**DISCIPLINARY CORE IDEAS—EARTH SCIENCES**

**Core Idea ESS1: Earth’s Place in the Universe**

ESS1.A: The Universe and Its Stars

ESS1.B: Earth and the Solar System

ESS1.C: The History of Planet Earth

**Core Idea ESS2: Earth’s Systems**

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

**ESS2.B: Plate Tectonics and Large-Scale System Interactions**

**ESS2.C: The Roles of Water in Earth’s Surface Processes**

**ESS2.D: Weather and Climate**

**ESS2.E: Bio-geology**

**Core Idea ESS3: Earth and Human Activity**

**ESS3.A: Natural Resources**

ESS3.B: Natural Hazards

**ESS3.C: Human Impacts on Earth Systems**

**ESS3.D: Global Climate Change**

**Core Idea ESS2** **Earth’s Systems**

*How and why is Earth constantly changing?*

Earth’s surface is a complex and dynamic set of interconnected systems—the geosphere, hydrosphere, atmosphere, and biosphere—that interact over a wide range of temporal and spatial scales. All of Earth’s processes are the result of energy flowing and matter cycling within and among these systems. For example, the motion of tectonic plates is part of the cycles of convection in Earth’s mantle, driven by outflowing heat and the downward pull of gravity, which result in the formation and changes of many features of Earth’s land and undersea surface. Weather and climate are shaped by complex interactions involving sunlight, the ocean, the atmosphere, clouds, ice, land, and life forms. Earth’s biosphere has changed the makeup of the geosphere, hydrosphere, and atmosphere over geological time; conversely, geological events and conditions have influenced the evolution of life on the planet. Water is essential to the dynamics of most earth systems, and it plays a significant role in shaping Earth’s landscape.

**ESS2.A: EARTH MATERIALS AND SYSTEMS**

*How do Earth’s major systems interact?*

Earth is a complex system of interacting subsystems: the geosphere, hydrosphere, atmosphere, and biosphere. The geosphere includes a hot and mostly metallic inner core; a mantle of hot, soft, solid rock; and a crust of rock, soil, and sediments. The atmosphere is the envelope of gas surrounding the planet. The hydrosphere is the ice, water vapor, and liquid water in the atmosphere, ocean, lakes, streams, soils, and groundwater. The presence of living organisms of any type defines the biosphere; life can be found in many parts of the geosphere, hydrosphere, and atmosphere. Humans are of course part of the biosphere, and human activities have important impacts on all of Earth’s systems.

All Earth processes are the result of energy flowing and matter cycling within and among Earth’s systems. This energy originates from the sun and from Earth’s interior. Transfers of energy and the movements of matter can cause chemical and physical changes among Earth’s materials and living organisms. Solid rocks, for example, can be formed by the cooling of molten rock, the accumulation and consolidation of sediments, or the alteration of older rocks by heat, pressure, and fluids. These processes occur under different circumstances and produce different types of rock. Physical and chemical interactions among rocks, sediments, water, air, and plants and animals produce soil. In the carbon, water, and nitrogen cycles, materials cycle between living and nonliving forms and among the atmosphere, soil, rocks, and ocean.

Weather and climate are driven by interactions of the geosphere, hydrosphere, and atmosphere, with inputs of energy from the sun. The tectonic and volcanic processes that create and build mountains and plateaus, for example, as well as the weathering and erosion processes that break down these structures and transport the products, all involve interactions among the geosphere, hydrosphere, and atmosphere. The resulting landforms and the habitats they provide affect the biosphere, which in turn modifies these habitats and affects the atmosphere, particularly through imbalances between the carbon capture and oxygen release that occur in photosynthesis, and the carbon release and oxygen capture that occur in respiration and in the burning of fossil fuels to support human activities.

Earth exchanges mass and energy with the rest of the solar system. It gains or loses energy through incoming solar radiation, thermal radiation to space, and gravitational forces exerted by the sun, moon, and planets. Earth gains mass from the impacts of meteoroids and comets and loses mass from the escape of gases into space.

