Atmospheric Radiation Measurement
Climate Research Facility
U.S. Department of Energy

Climate Education Update

NEWS AND INFORMATION ABOUT CLIMATE CHANGE STUDIES FOR TEACHERS AND STUDENTS

September 2005

The Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility supports education and outreach efforts for communities and schools located near its sites. The mission of the Education and Outreach Program is to promote basic science education and community awareness of climate change research by focusing on three goals: student enrichment, teacher support, and community outreach.

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At ARM's Length: Using Radiosondes to Extend Our Grasp of Weather and Climate

by Dr. Kevin Kloesel, University of Oklahoma

For centuries, observations of atmospheric temperature, pressure, humidity and winds were limited primarily by where instruments could be located. More recently, remote instrument platforms such as radars and satellites have been deployed to explore portions of the atmosphere beyond the reach of conventional weather instruments. With the objective of studying radiation transfer in the atmosphere as a whole, the ARM Program seeks to measure atmospheric properties not only at the surface of the Earth, but aloft, where clouds impact our weather and climate. As we deploy more remote sensing platforms (i.e. radars and satellites) to observe clouds, it makes sense to simultaneously place instruments with the clouds to assess the reliability and accuracy of radar and satellite instrumentation. The problem? Putting weather instruments into clouds is not a trivial pursuit!

An ARM technician releases a balloon-borne sounding system (BBSS) into the atmosphere at the Southern Great Plains site.

Attempts to directly measure clouds with instruments began in the United States in 1749 with experiments using large kites carrying primitive instruments. Most of us are aware of Benjamin Franklin's dangerous experiments using kites to fly instruments near thunderstorms to study electricity. If you have ever flown a kite, you know that they are impossible to fly in calm weather conditions. On the other hand, too much wind will cause your kite to crash into the ground. Many a weather instrument was destroyed in these kite-flying experiments, luckily with no human or animal casualties on the ground!

With the development of the hot air balloon in France in the early 1780s, scientists were able to fly weather instruments into the upper atmosphere to investigate cloud characteristics and wind patterns. These manned balloon flights lasted into the 1800s and proved to be very dangerous missions. In 1862, two men ascended to an altitude of about 11 km over Great Britain and nearly died from the extreme cold and lack of oxygen. In a flight taken over Europe in 1875, two French "aeronauts" died as a result of inadequate breathing equipment.

By the end of the 1800s, automated data recorders, called "meteorographs"

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were being carried aloft by unmanned balloons. Such missions sometimes reached the stratosphere, which was much higher in the atmosphere than any previous manned balloons or kites. Unfortunately, retrieval of these data was problematic. After the balloon burst, the meteorograph fell to Earth and preserved the recorded data for days or weeks until it was found, as long as it was not destroyed on impact. The other obvious drawback to this approach was that the data were not readily available and were lost if the meteorograph could not be recovered. Not to mention the risk of this package falling on someone's head!

In the 1900s, aircraft were used to measure weather conditions in the upper atmosphere. From 1925 until the onset of World War II, the United States Weather Bureau and U.S. Army Air Corps operated a network of about 20 aircraft sounding stations across the country. Unfortunately, like the kite, the aircraft could not be flown in stormy weather, and the data could not be analyzed until the plane landed. Furthermore, the maximum altitude achieved by these aircraft was only about 5 km, or about one-quarter of the height needed to comprehensively study clouds.

The inability of kites and aircraft to achieve high altitudes, operate in all kinds of weather, and provide real-time data, helped spur the development of a capability to transmit data remotely via radio. In the late 1920s, scientists began suspending crude radio transmitters from balloons and by the early 1930s the first radio-meteorographs or "radiosondes" were flown. The "radiosonde" was named by H. Hergesell using a combination of the words "radio" for the onboard radio transmitter, and "sonde" which is Old English for "messenger."

The basic sonde configuration dates back to January 1930, when Pavel Molchanov, a Russian meteorologist, made a successful balloon-borne radio sounding into the stratosphere over Pavlovsk. Radiosondes were first used by the U.S. Weather Bureau in 1936, and the radiosonde network ultimately replaced kite and aircraft sounding programs.

