EP5 Earth's atmosphere continuously interacts with the other components of the Earth System.

FC 5.1 – Earth's atmosphere exchanges energy and matter within the Earth System through processes such as photosynthesis, the water cycle, biogeochemical cycles, the rock cycle, and ocean currents.

FC 5.2 – Interactions and feedbacks among the components of the Earth System can produce short-term oscillations (such as El Niño and La Niña conditions in the Pacific Ocean), long-term changes in the state of the system (such as global warming), and abrupt, unexpected events (such as sudden release of methane from permafrost).

FC 5.3 – Earth's atmosphere plays an important role in biogeochemical cycles in the Earth System. For example, the atmosphere is a reservoir of carbon in the Earth System, storing carbon released from natural processes and fossil fuel burning. Plants extract carbon from the atmosphere through photosynthesis.

FC 5.4 – As a result of the long time-scales inherent in some Earth System processes, the impacts of some events may be felt only slowly throughout the Earth System and may continue to be influential long after the original event has changed. For example, because of the long time-scale of deep ocean circulation, an abrupt regional change in ocean salinity may take centuries to be reflected in the global circulation of the ocean.

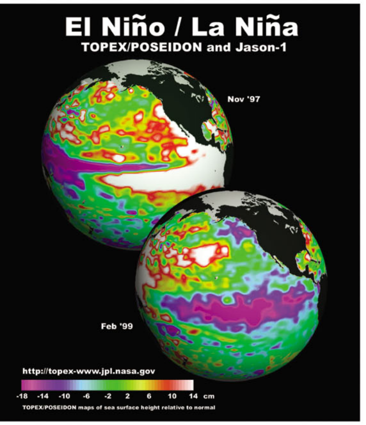

Figure 5 - Sea surface heights during El Niño and La Niña conditions, derived from TOPEX/POSEIDON and Jason-1 measurements. Images produced by Dr. Victor Zlotnicki, Dr. Lee-Lueng Fu, and Akiko Hayashi, of the Oceans Research Element at NASA's Jet Propulsion Laboratory.

EP6 We seek to understand the past, present, and future behavior of Earth's atmosphere through scientific observation and reasoning.

FC 6.1 – Our understanding of Earth's atmosphere comes from analysis, interpretation, and synthesis of accurate and purposeful observations of the atmosphere, ocean, biosphere, land surface, and Polar Regions.

FC 6.2 – Data about Earth's atmosphere are gathered by direct (in situ) measurement of temperature, precipitation, wind, pressure, and other variables, as well as by indirect (remote sensing) measurements taken at a distance using ground-based, satellite, and airborne instruments.

FC 6.3 – Our understanding of Earth's atmosphere allows scientists to develop numerical (computer) models that can be used to simulate Earth's weather and climate. Such models are fundamental to modern weather analysis and forecasting and are essential to scientists' efforts to understand Earth's past climate and predict future climate.

FC 6.4 – To generate predictions, numerical models must begin with observations of Earth's atmosphere and the planet's land and ocean surfaces. These data are used to provide starting conditions for models that are as complete as possible.

FC 6.5 – Inaccuracies and the imprecision inherent in instruments, mathematical representations of physical processes, model resolution, and discrete numerical calculations limit the accuracy of the resulting simulations and predictions. Models improve with technological and theoretical advances, which improve data quality and quantity and our ability to represent physical processes. The chaotic nature and inherent complexity of some natural processes ultimately limits how far in advance atmospheric phenomena can be predicted, forcing the use of statistical projections.

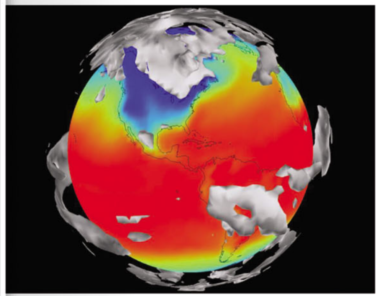

Figure 6 - Climate system models produce visualizations such as this one, and provide scientists, policy makers, and educators with ways to manipulate, understand, and predict what variables control the atmosphere, climate, and the Earth System. Copyright University Corporation for Atmospheric Research, NCAR Climate System Model.