Earth’s systems are dynamic; they interact over a wide range of temporal and spatial scales and continually react to changing influences, including human activities. Components of Earth’s systems may appear stable, change slowly over long periods of time, or change abruptly, with significant consequences for living organisms. Changes in part of one system can cause further changes to that system or to other systems, often in surprising and complex ways.

*Grade Band Endpoints for ESS2.A*

***By the end of grade 2*.** Wind and water can change the shape of the land. The resulting landforms, together with the materials on the land, provide homes for living things.

***By the end of grade 5*.** Earth’s major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). These systems interact in multiple ways to affect Earth’s surface materials and processes. The ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather. Rainfall helps shape the land and affects the types of living things found in a region. Water, ice, wind, living organisms, and gravity break rocks, soils, and sediments into smaller particles and move them around. Human activities affect Earth’s systems and their interactions at its surface.

***By the end of grade 8*.** All Earth processes are the result of energy flowing and matter cycling within and among the planet’s systems. This energy is derived from the sun and Earth’s hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth’s materials and living organisms. The planet’s systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth’s history and will determine its future.

***By the end of grade 12*.** Earth’s systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth’s systems is still lacking, thus limiting scientists’ ability to predict some changes and their impacts. Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth’s surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. The top part of the mantle, along with the crust, forms structures known as tectonic plates (link to ESS2.B). Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth’s interior and the gravitational movement of denser materials toward the interior. 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.

**ESS2.C: THE ROLES OF WATER IN EARTH’S SURFACE PROCESSES**

*How do the properties and movements of water shape Earth’s surface and affect*

*its systems?*

Earth is often called the water planet because of the abundance of liquid water on

its surface and because water’s unique combination of physical and chemical properties

is central to Earth’s dynamics. These properties include water’s exceptional

capacity to absorb, store, and release large amounts of energy as it changes state;

to transmit sunlight; to expand upon freezing; to dissolve and transport many

materials; and to lower the viscosities and freezing points of the material when

mixed with fluid rocks in the mantle. Each of these properties plays a role in how

water affects other Earth systems (e.g., ice expansion contributes to rock erosion,

ocean thermal capacity contributes to moderating temperature variations).

Water is found almost everywhere on Earth, from high in the atmosphere (as

water vapor and ice crystals) to low in the atmosphere (precipitation, droplets in

clouds) to mountain snowcaps and glaciers (solid) to running liquid water on the

land, ocean, and underground. Energy from the sun and the force of gravity drive

the continual cycling of water among these reservoirs. Sunlight causes evaporation

and propels oceanic and atmospheric circulation, which transports water around

the globe. Gravity causes precipitation to fall from clouds and water to flow

downward on the land through watersheds.

About 97 percent of Earth’s water is in the ocean, and most fresh water is

contained in glaciers or underground aquifers; only a tiny fraction of Earth’s water

is found in streams, lakes, and rivers. The relative availability of water is a major

factor in distinguishing habitats for different living organisms.

Water participates both in the dissolution and formation of Earth’s materials.

The downward flow of water, both in liquid and solid form, shapes landscapes

through the erosion, transport, and deposition of sediment. Shoreline waves in the

ocean and lakes are powerful agents of erosion. Over millions of years, coastlines

have moved back and forth over continents by hundreds of kilometers, largely due

to the rise and fall of sea level as the climate changed (e.g., ice ages).

*Grade Band Endpoints for ESS2.C*

***By the end of grade 2*.** Water is found in the ocean, rivers, lakes, and ponds.

Water exists as solid ice and in liquid form. It carries soil and rocks from one

place to another and determines the variety of life forms that can live in a particular

location.

***By the end of grade 5*.** Water is found almost everywhere on Earth: as vapor;

as fog or clouds in the atmosphere; as rain or snow falling from clouds; as ice,

snow, and running water on land and in the ocean; and as groundwater beneath

the surface. The downhill movement of water as it flows to the ocean shapes the

appearance of the land. Nearly all of Earth’s available water is in the ocean. Most

fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes,

wetlands, and the atmosphere.