Before computers, using radiosonde data for studying weather involved a significant amount of manual labor. The observation process was usually a three-person effort. All aspects of the observation, including preparing for the sounding balloon release, the actual launch, receiving the radio signals back from the instrument, logging and evaluating the incoming data, and preparing the weather maps and charts, were labor intensive. It wasn't until the late 1960s that the U.S. defense and weather agencies began experimenting with computerized acquisition and plotting of radiosonde data.

Radiosondes Today

Today's radiosonde consists of instruments capable of making direct measurements of air temperature, humidity and pressure, typically to altitudes of approximately 20 km. These data are transmitted in real-time to a ground-based antenna via a radio transmitter located within the instrument package. Ground-based equipment tracks the motion of the radiosonde during its ascent through the atmosphere. The recorded elevation and azimuth information are then converted to wind speed and direction by triangulation techniques. When the balloon bursts, the instrument package returns to Earth on a parachute. Approximately one-third of the radiosondes released by the National Weather Service (NWS) are found and returned to the Instrument Reconditioning Branch in Kansas City, Missouri where they are repaired and reissued for further use. Instructions printed on the radiosonde explain the use of the instrument and request the finder to mail the radiosonde, postage free, to the NWS. The finders receive satisfaction in knowing that they are helping reduce the overall cost of operating a critical weather observation network.

Worldwide, there are more than 900 radiosonde stations using 15 different types of instrument packages. Most stations are located in the Northern Hemisphere and all observations are taken at the same time each day at 00:00 and 12:00 UTC. Observations are made by the NWS at 93 stations - 72 in the conterminous United States, 13 in Alaska, 10 in the Pacific, and one in Puerto Rico. Radiosondes are also launched at each ARM site at regular intervals to help ARM scientists understand the complexities of clouds and their influence on our weather and climate. These data are vital in verifying data received from radar, satellite, and ground-based ARM observing systems. Using radiosonde observations, scientists are making significant progress toward reaching ARM's goal of understanding how the radiative processes of our earth-atmosphere system affect our weather and climate.

ARM sonde launching equipment

Teacher's Notes

The complete radiosonde system consists of a balloon-borne radiosonde instrument package, radio receiver, tracking unit and recorder.

Instrument Package

The main component of the radiosonde is a sturdy, lightweight, white cardboard and styrofoam instrument package, approximately the size of a small shoe box. The package is attached to a balloon and parachute. The following weather sensing instruments are located within or attached to this package:

Thermistor

The resistance thermistor is a white ceramic covered metallic rod that serves as a temperature sensor on most American radiosondes. The diameter of the rod is approximately 0.7 mm and its length is no more than 2 cm. The electrical resistance of this rod changes with a change in the air temperature. To increase contact with the air, the thermistor is located on an outrigger, extended a short distance from the outside of the instrument package. The thermistor is white to minimize the heating by sunlight. The temperature range for the thermistor lies between approximately +40 ^oC to -90 ^oC.

Hygristor

The hygristor is a humidity sensor consisting of a glass slide or plastic strip covered with a moisture sensitive film of lithium chloride (LiCl) and a binder; metal strips are located along the edges. The chemical's electrical resistance changes as atmospheric humidity changes. On most radiosondes, the hygristor is located within the instrument package at a place where the outside air passes over the hygristor. The hygristor on most radiosondes is designed to record the ambient relative humidity ranging from 15% to 100%.

Barometer

The radiosonde measures pressure by means of an aneroid barometer, consisting of a small, partially evacuated metal canister. This temperature-compensated instrument is central to the instrument package. The volume of the canister expands as the radiosonde ascends, in response to a reduction in the atmospheric pressure aloft. The aneroid is designed to register pressures from 1040 mb to 10 mb or less.

Radio Transmitter

A miniature radio transmitter generates the FM radio frequency carrier, operating on a modulated carrier frequency of 1680 MHz. Variable modulation is used to transmit the collected information, that is, the radio frequency is changed by the position of the contact arm on the baroswitch. The radio transmitter is located in the pointed plastic cylinder attached to the base of the instrument package. In flight this conical antenna housing is pointed downward.