EP7 Earth's atmosphere and humans are inextricably linked.

FC 7.1 – Most living organisms on Earth are dependent on Earth's atmosphere and its processes for survival. We require oxygen for breathing; rely on ozone in the stratosphere to protect us from harmful radiation from the Sun; depend on prevailing wind patterns to drive ocean upwelling and so supply food; rely on wind to power turbines, sails, and ventilators; and need rain for drinking water and agriculture.

FC 7.2 – Living organisms can and do change the composition of Earth's atmosphere and its processes. Many human activities, such as farming, forestry, building of cities, and burning of fossil fuels, alter atmosphere composition and thereby impact the functioning of ecosystems, human health, and climate on local, regional, and global scales.

FC 7.3 – Human cultures around the world have adapted differently over hundreds to thousands of years to their unique local and regional weather and climate. Societies have different levels of vulnerability to rapidly changing weather and climate conditions. Severe weather can have major impact on individuals as well as society. Global and regional climate change may bring major changes to vulnerable cultures.

FC 7.4 – Weather forecasts and predictions of future climate assist us in implementing mitigation strategies and adaptation to new climatic conditions.

FC 7.5 – Citizens need to become educated about Earth's atmosphere to make informed decisions on issues at local, regional, and global scales.

Figure 7 - Often visible as a funnel-shaped cloud, tornadoes can develop with little or no warning. Doppler radar and other advanced technology now give advance warning of many tornadoes which can devastate property and claim lives. Copyright University Corporation for Atmospheric Research, Photo by Bob Henson.

Framework Development Process

This framework for Atmospheric Science Literacy was developed in a collaborative effort with over 100 experts including atmospheric and climate scientists, K-12 and informal science educators, university faculty, and science policy specialists. Through the efforts of the organizing committee, a workshop was convened to draft the framework at the University Corporation for Atmospheric Research in Boulder, Colorado, in November 2007. The workshop included ~60 in-person participants, as well as ~40 online and video-conferencing participants. This final version of the framework represents the work of this community and additional experts after three revisions of the original draft arising from the workshop. Further information about the process, as well as access to earlier versions and comments provided by the community, are available at http://www.eo.ucar.edu/asl/. Development of the framework for Atmospheric Science Literacy was supported by the National Science Foundation's Geoscience Education Program.

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- Peter Schultz, Climate Change Program Office
- J. Marshall Shepherd, University of Georgia

This document is a component of a larger effort to develop a comprehensive literacy framework for the entire Earth System. Several other related frameworks have already been completed, including frameworks for Ocean Literacy and for Climate Literacy. Other framework development efforts are underway at this time. We expect that the products of preceding, concurrent, and future activities will be incorporated into the larger Earth System literacy framework.

Mapping to Educational Standards

By completing this framework, a first step has been taken toward relating the Essential Principles and Fundamental Concepts for Atmospheric Science Literacy to educational standards, a requirement for its utilization by the nation's schools. In order to facilitate use of this information by classroom teachers, it would be helpful to have these big ideas cross-referenced with educational standards (such as the National Science Education Standards and Benchmarks for Science Literacy). In collaboration with leading educators, we will develop an additional document providing this cross-linkage, and anticipate completion of this effort by July 2009.

Essential Principles and Fundamental Concepts for Atmospheric Science Literacy

UCAR · National Earth Science Teachers Association · NCAR · NOAA · CIRES · American Meteorological Society · AGU · NSF · National Association of Geoscience Teachers

Printed on recycled paper with soy ink.

All humans live in Earth's atmosphere – we depend on it for the air we breathe, the water we drink, and the food we eat. Humankind's dependent relationship with the atmosphere is aptly summarized by an unknown author:

> *"Man - despite his artistic pretensions, his sophistication, and his many accomplishments - owes his existence to a six inch layer of topsoil and the fact that it rains."*

Earth's atmosphere, hydrosphere, geosphere, and biosphere comprise the Earth System. The atmosphere is a complex system in its own right that has co-evolved over time with these other components of the Earth System. The atmosphere is continuously changing – changes from hour to hour and day to day give us weather, while changes over periods of months to millennia give us climate. While Earth's atmosphere provides many benefits, such as oxygen, rain, and power from the wind, it also brings hazards, such as tornadoes, hurricanes, floods, and drought.