***By the end of grade 8.*** Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation as well as downhill flows on land. The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns. Global movements of water and its changes in form are propelled by sunlight and gravity. Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents. Water’s movements—both on the land and underground—cause weathering and erosion, which

change the land’s surface features and create underground formations.

***By the end of grade 12*.** The abundance of liquid water on Earth’s surface and

its unique combination of physical and chemical properties are central to the

planet’s dynamics. These properties include water’s exceptional capacity to

absorb, store, and release large amounts of energy; transmit sunlight; expand

upon freezing; dissolve and transport materials; and lower the viscosities and

melting points of rocks.

**ESS2.D: WEATHER AND CLIMATE**

*What regulates weather and climate?*

Weather, which varies from day to day and seasonally throughout the year, is the condition of the atmosphere at a given place and time. Climate is longer term and location sensitive; it is the range of a region’s weather over 1 year or many years, and, because it depends on latitude and geography, it varies from place to place. Weather and climate are shaped by complex interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions can drive climate changes that occur over multiple time scales—from days, weeks, and months for weather to years, decades, centuries, and beyond.

The ocean exerts a major influence on weather and climate. It absorbs and stores large amounts of energy from the sun and releases it very slowly; in that way, the ocean moderates and stabilizes global climates. Energy is redistributed globally through ocean currents (e.g., the Gulf Stream) and also through atmospheric circulation (winds). Sunlight heats Earth’s surface, which in turn heats the atmosphere. The resulting temperature patterns, together with Earth’s rotation and the configuration of continents and oceans, control the large-scale patterns of atmospheric circulation. Winds gain energy and water vapor content as they cross hot ocean regions, which can lead to tropical storms.

The “greenhouse effect” keeps Earth’s surface warmer than it would be otherwise. To maintain any average temperature over time, energy inputs from the sun and from radioactive decay in Earth’s interior must be balanced by energy loss due to radiation from the upper atmosphere. However, what determines the temperature at which this balance occurs is a complex set of absorption, reflection, transmission, and redistribution processes in the atmosphere and oceans that determine how long energy stays trapped in these systems before being radiated away. Certain gases in the atmosphere (water vapor, carbon dioxide, methane, and nitrous oxides), which absorb and retain energy that radiates from Earth’s surface, essentially insulate the planet. Without this phenomenon, Earth’s surface would be too cold to be habitable. However, changes in the atmosphere, such as increases in carbon dioxide, can make regions of Earth too hot to be habitable by many species.

Climate changes, which are defined as significant and persistent changes in an area’s average or extreme weather conditions, can occur if any of Earth’s systems change (e.g., composition of the atmosphere, reflectivity of Earth’s surface). Positive feedback loops can amplify the impacts of these effects and trigger relatively abrupt changes in the climate system; negative feedback loops tend to maintain stable climate conditions.

Some climate changes in Earth’s history were rapid shifts (caused by events, such as volcanic eruptions and meteoric impacts, that suddenly put a large amount of particulate matter into the atmosphere or by abrupt changes in ocean currents); other climate changes were gradual and longer term—due, for example, to solar output variations, shifts in the tilt of Earth’s axis, or atmospheric change due to the rise of plants and other life forms that modified the atmosphere via photosynthesis. Scientists can infer these changes from geological evidence. Natural factors that cause climate changes over human time scales (tens or hundreds of years) include variations in the sun’s energy output, ocean circulation patterns, atmospheric composition, and volcanic activity.

When ocean currents change their flow patterns, such as during El Niño, some global regions become warmer or wetter and others become colder or drier. Cumulative increases in the atmospheric concentration of carbon dioxide and other greenhouse gases, whether arising from natural sources or human industrial activity (see ESS3.D), increase the capacity of Earth to retain energy. Changes in surface or atmospheric reflectivity change the amount of energy from the sun that enters the planetary system. Icy surfaces, clouds, aerosols, and larger particles in the atmosphere, such as from volcanic ash, reflect sunlight and thereby decrease the amount of solar energy that can enter the weather/ climate system. Conversely, dark surfaces (e.g., roads, most buildings) absorb sunlight and thus increase the energy entering the system.