Battery

A small battery is contained in the radiosonde package to serve as the power supply for the weather sensing instruments and the radio transmitter. The battery is activated and tested prior to launch.

Balloon & Parachute

The radiosonde package is carried aloft by a balloon. The balloon is made of a film of natural or synthetic rubber (neoprene). Before launch, a neoprene balloon is inflated with lighter-than-air gas, typically hydrogen, to a 6-foot diameter. This size provides sufficient lift to carry a radiosonde payload of several pounds. The thickness of the balloon skin ranges from 0.002 to 0.004 inch at the time of inflation, but becomes 0.0001 inch just before the balloon bursts. As the balloon ascends, it expands in size from approximately 6 ft to a diameter between 24 and 32 ft before it bursts. The balloon carries the instrument package to an altitude of approximately 25-35 km where the balloon bursts (at a pressure of approximately 10 mb).

An attached parachute returns the instrument package safely to the ground. Return mailing instructions are included in the instrument package. Radiosondes that are found and returned can be refurbished for subsequent flights, saving a considerable amount of the cost for a new radiosonde.

Ground Unit Radio Receiver Antenna

An antenna receives the telemetry signal transmitted from the radiosonde. Highly directional radio direction finding antenna is used also to obtain the wind speed and direction at various levels in the atmosphere by tracking the radiosonde and determining the azimuth and elevation angles. The ascent rate of the radiosonde is known and timed between intervals.

Complied by Dr. Kevin Kloesel, University of Oklahoma

Graphing the Layers of the Atmosphere

Objective

Make a graph to discover how the atmosphere can be divided into layers based on temperature changes at different heights.

Background

Students should know how to plot data on a graph with negative numbers. Go over the directions carefully, reading the *Layers of the Atmosphere* article aloud. Make a copy of the graph template for each student. Watch students carefully during the graph plotting activity, making sure graphing is correct.

Directions

1. Table 1 contains the average temperature readings at various altitudes in the Earth's atmosphere. Plot this data on a graph and connect adjacent points with a smooth curve. Be careful to plot the negative temperature numbers correctly. This profile provides a general picture of temperature at any given time and place; however, the actual temperature may deviate from the average values, particularly in the lower atmosphere.

TABLE 1

Average Temperature Readings at Various Altitudes

Altitude (km)	Temp (ºC)	Altitude (km)	Temp (ºC)
0	15	52	-2
5	-18	55	-7
10	-49	60	-17
12	-56	65	-33
20	-56	70	-54
25	-51	75	-65
30	-46	80	-79
35	-37	84	-86
40	-22	92	-86
45	-8	95	-81
48	-2	100	-72

2. Label the different layers of the atmosphere and the separating boundaries between each layer.

3. Mark the general location of the ozone layer. Eight words should be placed on your graph in the correct locations: troposphere, tropopause, stratosphere, stratopause, mesosphere, mesopause, thermosphere and ozone layer.

Critical thinking questions

1. What factor drives the atmosphere to be divided into four layers?
   The variations of temperature changes.

2. Does the temperature increase or decrease with altitude in the:
   troposphere? (*decrease*) stratosphere? (*increase*)
   mesosphere? (*decrease*) thermosphere? (*increase*)

3. What is the approximate height and temperature of the:
   tropopause: (*about 12-18 km*) (*about -60*)
   stratopause: (*about 46-45 km*) (*about -2 to 0*)
   mesopause: (*about 85-90 km*) (*about -90*)

