the model. (HS-ESS2-2, HS-ESS2-6)
10. Getting to Know Global Carbon: This activity provides an introduction to the carbon cycle and, more broadly, to biogeochemical cycling, the greenhouse effect and climate change. (HS-LS2-7, HS-ESS3-5)
11. Carbon Cycle Adventure Story: This activity provides an introduction to the carbon cycle. (HS-LS2-7)
12. Data Entry: After students have returned from the field with their paper data sheets, data can be shared with the GLOBE and scientific community by entering it into the GLOBE online science database (https://data.globe.gov). (All)
13. Data Visualization Tool: Use the GLOBE Visualization System to view/retrieve your data and compare with the data being collected around the world. (All)

temperatures over the last century?
    a. How can we distinguish between human-caused and naturally occurring influences?
6. What is the role of the carbon cycle in climate change?
    a. How can this be effectively communicated to the public?
7. How are mathematical and computational models applied to predict future climate scenarios?

NASA Assets: Data and lessons drawn from NASA's Earth science research program

NASA Next Gen STEM for Educators: Through authentic content students will be engaged in NASA mission activities and can provide contributions to NASA's work.

NASA Learning Activities:

My NASA Data Visualization Tool: Earth System Data Explorer

GLOBE Atmosphere Protocols and Related Earth System Data Explorer Data Sets: My NASA Data features resources for GLOBE protocols that provide

My NASA Data Lessons/Activities:

Earth's Energy Budget-Seasonal Cycles (HS-PS3-1, HS-ESS2-4)
Interpreting Earth's Energy Budget (HS-PS3-1, HS-ESS2-4)
Changes in Criteria Pollutant Levels in the U.S. (HS-ESS3-1, HS-ESS3-6, HS-LS2-7, HS-ETS1-1)

• Earth Science Data Visualizations: How to Read a Heat Map • Predicting Earth's Climate with NASA Data • Tour of the Electromagnetic Spectrum • How Humans are Affecting Our Planet • Satellite Meteorology Learning Modules **NASA Resources:** • Global Climate Change for Educators • NASA Earth Observatory • NASA Earth Observatory World Maps • The Earth's Radiation Budget • NASA Earth Science • NASA Earth Science Missions • What is … Earth's Atmosphere? • NASA Internships	connections to NASA datasets in the Earth System Data Explorer, as well as background information for the protocol, student data sheets, and related learning activities. **My NASA Data Earth's Energy Budget** **My NASA DATA Resource Pages:** • Energy and Matter Cycles • GLOBE Protocol Bundle: Air Quality • About the Atmosphere • System Thinking About the Earth System • Energy Transfer in Earth's Atmosphere • Air Temperatures • GLOBE Connections: Flow of Energy and Matter	Observing Solar Energy (HS-PS3-1, HS ESS2-4) Earth's Energy Budget Story Map (HS-PS3-1, HS-ESS2-4) How Do We Receive Energy from the Sun? (HS-PS3-1, HS-ESS2-4) Evaluating Natural and Human Activity Effects on Earth's Climate (HS-ESS3-1, HS-ESS3-6, HS-LS2-7, HS-ETS1-1) Atmospheric Methane (HS-ESS2-2, HS-ESS2-6) Earth's Heating Imbalances (HS-PS3-1, HS-ESS2-4) Mount St Helens Volcano (HS-ESS2-2, HS-ESS3-1, HS-ESS3-5) Which Eruption was Larger? A Data Expedition (HS-ESS2-2, HS-ESS3-1, HS-ESS3-5) Human Health and Air Quality (HS-ESS3-6) Particulates and Population (HS-ESS3-6) Describing Radiation in Earth's Energy Budget (HS-PS3-1) How the 2020 Creek Fire Impacted Air Quality (HS-ESS3-1) Criteria Pollutants (HS-ESS3-6) Pollutant Source and Transport (HS-ESS2-2)

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