We know, through our own experiences, scientific observations, and nearly daily news reports that Earth's atmosphere is changing along with the rest of the global environment. Some of these changes are outside of human control – determined in some cases by solar and geologic processes. We are also increasingly aware that human activities are changing Earth's atmosphere. Since there are no sharp boundaries in the atmosphere, pollutants resulting from industrial emissions in one place can travel across country and continental boundaries and negatively affect those that did not create the pollution.

We are challenged to live wisely with Earth's atmosphere, utilizing it as a valuable resource while being good stewards. To understand what is happening in the atmosphere and make wise decisions about our vital interactions with it, it is important for us to have a basic understanding of the relevant scientific knowledge. That is, we must be literate with respect to the essential principles and fundamental concepts of atmospheric science.

Atmospheric Science Literacy

People who are literate in atmospheric science understand the "big ideas" of the relevant scientific knowledge. Armed with this understanding, they will have the basis to communicate about Earth's atmosphere in a meaningful way, and be equipped to make informed and responsible decisions about activities that impact Earth's atmosphere. This framework for Atmospheric Science Literacy provides guidance to educators and the public on these big ideas. We have chosen to structure the framework with Essential Principles (EPs) at the highest level, on which more detailed information depends. Subordinate and more specific Fundamental Concepts (FCs) offer foundational knowledge which is needed to fully understand the Essential Principles.

EP1 Earth has a thin atmosphere that sustains life.

FC 1.1 – Earth's atmosphere is a mixture of gases with small, but important, quantities of liquid and solid particles.

FC 1.2 – The atmosphere has mass, is bound to Earth by gravity, and exerts pressure which is greater near Earth's surface and decreases with altitude.

FC 1.3 – The atmosphere, which is very thin relative to Earth's radius, varies vertically in layers which differ in composition, density, and temperature. The lowest 8-16 km of the atmosphere – the troposphere – contains most of Earth's weather systems.

Figure 1 - This view of Earth's horizon as the sun sets over the Pacific Ocean was taken on 21 July 2003 by an Expedition 7 crewmember onboard the International Space Station (ISS). Anvil tops of thunderclouds are also visible. Courtesy of NASA Human Space Flight Collection.

FC 1.4 – Earth's atmosphere sustains and protects living things. Its composition has changed over time, as it has been influenced by life and by geological and geochemical processes. Through photosynthesis, plants produce the oxygen in the atmosphere that makes life possible.

FC 1.5 – Other bodies in the Solar System also have atmospheres. Their composition and motions vary considerably from those of Earth's atmosphere due to planetary size, place in the Solar System, speed of rotation, and other planetary processes.

EP2 Energy from the Sun drives atmospheric processes.

FC 2.1 – Earth receives energy in the form of electromagnetic radiation from the Sun. Some of this solar energy is absorbed by the atmosphere, some is scattered back to space, and some is transmitted through the atmosphere to be absorbed or reflected by Earth's surface. The solar energy reflected by Earth's surface is absorbed, scattered, reflected, or transmitted by the atmosphere.

FC 2.2 – Energy from the Sun is transformed into other forms of energy in the Earth System. In the atmosphere these other forms include thermal energy of gas molecules, the kinetic energy of wind, and the latent heat of evaporation stored in water vapor.

FC 2.3 – On human time scales, the energy emitted by the Sun is nearly constant, varying only very slightly due to solar activity. The amount of solar energy received at a point on Earth's surface varies due to Earth's spherical shape, its daily rotation about its tilted axis, its annual revolution around the Sun, and the slight elliptical shape of Earth's orbit, leading to important cycles such as day and night, and the seasons. In addition, cloud cover and aerosols can reduce the amount of solar energy that reaches Earth's surface.

FC 2.4 – Solar energy drives many chemical, biological, and physical processes that affect Earth's atmosphere. These include processes such as photosynthesis, evaporation of liquid water to produce water vapor, formation of smog, and the formation and destruction of ozone.

