SPaRCE WORKBOOK

Number One

INTRODUCTION TO THE SPaRCE PROGRAM

and

SITING AND MAINTAINING METEOROLOGICAL INSTRUMENTS

SPaRCE Workbook One (revised November 1999).

This manual was developed as part of the Schools of the Pacific Rainfall Climate Experiment Program.

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The SPaRCE program is a cooperative field project involving students and teachers from many Pacific island nations as well as the U.S. The goals of the project are both research and education-oriented. The SPaRCE program is sponsored by:

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TABLE OF CONTENTS

Introduction to the SPaRCE Program

and

Siting and Maintaining Meteorological Instruments

I. Introduction to the Teacher

II. Introduction to the Students

III. Siting and Maintaining the Meteorological Instruments

A. Precipitation Measurements

B. Relative Humidity

C. Maximum/Minimum Temperature

D. Cloud Type and Cloud Cover

IV. Receiving Your Instruments

APPENDIX A Local Weather Service Office Contacts

APPENDIX B Instructions on reading and caring for your rain gauge

APPENDIX C Dew Point Table

APPENDIX D Weather Glossary

APPENDIX E Sample Data Sheet

I. Introduction to the Teacher

Teachers,

Welcome to the Schools of the Pacific Rainfall and Climate Experiment (SPaRCE). The SPaRCE program was developed to help you and your students explore the local environment as well as learn about Pacific climate change, global climate change, and involve your class in a significant way in the worldwide research effort to predict and understand these changes.

We encourage your students to form teams which will have the responsibility of siting and maintaining the instruments at your location as well as collecting measurements on a daily basis. We request the daily rainfall measurements be sent to your local Weather Service Office (see Appendix A for a list) on a monthly basis, where they will be collected and later sent to the SPaRCE headquarters to be analyzed. Data from all participants will be returned to you for further examination, experimentation, and analysis.

Questions concerning the instrument sites, instrumentation, or related issues should primarily be directed to your local Weather Service Office (WSO). If the WSO is unable to answer your questions, they will be forwarded to SPaRCE headquarters for resolution. We encourage you to contact us with any questions, problems, ideas, or suggestions you (and your students) may have. Our website is located at: http://www.evac.ou.edu/sparce . We can also be reached by electronic mail at sparce@hoth.ou.edu . For those who do not have internet access, issues will be addressed and either mailed directly back to you, or included in the Tradewinds Quarterly, a newsletter that will be sent regularly to all participating schools.

Accompanying this workbook is a corresponding videotaped lecture. A total of 5 workbooks and 6 videotaped lectures will be sent to you. Each workbook and video lecture will cover a different topic related to SPaRCE. The topics of the workbooks and videos include: Introduction to the Earth's Atmosphere; Basic Weather Phenomena; Global Climate and Climate Change; Pacific Regional Climate; Analysis and Experiments Using Rain Gauge Data; and Rain and Rainbows: A Study of Atmospheric Optics. We always appreciate comments and suggestions you may have on improving existing workbooks and videos and/ or ideas for new ones.

We would like to thank you for your interest and participation in the SPaRCE program. We hope that you and your students gain valuable knowledge and insight from your work with this program. We look forward to getting to know about you, your school, and your island, and we appreciate your help in this valuable research effort.

Sincerely,

Susan Postawko

Director, SPaRCE Program

II. Introduction to the Students and Other Participants

Why study weather and climate? Those who live on tropical islands know that the daily weather doesn't seem to change much. Even the weather throughout the year, or from year to year seems to be fairly consistent. This unchanging weather pattern over many years characterizes the climate typical of the tropics; however, changes that occur daily create your local weather. In other words, weather is what is happening now or in the near future while climate reflects the general weather characteristics over a much longer period of time. Climate change is especially important to you, your friends, and family because **any change in the Earth's climate is likely to have a significant effect on the Pacific ecosystem**. A small increase in the global surface temperature will reduce the Arctic and Antarctic ice caps causing a rise in sea-level. This will lead to a significant decrease in, or in some cases and elimination of, habitable land areas in the Pacific. Changes in local weather brought about by climate change may alter temperatures and rainfall patterns affecting the agricultural and industrial activities in your area.

These changes don't take place overnight. Because there are natural yearly variations in local weather, it may take several years to even be sure that a real climate change is taking place. Though we may be contributing to global climate change, we may not be able to do anything to prevent it (there were natural fluctuations in the Earth's climate before people inhabited the land), but if we know what is happening and how it is happening we can take measures to cope with these changes.

Rainfall is perhaps the single most important variable in understanding the climate and predicting climate change. Variations in the averaged rainfall over time determine changes in the amount of energy released into the atmosphere. Complex computer models of the atmosphere require rainfall measurements (like the ones you will be taking) to make reliable predictions of the changing climate.

Rainfall is generally measured using a standard rain gauge located on land. However, in the Pacific very little land area exists compared to the ocean. So how can rain gauges be useful in the Pacific? The answer to this question is relatively simple. Satellites can be used to measure rainfall over all areas of the Pacific, unfortunately, the satellites estimate rainfall indirectly and must be compared to surface rain gauge measurements at various locations for accuracy. Through comparisons with surface rain gauge measurements, the satellite estimates can be adjusted to correct the values. Thus, rain gauges are not required everywhere, but only within areas representing certain climate regimes in the Pacific. In addition to rainfall, other meteorological variables such as temperature, relative humidity, and cloud cover are also important in determining if the global climate is changing.

The Tradewinds Quarterly, a SPaRCE newsletter, will be published 4 times per year. This newsletter will contain stories from SPaRCE participants as well as articles compiled by us about SPaRCE related activities. The Tradewinds Quarterly will be distributed throughout the Pacific and throughout the world. You are encouraged to submit one to two page articles about subjects which you think might interest other SPaRCE participants for use in the newsletter. Examples of articles might include a description of your school, interesting weather events, description of your culture, or any other worth-while event that has taken place in your area. Graphs and pictures are welcome with your contributions (please make sure that there are no copywrite infringements if these items are not your own). In addition to sending these stories or articles, please feel free to send us questions about the program, weather, or climate. We will send you a personal reply as well as share your question with other SPaRCE participants so they can all benefit from the information exchange.

Please send your data sheets (with daily rainfall data), questions, and newsletter contributions to the following address:

The SPaRCE Program

EVAC

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USA

If you have internet access, you can visit our website at http://www.evac.ou.edu/sparce or send us electronic mail at sparce@hoth.ou.edu .

It is not the purpose of the SPaRCE program to make meteorologists out of everyone, however, if you become interested in studying weather and climate you are certainly encouraged to pursue these studies! Rather the SPaRCE program hopes to help you develop an understanding of regional and global weather and climate, and to become more environmentally aware, not only in your own area, but in other regions as well.

III. Siting and Maintaining the Meteorological Instruments

Weather affects us in every aspect of our lives. We are responsible for the world that we pass on to our children and grandchildren, and through research and subsequent knowledge, we will be better able to care for it.

This workbook is designed to assist you in siting and maintaining your meteorological equipment. At this time, participants in the SPaRCE program are using three types of instruments to monitor the weather and climate: a rain gauge, a sling psychrometer, and a maximum/ minimum thermometer.

A. Precipitation Measurements

Why are we interested in measuring precipitation?