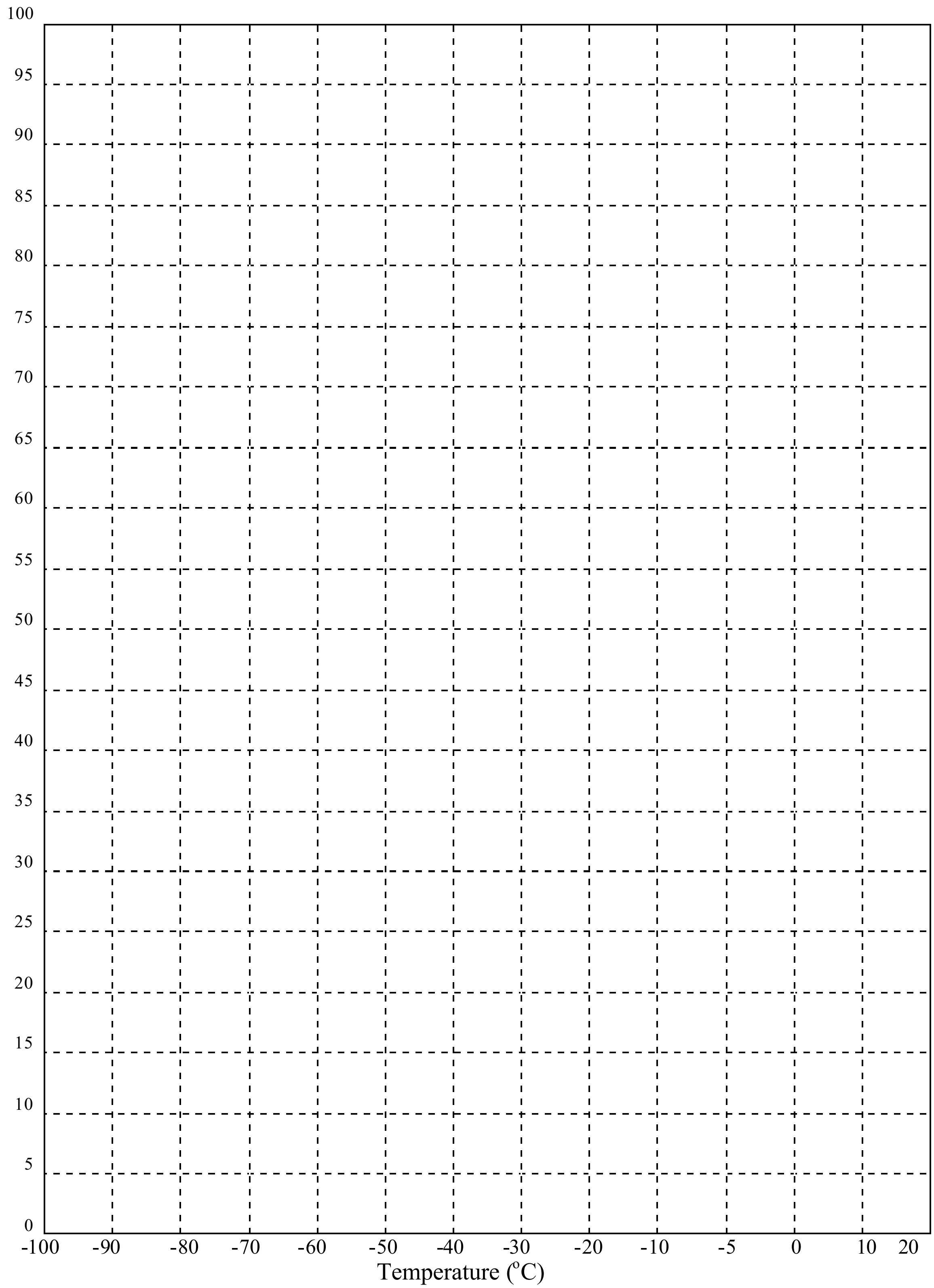
4. What causes the temperature to increase with height through the stratosphere and decrease with height through the mesosphere? *The temperature increases in the stratosphere due to ozone layer capturing ultraviolet radiation. The temperature decreases in the mesosphere since there is no ozone and the amount of air is decreasing.*

5. What causes the temperature to decrease with height in the troposphere? *As solar energy hits the Earth's surface it is converted into heat. That heat radiates upward from the Earth's surface. The farther away from the warm Earth's surface we go, the less heat we feel until we hit the ozone layer in the stratosphere. The temperature of the troposphere therefore decreases steadily until the stratosphere.*