*Grade Band Endpoints for ESS2.D*

***By the end of grade 2*.** Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region at a particular time. People measure these conditions to describe and record the weather and to notice patterns over time.

***By the end of grade 5*.** Weather is the minute-by-minute to day-by-day variation of the atmosphere’s condition on a local scale. Scientists record the patterns of the weather across different times and areas so that they can make predictions about what kind of weather might happen next. Climate describes the ranges of an area’s typical weather conditions and the extent to which those conditions vary over years to centuries.

***By the end of grade 8*.** Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. Because these patterns are so complex, weather can be predicted only probabilistically.

Oceans exert a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents. Greenhouse gases in the atmosphere absorb and retain the energy radiated from land and ocean surfaces, thereby regulating Earth’s average surface temperature and keeping it habitable.

***By the end of grade 12*.** The foundation for Earth’s global climate system 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 reradiation into space. Climate change can occur when certain parts of Earth’s systems are altered. Geological evidence indicates that past climate changes were either sudden changes caused by alterations in the atmosphere; longer term changes (e.g., ice ages) due to variations in solar output, Earth’s orbit, or the orientation of its axis; or even more gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen. The time scales of these changes varied from a few to millions of years. Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate (link to ESS3.D).

Global climate models incorporate scientists’ best knowledge of physical and chemical processes and of the interactions of relevant systems. They are tested by their ability to fit past climate variations. 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 the biosphere. Hence the outcomes depend on human behavior) as well as on natural factors that involve complex feedbacks among Earth’s systems.

**ESS2.E: BIOGEOLOGY**

*How do living organisms alter Earth’s processes and structures*?

Evolution, including the emergence and extinction of species, is a natural and ongoing process that is shaped by Earth’s dynamic processes. The properties and conditions of Earth and its atmosphere affect the environments and conditions within which life emerged and evolved—for example, the range of frequencies of light that penetrate the atmosphere to Earth’s surface. Organisms continually evolve to new and often more complex forms as they adapt to new environments. The evolution and proliferation of living things have changed the makeup of Earth’s geosphere, hydrosphere, and atmosphere over geological time. Plants, algae, and microorganisms produced most of the oxygen (i.e., the O2) in the atmosphere through photosynthesis, and they enabled the formation of fossil fuels and types of sedimentary rocks. Microbes also changed the chemistry of Earth’s surface, and they continue to play a critical role in nutrient cycling (e.g., of nitrogen) in most ecosystems. Organisms ranging from bacteria to human beings are a major driver of the global carbon cycle, and they influence global climate by modifying the chemical makeup of the atmosphere. Greenhouse gases in particular are continually moved through the reservoirs represented by the ocean, land, life, and atmosphere. The abundance of carbon in the atmosphere is reduced through the ocean floor accumulation of marine sediments and the accumulation of plant biomass; atmospheric carbon is increased through such processes as deforestation and the burning of fossil fuels.

As Earth changes, life on Earth adapts and evolves to those changes, so just

as life influences other Earth systems, other Earth systems influence life. Life and

the planet’s nonliving systems can be said to co-evolve.

*Grade Band Endpoints for ESS2.E*

***By the end of grade 2*.** Plants and animals (including humans) depend on the land,

water, and air to live and grow. They in turn can change their environment (e.g.,

the shape of land, the flow of water).

***By the end of grade 5*.** Living things affect the physical characteristics of their

regions (e.g., plants’ roots hold soil in place, beaver shelters and human-built

dams alter the flow of water, plants’ respiration affects the air). Many types of

rocks and minerals are formed from the remains of organisms or are altered by

their activities.