- Nearly all life on Earth is dependent on water in one way or another.
- Precipitation is an important part of the hydrologic cycle.
- What is the hydrologic cycle? It is a cycle by which water evaporates from land and ocean, passes through the atmosphere, falls to the surface as precipitation, and then returns to the oceans.
- Climate in a given region is based in part in the amount of precipitation that region receives (where precipitation is scarce we have deserts, where it is abundant we find dense vegetation).

Precipitation refers to any or all forms of liquid or solid water particles that fall from the atmosphere and reach the Earth's surface.

Collecting precipitation data can help scientists understand the long-term variability of precipitation in a region. **Because the patterns of precipitation around**

the globe are expected to change as climate changes, monitoring rainfall patterns is vital to detecting global climate change.

The rain gauge

The rain gauge you will be supplied with is known as a standard direct reading gauge (Figure 1) which consists of four parts; 1.) the collector – the upper portion which is attached to the measuring tube (a graduated cylinder); 2.) the measuring tube – a small cylindrical tube that has a uniform diameter and a graduated scale located on the side of the tube (Figure 2); 3.) the overflow tube – a large cylinder designed to catch any overflow of rain during a period of heavy rainfall; and 4.) a mounting bracket. The measuring tube is inserted into the overflow tube and the collector is fitted into the measuring tube and the overflow tube as shown in below.

Liquid precipitation is classified as rainfall or drizzle.

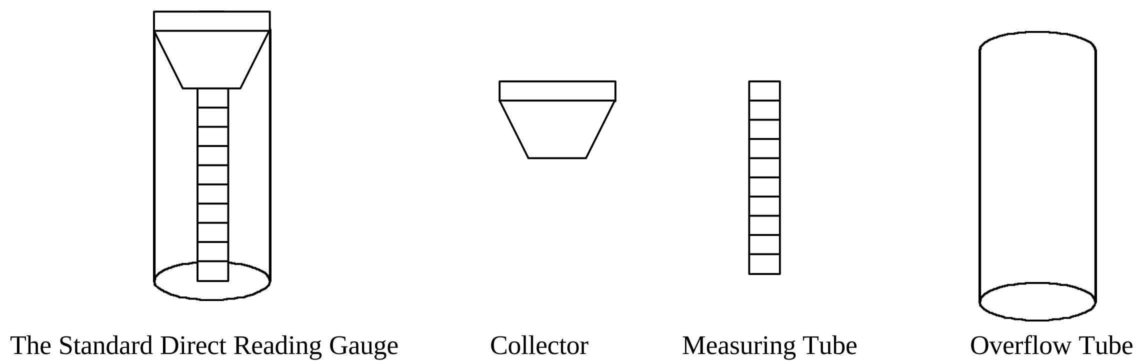
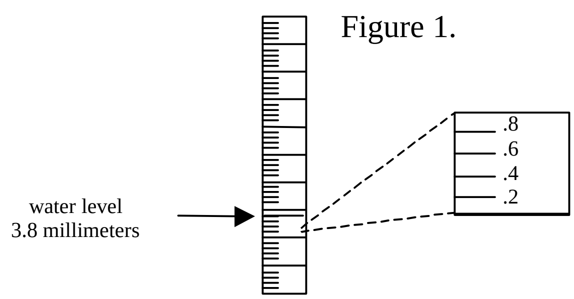


Figure 1.



The measuring scale, which is molded to the outside of the tube is graduated in millimeters (mm).

Figure 2.

The mounting bracket should be fastened to a piece of supporting lumber approximately 2 meters in height and having a width approximately that of your rain gauge (6.35 cm). The bracket should be fastened such that the top of the rain gauge extends approximately 4 to 5 cm beyond the top of the supporting lumber (Figure 3).

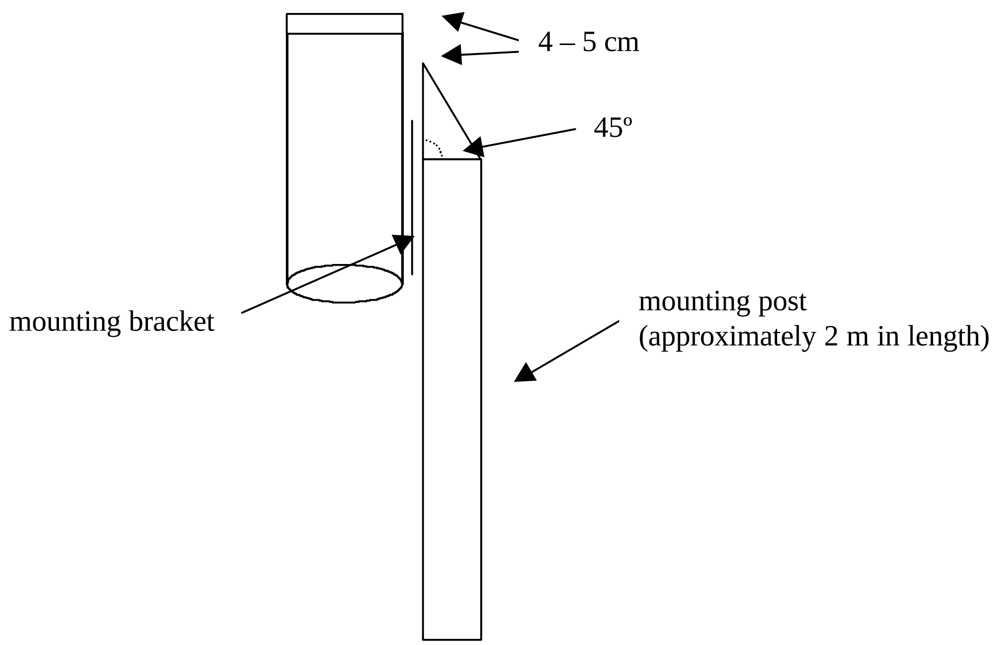


Figure 3.

Siting your rain gauge

Selecting an appropriate site for your rain gauge is most important. It should be easily accessible by you so that you and your team can make daily measurements. Do not locate your gauge under any structure such as a tree or building or near hard surfaces such as parking lots. This is to avoid errors caused by splash-in, or water splashing into the gauge. A good location for the rain gauge would eliminate all wind effects near the gauge that tend to carry away precipitation. Ideally, a rain gauge would be located on an open, flat grassy or sandy area surrounded by tall vegetation at a distance if at least four times the height of the trees (Figure 4).

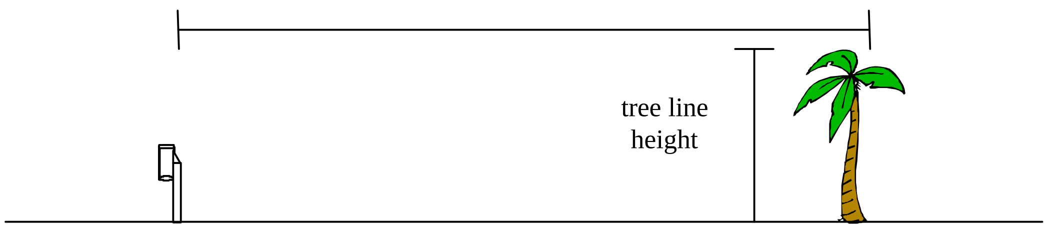


Figure 4.

For correct measurement of rainfall, the mounted and placed rain gauge should be level. This can be checked by placing a carpenter's level across the open top of the gauge in two directions – one crossing the other at a right angle (forming an + across the gauge). The exact latitude and longitude (in degrees) coordinates of your site should be determined using a map or some other means (your local Weather Service Office may be able to help with this).