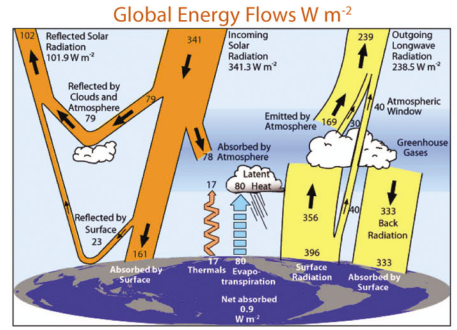
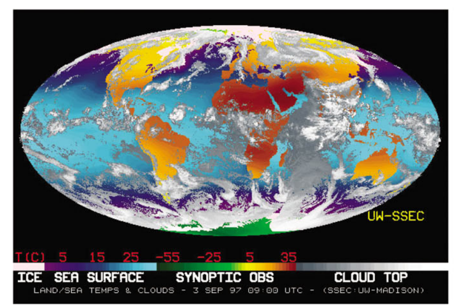


Figure 2 – The flow of energy into and out of the Earth System. Trenberth, K. E., J. T. Fasullo, and J. Kiehl, 2008: Earth's global energy budget. Bull. Amer. Meteor. Soc., submitted.

FC 2.5 – Earth also emits energy in the form of electromagnetic radiation. Almost all of the energy emitted comes from the solar energy absorbed by Earth's surface. This terrestrial energy is absorbed by atmospheric trace gases, such as water vapor, carbon dioxide, and other gases in Earth's atmosphere. It may be reemitted from the atmosphere, either to space, where it is lost to the Earth System, or back to Earth, where it is again absorbed, producing a "Greenhouse Effect". This natural Greenhouse Effect is necessary for life to exist on Earth.

EP3 Atmospheric circulations transport matter and energy.

Figure 3 - This global montage is created and updated every 6 hours using satellite data, sea surface temperatures, and observed land temperatures. Courtesy of the Space Science and Engineering Science Center, University of Wisconsin – Madison.



FC 3.1 – Horizontal and vertical energy imbalances in the Earth System produced by unequal heating of Earth's surface create movement in the atmosphere and the ocean.

FC 3.2 – Energy is exchanged within the atmosphere, as well as gained and lost across its interfaces with land and ocean through physical, geological, and biological processes organized in Earth System cycles (e.g., the water cycle). These exchanges help drive atmospheric circulations.

FC 3.3 – Patterns of circulation in Earth's atmosphere can be observed at many different spatial scales from global to local. Temperature differences, the rotation of Earth on its axis, and the configuration of the continents and oceans establish the large-scale atmospheric circulation.

FC 3.4 – Atmospheric transport of water affects the formation and development of clouds, precipitation, and weather systems, which are all important components of the global water cycle.

FC 3.5 – Atmospheric circulations distribute matter and energy globally and establish weather and climate patterns.

EP4 Earth's atmosphere changes over time and space, giving rise to weather and climate.

FC 4.1 – Weather is the state of Earth's atmosphere at a particular place and time. The climate of a particular place encompasses the long term range of weather conditions at that place. Earth's global climate is determined by the energy received from the Sun and is regulated by atmospheric composition and by atmospheric and oceanic circulations.

Figure 4 - The formation of this massive cumulus cloud demonstrates how energy and moisture in the atmosphere can give rise to dramatic weather. Copyright Roberta M. Johnson.

FC 4.2 – Weather changes over time periods ranging from seconds to weeks. Climate changes over intervals ranging from years to millennia. Earth's history has been marked by gradual variations in global climate caused by long-term cyclic variations in Earth's orbit and axial tilt, and modulated by changes over geologic time in the sizes and distribution of the continents. These gradual variations have been punctuated by relatively abrupt climatic shifts caused by volcanic eruptions and sudden redistributions of mass and energy in the Earth System.

FC 4.3 – Both weather and climate vary by region based on latitude, altitude, land use, proximity to physical features such as the ocean and mountains, and ocean currents.

FC 4.4 – Weather phenomena are important to human society. As evidenced in art, literature, and human culture over time, some atmospheric phenomena are beautiful, inspiring the human spirit. Severe weather, such as thunderstorms, tornadoes, and hurricanes, can bring rapid, dramatic changes to ecosystems and to individuals, property, and infrastructure.