***By the end of grade 8*.** Evolution is shaped by Earth’s varying geological conditions.

Sudden changes in conditions (e.g., meteor impacts, major volcanic eruptions)

have caused mass extinctions, but these changes, as well as more gradual

ones, have ultimately allowed other life forms to flourish. The evolution and proliferation

of living things over geological time have in turn changed the rates of

weathering and erosion of land surfaces, altered the composition of Earth’s soils

and atmosphere, and affected the distribution of water in the hydrosphere.

***By the end of grade 12*.** The many dynamic and delicate feedbacks between the

biosphere and other Earth systems cause a continual co-evolution of Earth’s surface

and the life that exists on it.

**Core Idea ESS3** **Earth and Human Activity**

*How do Earth’s surface processes and human activities affect each other?*

Earth’s surface processes affect and are affected by human activities. Humans

depend on all of the planet’s systems for a variety of resources, some of which

are renewable or replaceable and some of which are not. Natural hazards and

other geological events can significantly alter human populations and activities.

Human activities, in turn, can contribute to the frequency and intensity of some

natural hazards. Indeed, humans have become one of the most significant agents

of change in Earth’s surface systems. In particular, it has been shown that climate

change—which could have large consequences for all of Earth’s surface systems,

including the biosphere—is driven not only by natural effects but also by human

activities. Sustaining the biosphere will require detailed knowledge and modeling

of the factors that affect climate, coupled with the responsible management of

natural resources.

**ESS3.A: NATURAL RESOURCES**

*How do humans depend on Earth’s resources?*

Humans depend on Earth’s land, ocean, atmosphere, and biosphere for many

different resources, including air, water, soil, minerals, metals, energy, plants,

and animals. Some of these resources are renewable over human lifetimes, and

some are nonrenewable (mineral resources and fossil fuels) or irreplaceable if lost

(extinct species).

Materials important to modern technological societies are not uniformly

distributed across the planet (e.g., oil in the Middle East, gold in California). Most

elements exist in Earth’s crust at concentrations too low to be extracted, but in

some locations—where geological processes have concentrated them—extraction

is economically viable. Historically, humans have populated regions that are climatically,

hydrologically, and geologically advantageous for fresh water availability,

food production via agriculture, commerce, and other aspects of civilization.

Resource availability affects geopolitical relationships and can limit development.

As the global human population increases and people’s demands for better living

conditions increase, resources considered readily available in the past, such as land

for agriculture or drinkable water, are becoming scarcer and more valued.

All forms of resource extraction and land use have associated economic,

social, environmental, and geopolitical costs and risks, as well as benefits. New

technologies and regulations can change the balance of these factors—for example,

scientific modeling of the long-term environmental impacts of resource use

can help identify potential problems and suggest desirable changes in the patterns

of use. Much energy production today comes from nonrenewable sources, such as

coal and oil. However, advances in related science and technology are reducing the

cost of energy from renewable resources, such as sunlight, and some regulations

are favoring their use. As a result, future energy supplies are likely to come from a

much wider range of sources.

*Grade Band Endpoints for ESS3.A*

***By the end of grade 2*.** Living things need water, air, and resources from the land,

and they try to live in places that have the things they need. Humans use natural

resources for everything they do: for example, they use soil and water to grow

food, wood to burn to provide heat or to build shelters, and materials such as iron

or copper extracted from Earth to make cooking pans.

***By the end of grade 5*.** All materials, energy, and fuels that humans use are derived

from natural sources, and their use affects the environment in multiple ways.

Some resources are renewable over time, and others are not.

***By the end of grade 8*.** Humans depend on Earth’s land, ocean, atmosphere, and

biosphere for many different resources. Minerals, fresh water, and biosphere

resources are limited, and many are not renewable or replaceable over human

lifetimes. These resources are distributed unevenly around the planet as a result of

past geological processes (link to ESS2.B). Renewable energy resources, and the

technologies to exploit them, are being rapidly developed.