Measuring rainfall and recording your measurements

Rainfall is defined as the depth of water that crosses a horizontal surface over a given period of time. Rainfall rate is the rainfall unit per unit

You can determine the amount of rainfall in your rain gauge by reading the value on the measuring tube that corresponds with the water level (see Figure 2). Note that the markings on the measuring tube are in **millimeters**. This however, is an expanded scale. If you hold a ruler up to the scale on the measuring tube, you will see that the distance between the markings on the measuring tube are not the same as they are on the ruler. This is because the collection area of the gauge funnel is 10 times larger than the measuring tube. The difference in size causes a need for the markings on the measurement tube to appear large so that the amount of rain can be read directly from the markings. This makes reading small amounts of rainfall much easier.

Find a convenient time for you and your team to go out and take measurements. Make sure that you **try to take your measurements at the same time each day**. While taking your reading, make sure your eyes are level with the tube and note the water level on the measuring tube and any overflow in the overflow tube. Record the accumulated depth of water (**in millimeters**), the date of the reading, the time the measurements were taken, and any relevant comments on the provided data sheets. (See Appendix B for further instructions on how to read and care for your rain gauge.)

After each measurement, the rain in the measuring tube should be emptied by turning the tube upside down and allowing it to drain. During periods of heavy rainfall, the rain water may exceed the capacity of the measuring tube and flow into the overflow tube. When this happens, the level of rainfall in the measuring tube should be noted and the tube emptied. Then the water from the overflow tube should be poured into the measuring tube so that a measurement can be taken – this may have to be done several times in order to empty the overflow tube. The resulting amounts of water should then be summed to determine an overall amount of rainfall.

On many days, no rain will have fallen. On these days, record a zero in the rainfall amount column on the data sheet. If the rain gauge is broken or not functioning, or if the measurement gets lost, **it is extremely important that an "M" (for missing) be recorded in the rainfall amount column on the data sheet**. Placing a zero where an "M" should be will lead to erroneous analysis, so please be sure to record the correct symbol.

Although rainfall should be measured daily, situations may occasionally arise that prevents this from happening. If this occurs, the water should be allowed to accumulate in the rain gauge. The days that measurements cannot be taken should be recorded as "**A**" (for accumulation days). **It is important to record an "A" on days that the rain gauge was functional, but that a measurement was not taken.** The next reading will represent the amount of rainfall that accumulated in the rain gauge as well as any for the present day. (Please try not to allow rainfall to accumulate in the rain gauge for more than five days.)

There will also be days in which the amount of rainfall will be very small, so small that the depth cannot be read on the measuring tube. On these days, place the symbol "**Tr**" (for trace) in the rainfall amount column. This tells us that extremely light rainfall occurred. This information can be used for those research studies that need to know only that it rained, not the rainfall amount.

Even if you know it has not rained, the rain gauge should be checked daily to make sure that it is free of debris (windblown leaves, twigs, papers, etc.).

Snow depth and snow boards

Some SPaRCE participants live in areas where snow and ice may occasionally fall. In these areas, the depth of the fallen solid precipitation is measured, and the liquid water equivalent of that precipitation is calculated.

> Solid precipitation includes snow, ice pellets, hail, ice crystals, and freezing rain.

Snow boards are used to provide a reference level in the measurement of the depth of new snowfall and ice. Snow boards identify an existing surface of snow or ice that has been covered by a more recent snowfall. The boards may be made of thin wood, metal, or other lightweight material that will not sink into the snow – but not so light that it will be blown away by a strong wind. The boards should be at least 41 cm by 41 cm in size so that more than one snow depth measurement can be made. Be sure to mark the location of the snow board so it can be easily located after it has been covered by a new snowfall. To measure the depth of snowfall, use a simple metal rod or other similar measuring stick with increments marked in **millimeters** on it.

Snow board siting

The snow board should be sited in an area similar to the area in which your rain gauge was placed. This area should be easily accessible, away from trees and buildings, and away from hard surfaces such as parking lots on a flat grassy or sandy surface that is surrounded by tall vegetation. (See Figure 4.) The best place is level ground where the snow depth is most frequently representative of the average depth over the surrounding area. If the surrounding area is hilly, and a hillside slope provides the most representative exposure, a slope with an exposure away from the sun will usually provide the best depth measurements (this means a northerly exposure in the Northern Hemisphere and a southerly exposure in the Southern Hemisphere).

The snow board should be placed on top of existing snow and pushed down until the top of the board is flush with the snow surface. Prior to the first snowfall, the snow board is not necessary, and the snow depth stick can be used directly to measure the depth of the first snowfall.

Measuring snow depth

To measure the depth of solid precipitation on the ground, simply insert the measuring stick vertically into the snow until it rests on the surface (either the snowboard or the ground). In areas where one snowfall does not melt before the next snowfall, the snowboard will be used as a reference for measuring the amount of new snow. **Be careful not to mistake an ice layer or crusted snow for the snowboard or the ground!** Repeat the measurement in several places where the snow is least affected by drifting. The average of your measurements is what should be reported as snow depth. **This number should be recorded in the rainfall amount column and snowfall should be written in the comments column.** (If measured depth is less than 0.5 millimeters, record "**Tr**" in the rainfall amount column and write snowfall in the comments column.) After each observation the snowboard should be removed from the snow, cleaned, and again placed on top of the snow and pushed flush with the snow surface.

> Like liquid precipitation measurements, snowfall measurements should be taken daily at approximately the same time each day.

Liquid water equivalent of solid precipitation

Not all snowfalls are alike – sometimes snow is very light and fluffy, and other times it is very wet and heavy. To measure the liquid content of solid precipitation, a collection container is necessary. The plastic rain gauges used for liquid precipitation may crack and break under freezing conditions making them poor options for the collection of frozen precipitation.

> The liquid content of solid precipitation is determined by melting a sample of the solid precipitation and measuring the resulting liquid.

Once you have measured the depth of daily snowfall on the snowboard, take the large cylinder from the rain gauge and invert it on the snowboard. Push the cylinder down carefully so that it touches the board surface. If the depth of snow is greater than the depth of the overflow cylinder, you may compact the snow in the cylinder. In doing this, be careful that you are not pushing snow out of the path of the cylinder. If the snow is too deep, you may not be able to compact the snow into the cylinder as a single sample. Depending on the size of your snowboard and the depth of the snowfall, there are at least two ways to get that circle of snow into your cylinder:

1. If your snowboard is not too large or too heavy, and if the snow depth can be compacted into the large cylinder, hold the cylinder against the board and invert both the snowboard and the cylinder. This will cause the snow outside the cylinder to fall off the board, so be sure you've made your depth measurement first! The snow trapped in the cylinder can now be taken indoors.
2. If your snowboard is too big or heavy to turn over easily, or if the snow column (even when compacted) will not fit into the cylinder, you will have to carefully transfer the snow into the cylinder (or other container) by hand. Carefully lift the cylinder off the snow column, and you should have a nice circle of snow in the shape of the cylinder. Now carefully scoop the snow from within this circle into your cylinder or other container.