Reference: Geological Society of America. Layers of the Atmosphere by Jack Fearing. ©2005 Geological Society of America, http://www.geosociety.org/educate/LessonPlans/Layers_of_Atmosphere.pdf

Graph of Temperature at Various Altitudes

ALTITUDE (km above sea level – Y-axis)

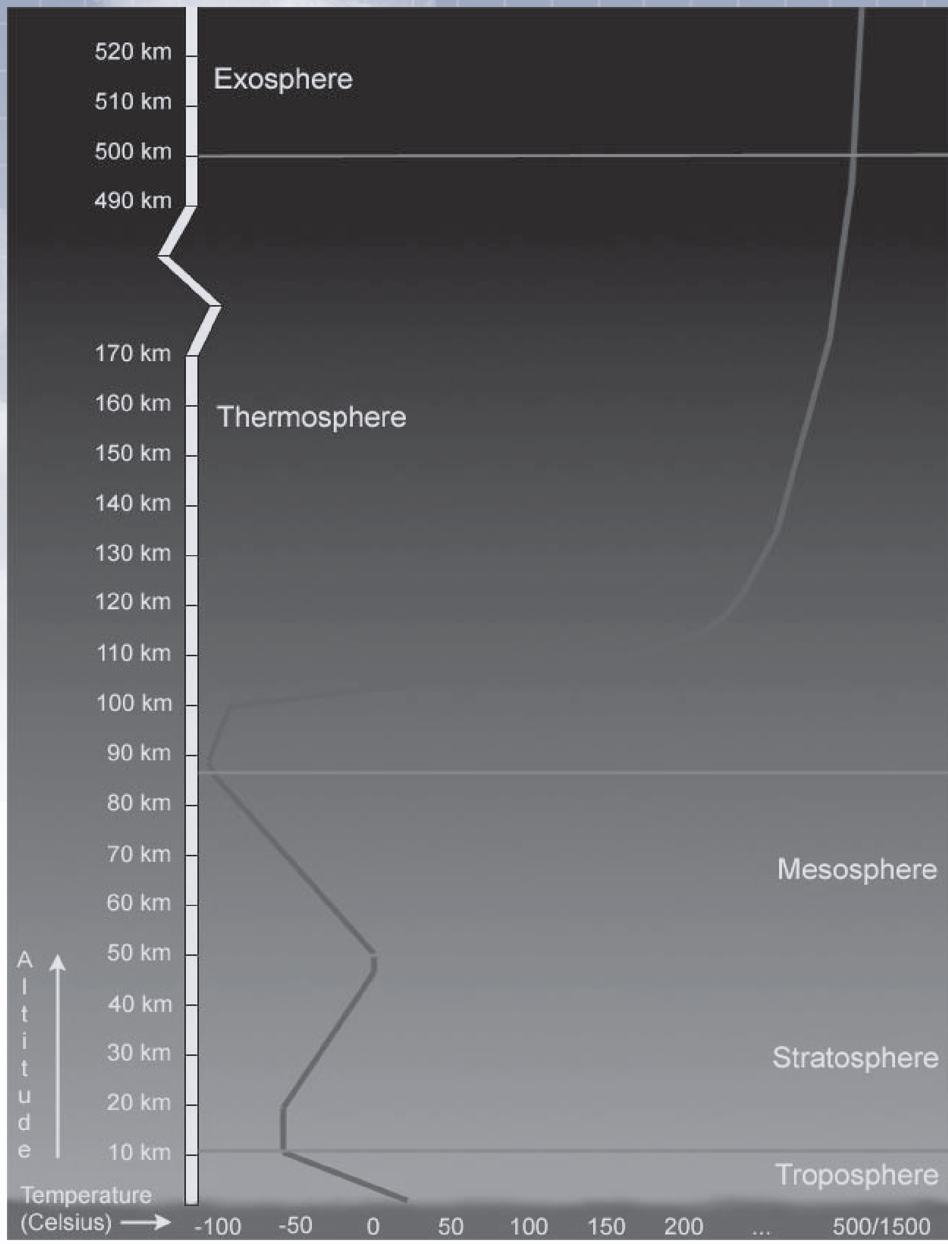


Layers of Atmosphere

The atmosphere surrounds Earth and protects us by blocking out dangerous rays from the sun. The atmosphere is a mixture of gases that becomes thinner until it gradually reaches space. It is composed of nitrogen (78%), oxygen (21%), and other gases, and can be divided into five layers based on temperature variations.