***By the end of grade 12*.** Resource availability has guided the development of

human society. All forms of energy production and other resource extraction

have associated economic, social, environmental, and geopolitical costs and

risks, as well as benefits. New technologies and regulations can change the balance

of these factors.

**ESS3.C: HUMAN IMPACTS ON EARTH SYSTEMS**

*How do humans change the planet?*

Recorded history, as well as chemical and geological evidence, indicates that

human activities in agriculture, industry, and everyday life have had major impacts

on the land, rivers, ocean, and air. Humans affect the quality, availability, and distribution

of Earth’s water through the modification of streams, lakes, and groundwater.

Large areas of land, including such delicate ecosystems as wetlands, forests,

and grasslands, are being transformed by human agriculture, mining, and the

expansion of settlements and roads. Human activities now cause land erosion and

soil movement annually that exceed all natural processes. Air and water pollution

caused by human activities affect the condition of the atmosphere and of rivers

and lakes, with damaging effects on other species and on human health. The activities

of humans have significantly altered the biosphere, changing or destroying

natural habitats and causing the extinction of many living species. These changes

also affect the viability of agriculture or fisheries to support human populations.

Land use patterns for agriculture and ocean use patterns for fishing are affected

not only by changes in population and needs but also by changes in climate or

local conditions (such as desertification due to overuse or depletion of fish populations

by over-extraction).

Thus humans have become one of the most significant agents of change in

the near-surface Earth system. And because all of Earth’s subsystems are interconnected,

changes in one system can produce unforeseen changes in others.

The activities and advanced technologies that have built and maintained

human civilizations clearly have large consequences for the sustainability of these

civilizations and the ecosystems with which they interact. As the human population

grows and per-capita consumption of natural resources increases to provide a

greater percentage of people with more developed lifestyles and greater longevity,

so do the human impacts on the planet.

Some negative effects of human activities are reversible with informed

and responsible management. For example, communities are doing many things

to help protect Earth’s resources and environments. They are treating sewage,

reducing the amount of materials they use, and reusing and recycling materials.

Regulations regarding water and air pollution have greatly reduced acid rain

and stream pollution, and international treaties on the use of certain refrigerant

gases have halted the growth of the annual ozone hole over Antarctica.

Regulation of fishing and the development of marine preserves can help restore

and maintain fish populations. In addition, the development of alternative energy

sources can reduce the environmental impacts otherwise caused by the use of

fossil fuels.

The sustainability of human societies and of the biodiversity that supports

them requires responsible management of natural resources not only to reduce

existing adverse impacts but also to prevent such impacts to the extent possible.

Scientists and engineers can make major contributions by developing technologies

that produce less pollution and waste and that preclude ecosystem degradation.

*Grade Band Endpoints for ESS3.C*

***By the end of grade 2.*** Things that people do to live comfortably can affect the

world around them. But they can make choices that reduce their impacts on the

land, water, air, and other living things—for example, by reducing trash through

reuse and recycling.

***By the end of grade 5.*** Human activities in agriculture, industry, and everyday life

have had major effects on the land, vegetation, streams, ocean, air, and even outer

space. But individuals and communities are doing things to help protect Earth’s

resources and environments. For example, they are treating sewage, reducing the

amounts of materials they use, and regulating sources of pollution such as emissions

from factories and power plants or the runoff from agricultural activities.

***By the end of grade 8.*** Human activities have significantly altered the biosphere,

sometimes damaging or destroying natural habitats and causing the extinction

of many other species. But changes to Earth’s environments can have different

impacts (negative and positive) for different living things. Typically, as human

populations and per-capita consumption of natural resources increase, so do the

negative impacts on Earth unless the activities and technologies involved are engineered

otherwise.

***By the end of grade 12.*** The sustainability of human societies and the biodiversity

that supports them requires responsible management of natural resources.

Scientists and engineers can make major contributions—for example, by developing

technologies that produce less pollution and waste and that preclude ecosystem

degradation. When the source of an environmental problem is understood

and international agreement can be reached, human activities can be regulated to

mitigate global impacts (e.g., acid rain and the ozone hole near Antarctica).