When you have collected your snow from the snowboard, clean the snowboard and again place it into the snow so that the top of the board is even with the top of the snow's surface. Once the snow is inside the cylinder or other container, bring it indoors and allow it to melt. Place a cover over the top of the cylinder to prevent evaporation. When the snow has melted, carefully pour the melt water into the measuring tube of the rain gauge (you may want to use the rain gauge funnel to help), and read the depth of water in the same way you read the rainfall.

It is possible that an overnight snowfall may melt before the daily precipitation measurement is made. If you have left your overflow cylinder outside, you can still report the liquid water equivalent of your snowfall. In this case you would enter "M" for Daily Depth of New Snow. In cases like this, a message can be entered under "Comments" noting that snow fell and melted or blew away.

B. Relative Humidity

Relative Humidity (**RH**) is a measure of how much water vapor is in the air relative to how much water vapor the air can hold.

> Water vapor is a gas which is transparent and cannot be seen. Humidity refers to the amount of water vapor in the air.

- The maximum amount of water vapor the air can hold depends on the temperature.
    - Warm air can hold more water vapor than cold air can.
- When the air is saturated the relative humidity is 100%.
- Clouds are actually suspended liquid water droplets or ice crystals which form when water vapor condenses or freezes onto small dust or other "aerosol" particles.
    - These particles are called "condensation nuclei".
- The dew point temperature is another way to describe the water vapor content of the air.

♦ The dew point temperature is defined as the temperature to which air must be cooled to reach saturation. (The moisture that you may find on the grass early in the early morning is the result of the air close to the ground cooling to its dew point temperature.)

The Sling Psychrometer

The general term for an instrument that measures the water vapor content of the atmosphere is a hygrometer. You will be measuring relative humidity using a specific type of hygrometer called a **sling psychrometer** (Figure 5). This instrument consists of two thermometers mounted side-by-side. One thermometer is covered with a sleeve of cotton fibers, called a wick, which you will wet before taking your relative humidity measurements. This is the **wet-bulb thermometer**. The uncovered thermometer is called the **dry-bulb thermometer** and is used to take the air temperature. Prior to wetting the wick in the wet-bulb thermometer, the temperature reading on both thermometers should be the same.

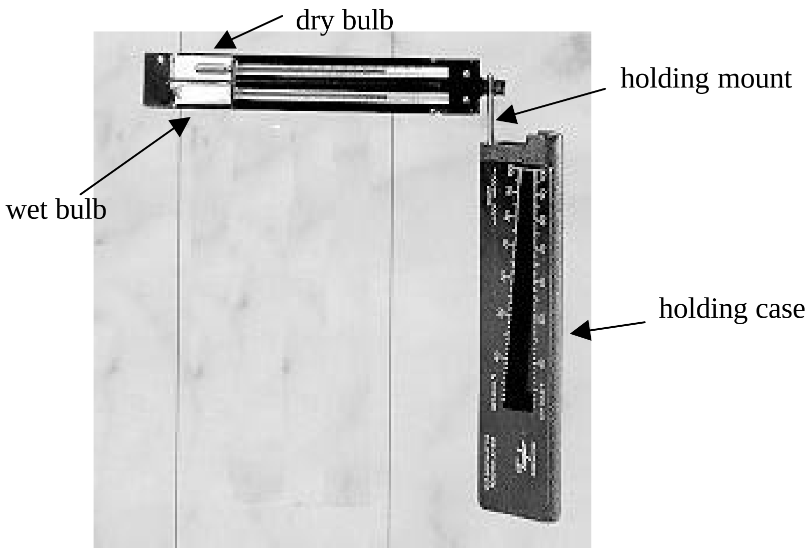


Figure 5. A sling psychrometer.

Photo taken from: http://www.weatheraffects.com/wa/5254.htm

Using the sling psychrometer

The procedure for the sling psychrometer is as follows:

- Slide the arm with the thermometers out of the case **very carefully**. They are easily broken.
- Bend the thermometer holding mount about the holding case to make a right angle (as shown in Figure 5). Note that it only bends in one direction!
- Make sure the temperature reading on both thermometers is the same.
- Wet the wick of the wet-bulb thermometer using approximately room temperature water.
- Twirl the sling psychrometer for about 2 minutes, taking readings every 30 seconds. (Very little wrist movement is needed to twirl the psychrometer.)
- Continue to twirl the psychrometer and take readings about every 30 seconds until the temperature on the wet-bulb thermometer is stable, or starts to rise again.
- Note the **lowest** reading from the wet-bulb thermometer on your data sheet– this is your wet-bulb temperature.
- Note the dry-bulb thermometer temperature on your data sheet.
- **The wet-bulb temperature should always be equal to or less than the dry-bulb temperature!**

Computing Dew Point

Once you have your wet-bulb and dry-bulb thermometer readings, you are ready to calculate relative humidity and dew point. First, subtract the wet-bulb temperature from the dry bulb temperature; this value is known as the **wet-bulb depression**.

dry-bulb temperature – wet-bulb temperature = <u>wet-bulb depression</u>

Using the dew point temperature psychometric table (see Appendix C), find the dry bulb temperature that you measured in the column labeled "dry-bulb temperature" (you may have to round up or down to the nearest temperature on the list). Next, find the wet-bulb depression value under the column labeled "wet-bulb depression". Follow the row with your measured dry-bulb temperature value to the right until it intersects with the column containing the calculated wet-bulb depression value. The number where your dry-bulb temperature value and your wet-bulb depression calculation meet is the dew point.

For example:
If you have a dry-bulb temperature of 27º C and a wet-bulb depression of 5º C, the dew point temperature is 20º C. That is, at the current humidity level, the air would have to be cooled from 27º C to 20º C for saturation to occur (i.e., for clouds to form).

Dew Point Temperature (ºC)
(Pressure = 970 mb)

Air Temp (ºC)	Wet-bulb depression (ºC) 1	2	3	4	5	6	7	8
25	24	22	21	19	18	16	14	13
26	25	23	22	20	19	17	16	14
27	26	24	23	22	20	18	17	15
28	27	25	24	23	21	20	18	16
29	28	26	25	24	22	21	19	18

Excerpt from the Dew Point Temperature Table.

Protocol for making wet-bulb, dry-bulb, and dew point measurements

♦ You should use your sling psychrometer at the same time that you take your rain gauge reading.

- The sling psychrometer should be used in a shaded area so that the direct sunlight does not affect the reading on the dry-bulb thermometer.
- Be sure to stand away from solid objects (including people!) so you don't accidentally hit the psychrometer and break the thermometers.
- Check the wick on the wet-bulb thermometer at least once each month to see if it is still in good shape. If the wick starts to fray, please contact your local Weather Service Office and they will send you a replacement wick.

C. Maximum/Minimum Temperature

Meteorologists are interested in several types of temperature measurements. One is the **current temperature**, that is, air temperature measured at a particular time each day. **Maximum temperature** typically refers to the highest temperature reached during a 24-hour period (generally taken from one current temperature reading to another). Likewise, the **minimum temperature** typically refers to the lowest temperature that was reached within the same 24-hour period.

> Temperature is simply a measure of how hot or cool something is.

When we think of how places around the world are different from one another, several things may come to mind. We may describe differences in terms of food, culture, technology, or any number of other variables. However, we would almost certainly describe variations around the globe in terms of temperature. Who can think of the North or South Pole without associating it with cold, or think of the tropics without associating it with warmth? Even our concern with climate change is now being expressed by the phrase "global warming," which instantly implies a change in temperature (even though things such as rainfall will likely change in response to climate change).