Closest to the Earth is a layer called the troposphere. Above this layer is the stratosphere, followed by the mesosphere, then the thermosphere. The upper boundaries between these layers are known as the tropopause, stratopause, and the mesopause, respectively. The atmosphere finally merges into space in the extremely thin layer called the exosphere, which is the upper limit of our atmosphere.

Temperature variations in the five layers result from the way solar energy is absorbed as it moves downward through the atmosphere. The troposphere is the lowest region of the Earth's atmosphere where masses of air are very well mixed. The temperature decreases with altitude as air is heated from the ground (because the surface of the Earth absorbs energy and heats up faster than the air). Earth's weather occurs in the troposphere and most clouds form in this layer.



Courtesy of Windows to the Universe, http://www.windows.ucar.

In the stratosphere, the temperature increases with altitude because of the presence of an ozone layer at about 25 kilometers above the Earth's surface. The ozone molecules absorb high-energy ultra violet rays from the sun, which warm the atmosphere at that level.

The mesosphere extends from the top of the stratosphere to an altitude of about 90 kilometers. In the mesosphere, air masses are relatively mixed and temperatures decrease with altitude, reaching the lowest average value around -90°C. Solar radiation first hits the Earth's atmosphere in this layer and begins to warm it. Because the atmosphere is so thin here, a thermometer cannot measure the temperature accurately and special instruments are needed.

At very high altitudes, the atmosphere becomes very thin. The region where atoms and molecules escape into space is called the exosphere. This is the true upper limit of the Earth's atmosphere.

Reference: Windows to the Universe team. Layers of the Atmosphere. Boulder, CO: ©2000-04 University Corporation of Atmospheric Research (UCAR), ©1995-1999, 2000 The Regents of the University of Michigan

News Notes

ARM Kiosk on Display at Bradbury Science Museum

An educational kiosk developed by ACRF Education and Outreach is on display at the Bradbury Science Museum in Los Alamos, New Mexico. Originally designed for the community of Barrow, Alaska, home to one of ARM's research sites, accessibility to the kiosk has been extended to the Los Alamos community, home to Los Alamos National Laboratory and thousands of scientists from around the world.

The kiosk, titled "Climate Change: Science and Traditional Knowledge," has been on permanent display at the Iñupiat Heritage Center (IHC) in Barrow since October 2003. The IHC was a collaborator on the kiosk project and facilitated discussions between ACRF Education and Outreach and community elders, leaders, educators and students. The kiosk features interviews with local community members about their observations of climate change on the North Slope of Alaska, and interviews with ARM scientists provide basic information about climate change studies. The kiosk provides an opportunity for users to learn about climate change from both scientific and indigenous perspectives.

The Bradbury Science Museum serves as a bridge between the Laboratory and the Los Alamos community by helping to improve science education and science literacy. Joining approximately 40 other interactive exhibits, the NSA kiosk will provide a unique learning opportunity to the nearly 100,000 people that visit the Museum every year.

Weather and Water Teacher Workshop

The Oklahoma Climatological Survey hosted the national Weather and Water Teacher Workshop in conjunction with Delta Education and the Full Option Science Series (FOSS) program and the University of California at Berkeley. Twenty-five teachers from around the United States participated in the week-long experience using weather and climate data in middle school classrooms. Teachers were exposed to a variety of datasets including both in-situ and remote measurements, and used ARM data in extension activities with the FOSS Kits provided by Delta Education.

For lessons, activities, and more information about the ARM climate research facility in Oklahoma, visit the EarthStorm web site at *http://earthstorm.ocs.ou.edu/default.php*.

Teachers at Weather and Water workshop practice the Skin Temperature activity.

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