**ESS3.D: GLOBAL CLIMATE CHANGE**

*How do people model and predict the effects of human activities on Earth’s climate?*

Global climate change, shown to be driven by both natural phenomena and by

human activities, could have large consequences for all of Earth’s surface systems,

including the biosphere (see ESS3.C for a general discussion of climate). Humans

are now so numerous and resource dependent that their activities affect every part

of the environment, from outer space and the stratosphere to the deepest ocean.

However, by using science-based predictive models, humans can anticipate longterm

change more effectively than ever before and plan accordingly.

Global changes usually happen too slowly for individuals to recognize, but

accumulated human knowledge, together with further scientific research, can help

people learn more about these challenges and guide their responses. For example,

there are historical records of weather conditions and of the times when plants

bloom, animals give birth or migrate, and lakes and rivers freeze and thaw. And

scientists can deduce long-past climate conditions from such sources as fossils, pollen

grains found in sediments, and isotope ratios in samples of ancient materials.

Scientists build mathematical climate models that simulate the underlying

physics and chemistry of the many Earth systems and their complex interactions

with each other. These computational models summarize the existing evidence, are

tested for their ability to match past patterns, and are then used (together with

other kinds of computer models) to forecast how the future may be affected by

human activities. The impacts of climate change are uneven and may affect some

regions, species, or human populations more severely than others.

Climate models are important tools for predicting, for example, when and

where new water supplies will be needed, when and which natural resources will

become scarce, how weather patterns may change and with what consequences,

whether proposed technological concepts for controlling greenhouse gases will

work, and how soon people will have to leave low-lying coastal areas if sea levels

continue to rise. Meanwhile, important discoveries are being made—for example,

about how the biosphere is responding to the climate changes that have already

occurred, how the atmosphere is responding to changes in anthropogenic greenhouse

gas emissions, and how greenhouse gases move between the ocean and the

atmosphere over long periods. Such information, from models and other scientific

and engineering efforts, will continue to be essential to planning for humanity’s—

and the global climate’s—future.

It is important to note that although forecasting the consequences of environmental

change is crucial to society, it involves so many complex phenomena

and uncertainties that predictions, particularly long-term predictions, always have

uncertainties. These arise not only from uncertainties in the underlying science

but also from uncertainties about behavioral, economic, and political factors that

affect human activity and changes in activity in response to recognition of the

problem. However, it is clear not only that human activities play a major role in

climate change but also that impacts of climate change—for example, increased

frequency of severe storms due to ocean warming—have begun to influence

human activities. The prospect of future impacts of climate change due to further

increases in atmospheric carbon is prompting consideration of how to avoid or

restrict such increases.

*Grade Band Endpoints for ESS3.D*

***By the end of grade 2*.** [Intentionally left blank.]

***By the end of grade 5*.** If Earth’s global mean temperature continues to rise, the

lives of humans and other organisms will be affected in many different ways.

***By the end of grade 8*.** Human activities, such as the release of greenhouse gases

from burning fossil fuels, are major factors in the current rise in Earth’s mean surface

temperature (global warming). Reducing human vulnerability to whatever climate

changes do occur depend on the understanding of climate science, engineering

capabilities, and other kinds of knowledge, such as understanding of human

behavior and on applying that knowledge wisely in decisions and activities.

***By the end of grade 12*.** Global climate models are often used to understand the

process of climate change because these changes are complex and can occur slowly

over Earth’s history. Though the magnitudes of humans’ impacts are greater than

they have ever been, so too are humans’ abilities to model, predict, and manage

current and future impacts. Through computer simulations and other studies,

important discoveries are still being made about how the ocean, the atmosphere,

and the biosphere interact and are modified in response to human activities, as

well as to changes in human activities. Thus science and engineering will be essential

both to understanding the possible impacts of global climate change and to

informing decisions about how to slow its rate and consequences—for humanity

as well as for the rest of the planet.