By measuring temperature in one place regularly, we will be able to tell how much the temperature varies from season to season from year to year (ie, we want to know if this summer was warmer or cooler than last summer or if winters are becoming colder than they were five to ten years ago). Keeping accurate global temperature records can help keep track of any systematic changes in the Earth's atmosphere. Current theories predict a slow warming of the Earth due to increasing amounts of certain gases in the atmosphere, much of which come from human activities. By monitoring the changes in the atmosphere over time we can test the validity of the predictions.

The Maximum/ Minimum Thermometer

The maximum/ minimum thermometer used by SPaRCE participants is a U- shaped tube with two indices that indicate the maximum and minimum temperatures (See Figure 6). On the Max side, the temperature is such that the temperature increases as you go from the bottom to the top (like a normal thermometer). However, on the Min side, the scale shows the temperature **decreasing** as you go from the bottom to the top. As the temperature increases, the indicator on the Max side is pushed upwards. When the maximum temperature of the day has been reached and it begins to cool off, the mercury on the Max side will begin to fall; however, the indicator will remain in place marking the high temperature of the day. Similarly, as the temperature drops, the indicator on the Min side will begin to rise. When the minimum temperature has been reached and it begins to warm up again, the mercury on the minimum side will fall, leaving the indicator to mark the low temperature of the day. (**Be sure to read the temperature at the bottom of the indicator!!**)

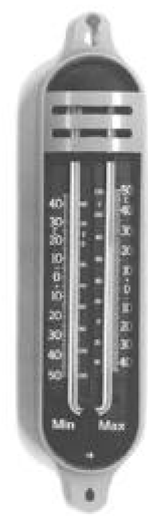


Figure 6.
Max/Min
Thermometer

IMPORTANT!
Please note that should the mercury column become separated in transit, hold the thermometer firmly at the top and swing steadily at arms length and away from others, gradually forcing the mercury back together. If this doesn't work, try gently tapping the thermometer against the palm of your hand to bring the mercury back together.

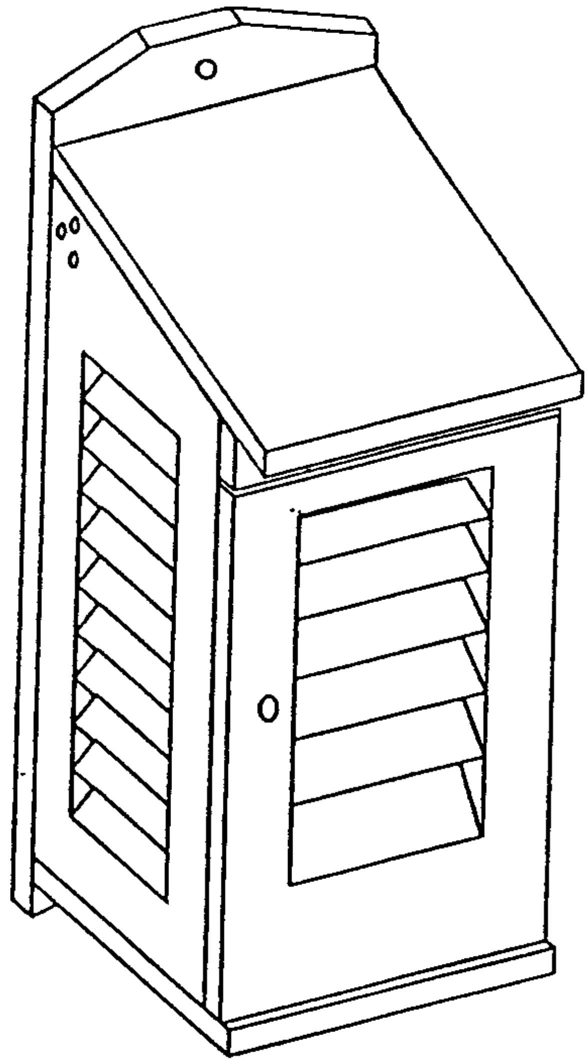
In order to get accurate readings, the maximum/ minimum thermometer must be protected from direct sunlight, blowing debris, and rain. To properly accomplish this, the thermometer should be mounted in an instrument shelter so that the thermometer is about 1.5 meters above the ground (or 0.6 meters above the average snow depth, whichever is higher). The shelter protects the thermometer from radiation from the sun, sky, ground, and any other surrounding objects. At the same time, the shelter will allow air flow through so that the temperature sensed by the thermometer is an accurate representation of the actual air temperature outside the shelter.

The thermometer should be mounted in the shelter so that there is air flow all around the thermometer case. No part of the thermometer should be in direct contact with the walls, floors or ceiling of the shelter.

The shelter should be placed in an area similar to (or in the same place as) the location of the rain gauge and snow boards. Shelters should be mounted on a post which is secured in the ground as firmly as possible to eliminate vibrations. (Strong winds could cause vibrations which would displace the indicators, resulting in erroneous readings.) It should also be situated so that the shelter door faces the north in the Northern Hemisphere and the south in the Southern Hemisphere to minimize exposure of the thermometer to direct sunlight when the door is open and the daily temperature is taken.

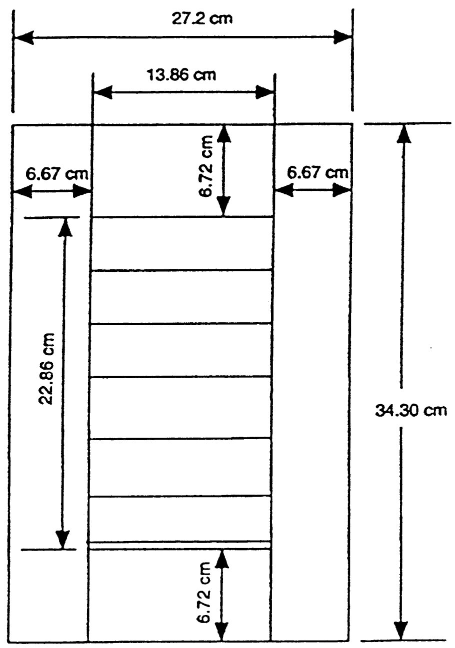
Instructions for building an instrument shelter are included on the following pages. Here are some helpful tips and advice:

- The instrument shelter is best constructed of 1.9 cm white pine, and painted white both on the inside and outside (to maximize the amount of sunlight that it reflects), noting that the paint should be touched up when needed and the shelter dusted occasionally with a dry cloth.
- A lock may be installed to prevent tampering with the instruments.
- Mounting blocks should be installed in the interior to ensure that the maximum/ minimum thermometer does not touch the walls. (That is, small blocks of wood can be mounted on the back inside wall of the shelter. The thermometer is then screwed into these blocks. Using the mounting blocks keeps the thermometer out of direct contact with the shelter walls, and also allows for air to flow freely all around the thermometer.)
- The door should be hinged on the right side.
- The parts should be screwed together.
- The plans are specified in metric units. (However, conversion to inches should result in standard wood thickness and drill sizes.)

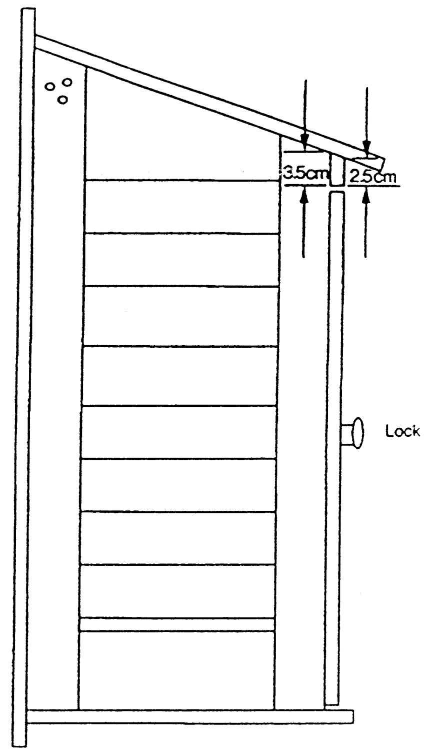


Instrument Shelter

Instrument Shelter Plans

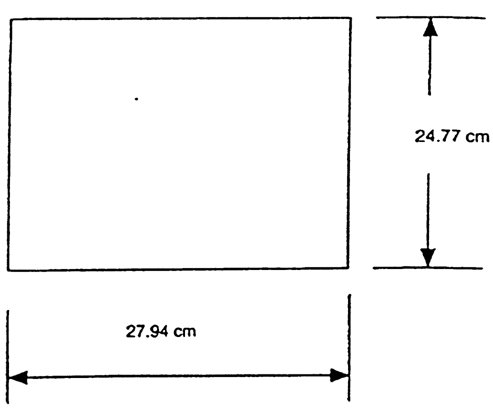


Front Door

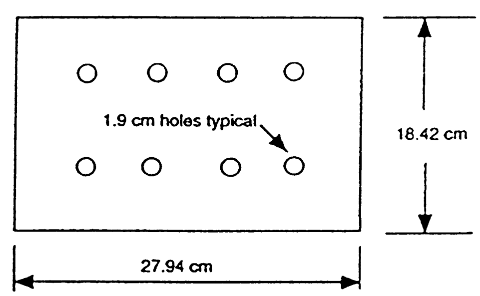


Side View

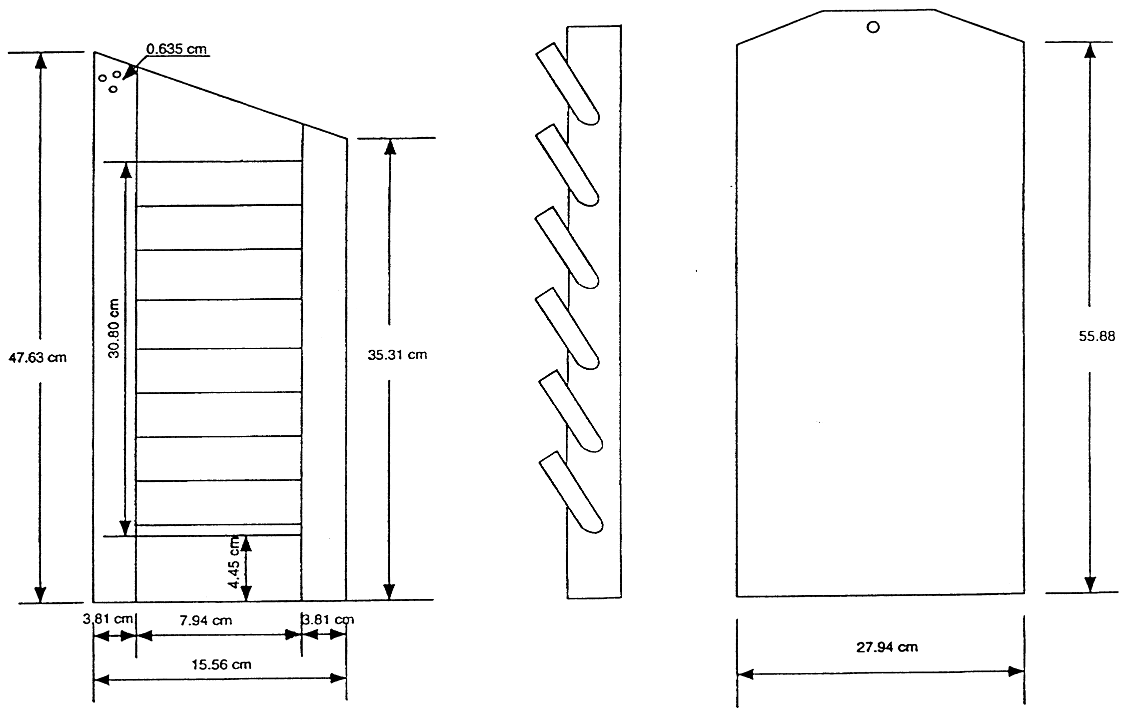
Note: Louvers are 0.64 cm thick and 4.13 cm wide



Roof



Bottom



Side panel Louvre Detail Back

Calibration of the Maximum/ Minimum Thermometer

When you receive your maximum/ minimum thermometer you should first make sure that the column of mercury is continuous (sometimes during shipping the mercury column can separate into segments). If there are gaps in the mercury column, grasp the thermometer by the case, making sure the thermometer is in an upright position, and swing or gently shake the case until the mercury forms a continuous column. Make sure to not press against the stem of the thermometer as this could cause it to break.

Next, make sure that the temperature indicated by the tops of the mercury columns on both the Max and the Min side are the same (don't forget to take the reading from the **bottom** of the indicators). Both sides of the thermometer should give you the same current temperature reading. If they do not, you will need to calibrate the thermometer before knowing which is the correct temperature to adjust to. Even if both sides of the thermometer give the same reading, it is a good idea to check the temperature with an independent source (ie, another thermometer) to be sure you are getting an accurate reading.

To calibrate the maximum/ minimum thermometer you can either compare it with a standard thermometer at you local Weather Service Office or some other thermometer. This calibration thermometer should be a typical, liquid filled, single-tube thermometer which can record temperatures at least as low as -5ºC. The calibration thermometer itself must first be tested for accuracy by placing it in an ice water bath.

To use the ice water bath method, prepare a mixture of 1 part liquid water to 1 part crushed ice. Let the bath to sit for 10 – 15 minutes to allow it to reach its lowest temperature. The bulb of your calibration thermometer should then be placed in the bath for approximately 2 minutes. It should read between 0.0 and 0.5ºC. If it does not, then it is not a reliable check for your maximum/ minimum thermometer, and another thermometer should be used.

Once you are confident in the accuracy of you calibration thermometer, it should be hung by a hook in the instrument shelter with the max/ min thermometer. After 24 hours, compare the temperature in the calibration thermometer with the current temperature on the max/ min thermometer. If they differ by more than a degree, they should be adjusted to the calibration thermometer by adjusting the temperature scales on the max/ min thermometer. (Note that the temperature scales on both sides of the thermometer can be adjusted by loosening the small screw located on the back of the thermometer. Once this screw is loosened, the scales can slide up or down independently of each other.)

Making Temperature Readings

The maximum/ minimum temperature readings should be taken at the same time each day, preferably at the same time you take your rain gauge readings. As with rainfall measurements, consistency in recording the data is extremely important. When reading the thermometers, stand as far from them as possible to prevent body heat from changing the current temperature reading – this is especially important in cold weather. Likewise, do not touch the temperature-sensing parts of the thermometer as this too may affect the current temperature reading. Here are some points to remember while you're taking your daily temperatures:

- The current daily temperature should be read from the top of the **mercury column** (don't confuse the current daily temperature and the maximum temperature).
- Take the maximum and minimum readings from the **base of the indicators**.

- Make sure that your eyes are level with the top of the mercury column (if you are taking the current daily temperature) or the base of the indicators (if you are taking the max/ min temperature). If you don't do this, your reading will be too high or too low.
- Reset the indicators on the max/ min thermometers once the temperatures have been read. This is done by taking the small magnet at the base of the thermometer and dragging the indicators down until they are sitting on top of the mercury column.
- To avoid losing the magnet, it is a good idea to attach it to the thermometer or the shelter with a piece of string.

If a temperature observation is missed, the indicators should be reset (using the magnet) and only the current temperature should be recorded at the next observation. This is done because if more than 24-hours has elapsed between readings, we have no way of knowing what day the maximum and minimum temperatures occurred.

D. Cloud Type and Cloud Cover

Both cloud type and amount of cloud cover should be recorded at the same time you take your other measurements (rainfall, wet- and dry-bulb temperature, max/min temperature, and current temperature).

> A cloud is a visible aggregate of tiny particles of water, ice, or both in the free air. This aggregate may include larger particles of water and ice, aerosols, or solid particles that are present in things such as fumes, smoke, or dust.
> Cloud cover refers to the amount of sky which is covered by clouds.

Cloud cover

To estimate cloud cover, you need to be outside and have an unobstructed view of the entire sky. Cloud cover should be reported according to the following classifications:

clear – sky is cloudless or cloud cover averages less than one-tenth of the sky,

scattered clouds – an average of one-tenth through five-tenths (one-half) of the sky is covered by clouds,

broken clouds – an average of six-tenths through nine-tenths of the sky is covered by clouds,

overcast – more than nine-tenths of the sky is covered by clouds.

In reality, even seasoned observers have a difficult time in accurately estimating cloud cover (and cloud type for that matter!), particularly in distinguishing between scattered and broken cloud cover. The general rule-of-thumb to use to help decide which of these is correct is that if you see more blue sky than clouds, then the cloud cover is considered to be scattered; if you see more clouds than blue sky, then the cloud cover is broken. Only one of the four categories should be reported daily.

Cloud type

Determining cloud type requires a relatively unobstructed view of the entire sky as well. Refer to your cloud chart and the following definitions to help you determine which types of clouds are present when you are making you observations. Keep in mind that: more than one cloud type can be reported and you don't need to estimate the **amount** of each type of cloud, just each **type** that you observe.

Clouds are characterized by their appearance and their altitude in the atmosphere.

High Clouds

- **Cirrus**
- **Cirrocumulus**
- **Cirrostratus**

Cirrus

Detached clouds in the form of white, delicate filaments or white or mostly white patches or narrow bands. These clouds have a fibrous (hair-like) appearance, or a silky sheen, or both.

Cirrocumulus

Thin, white patch, sheet or layer of cloud without shading, composed of very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged. Most of the elements have an apparent width of less than one degree (approximately the apparent width of the little finger at arm's length).

Cirrostratus

Transparent, whitish cloud veil of fibrous or smooth appearance, totally or partly covering the sky, and generally producing halo phenomena.

Middle Clouds

- **Altocumulus**
- **Altostratus**
- **Nimbostratus**

Altocumulus

White or gray, both white and gray, patch, sheet or layer of cloud, genera1ly with shading, composed of laminae, rounded masses, rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged. Most of the regularly arranged small elements usually have an apparent width of between one and five degrees (five degrees is approximately the apparent width of three fingers at arm's length.)

Altostratus

Grayish or bluish cloud sheet or layer of striated, fibrous or uniform appearance, totally or partly covering the sky, and having parts thin enough to reveal the sun at least vaguely, as through ground glass. Altostratus does not show halo phenomena.

Nimbostratus

Grey cloud layer, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. It is thick enough to blot out the sun. Low, ragged clouds frequently occur below the layer; with which they may or may not merge.

Low Clouds

- **Stratocumulus**
- **Stratus**
- **Cumulus**
- **Cumulonimbus**

Stratocumulus

Grey or whitish, or both gray and whitish, patch, sheet or layer of cloud which almost always has dark parts, composed of tessellations, rounded masses, rolls, etc., which are non-fibrous (except for virga) and which may or may not be merged. Most of the regularly arranged small elements have an apparent width of more than five degrees.

Stratus

Generally gray cloud layer with a fairly uniform base, which may give drizzle, ice prisms or snow grains. When the sun is visible through the cloud, its outline is clearly discernible. Stratus does not produce halo phenomena except, possibly, at very low temperatures. Sometimes Stratus appears in the form of ragged patches.

Cumulus

Detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes or towers, of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white; their base is relatively dark and nearly horizontal. Sometimes Cumulus is ragged.

Cumulonimbus

Heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or huge towers. At least part of its upper portion is usually smooth, or fibrous or striated, and nearly always flattened; this part often spreads out in the shape of an anvil or vast plume. Under the base of this cloud which is often very dark, there are frequently low ragged clouds either merged with it or not, and precipitation sometimes evaporates before reaching the ground.

IV. Receiving Your Instruments

You should have received your rain gauges at approximately the same time you received this workbook. If you have not received your rain gauges, and do not receive them within a week after receiving this book, please contact your local Weather Service Office as soon as possible. We urge you to set up your rain gauges as quickly as is convenient and begin taking measurements. The remainder of the workbooks and videos will be sent to you on a regular basis.

Once your rain gauges are set up and you begin to send data in on a regular basis, we will send you a sling psychrometer so you can begin taking wet- and dry-bulb measurements. After you've had time to get used to the sling pshychrometer and are sending in data regularly, we will send you the max/ min thermometer. The instruments will come to you over a period of time to allow you to become familiar, experienced, and comfortable with them and not overwhelmed by them. However, feel free to begin taking cloud cover and type observations as soon as you get the necessary materials (this workbook and a cloud chart which will be sent to you in one of the early shipments of materials).

Appendix D is a data sheet like the one that you will be recording your observations on and sending to the Weather Service. Try to follow the format shown in the sample data sheet, and remember to write as neatly as you can. Generally, one data sheet should be sufficient for each month. You will be receiving new data sheets on a regular basis, but if you need more, please contact your local Weather Service.

On a monthly basis, you will need to send your completed data sheets (**complete with site name, site ID, school name, school location, month and year, and the latitude and longitude of your site**) to your local Weather Service Office where they will send the data to SPaRCE headquarters for analysis.

We thank you for being a part of this program. We hope you have fun while learning more about the world around you!

APPENDIX A

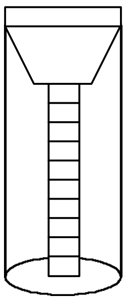
Local Weather Service Office Contacts

American Samoa Mr. Leilua Akapo Akapo Meteorologist - Warning and preparedness National Weather Service PO Box 789 Pago Pago	Tel: (684) 699-9130 Fax: (684)699-1550 E-mail:Akapo.Akapo@noaa.gov or: scape39@.hotmail.com
Cook Islands Mr. Arona Ngari Director Cook Islands Meteorological Service PO Box l27 Rarotonga	Tel: (682) 20-603 Fax: (682) 21-603 E-mail:angari@met.co.ck
Federated States of Micronesia Mr. Akira Suzuki Official in Charge/Coordinator FSM Weather Service Office PO Box 69 Kolonia Pohnpei FM 69641	Tel: (691) 320-2248 Fax: (691)320-5787 E-mail:weather@mail.fm
Chuuk	
Kosrae	
Yap	
Fiji Fiji Meteorological Service Private Mail Bag (NAP0351) Nadi Airport	Tel: (679) 724-888 Fax: (679) 720-430
Kiribati Mr. Tekena Teibita Director Meteorological Service PO Box 486 Tarawa	Tel: (686)26-5l1 Fax: (686) 26-089 E-mail:kirmet@tskl.net.ki

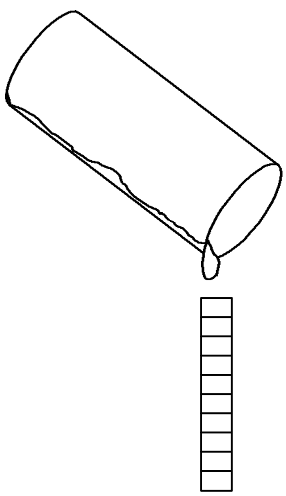
Nauru Mr. Nicholas Duburiya Officer-in-Charge ARM Project Department of Island Development and Industry Government Offices PO Box 184 Yaren District	Tel: (674) 444-3276 Fax: (674) 444-3278 E-mail: Arcsz@cenpac.net.nr
Niue Mr. Sionetasi Pulehetoa Manager Niue Meteorological Service PO Box 82 Alofi	Tel: (683) 4600/4601 Fax: (683)4602 E-mail: manager.met@mail.gov.nu
Palau Weather Service Office PO Box 520 Koror Palau 96940	Tel: (680) 488-1034 Fax: (80)488-1436 E-mail: Wso.koror@Palaunet.com
Papua New Guinea Mr. James Nako Director PNG National Weather Service PO Box 1240 Boroko	Tel: (675) 325-2788 Fax: (675)325-2740/5201 E-mail: pngnws@daltron.com.pg
Samoa Mr. Faatoia Malele Chief Executive Samoa Meteorological Services Division PO Box 3020 Apia	Tel: (685) 20-855 Fax: (685) 20-857 E-mail: meteorology@samoa.net
Solomon Islands Mr. Chanel Iroi Acting Director Solomon Islands Meteorological Service PO Box 2l Honiara	Tel: (677) 21-757/18 Fax: (677) 20-046 E-mail: met@welkam.solomon.com.sb

Tonga Mr. Paea Havea Chief Meteorology Officer Tonga Meteorological Service Ministry of Civil Aviation and Meteorological Service PO Box 845 Nuku'alofa	Tel: (676)23-401 Fax: (676) 24-145 E-mail: tongamet@candw.to or: tongamet@kalianet.to
Tuvalu Ms. Hilia Vavae Director Tuvalu Meteorological Service Ministry of Works, Energy and Communication Private Mail Bag Funafuti	Tel: (688) 20-736 Fax: (688) 20-009 E-mail: tuvmet@ibm.net
Vanuatu Mr. Wilson T. Vuti Director Vanuatu Meteorological Service Private Mail Bag 054 Port Vila	Tel: (678) 22-331/932/23-866 Fax: (678)22-310 E-mail: meteo@vanuatu.com.vu

APPENDIX B
Rainfall Measurement Summary

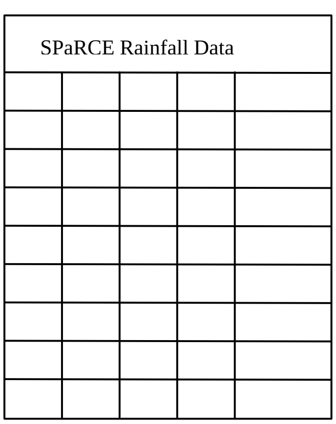


- Check the gauge at the same time each day, even if you know that no rain has fallen in the past 24 hours.



- If so much rain has fallen that the center tube is full and rain has overflowed into the outer container, carefully pour the water from the outer tube into the measuring tube and add up the total amount that has fallen.

- Enter the date, time, and total rainfall amount on your data sheet.



- Send your data in monthly!

Wet-bulb Temperature, Dry-bulb Temperature, and Dew Point Measurement

Summary

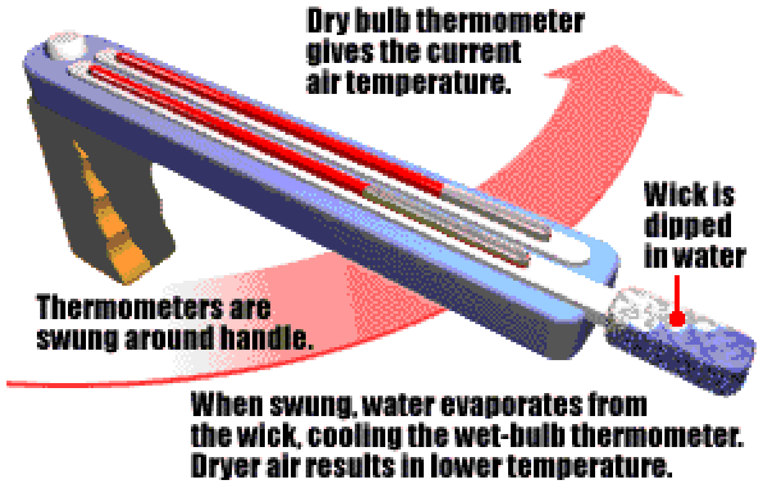


Photo taken from: http://www.indiana.edu/~geog109/topics/humidity/humidity.htm

- Carefully pull the thermometers out of the protective case.
- Wet the wick on the wet-bulb thermometer.
- Gently twirl the psychrometer until the wet-bulb thermometer has reached a stable temperature.
- Record the wet-bulb and dry-bulb temperatures on your data sheet.
- Take the difference between the dry-bulb temperature and the wet-bulb temperature.
- Use the psychrometric tables (Appendix ?) to determine the dew point and record that value on your data sheet.

Appendix D
GLOSSARY:
Environmental Science and Weather Definitions

Acid Deposition is precipitation (rain, snow, etc.) made acidic by the addition of sulfur dioxide and nitrogen oxides into the atmosphere as a result of fossil fuel burning. Automobile exhaust and emissions from coal-fired power plants are two significant causes of acid deposition. In severe cases, acid precipitation kills fish and other aquatic life and damages and/or destroys trees and crops. In some instances, it has rendered entire lakes and forests nearly lifeless.

Advection is horizontal transport of any property, such as heat or humidity

Aerosol is a gaseous suspension of fine solid particles.

Albedo is the fraction of light reflected by a surface, often expressed as a percentage. Light colored surfaces, such as snow and ice, have a high albedo, while dark, light-absorbing surfaces have a low albedo.

Anthropogenic means caused or created by human beings. For example, anthropogenic carbon dioxide emissions are those caused by human activities such as burning fossil fuels.

Atmosphere is the envelope of gases that surrounds a planet. Earth's atmosphere is one of five interrelated components that make up the Earth system. The other four are the biosphere, hydrosphere, cryosphere, and pedosphere, which are defined below.

Atmospheric Pressure is the force exerted by the air on each unit of area of a surface, essentially equivalent to the weight of the overlying atmosphere. High atmospheric pressure generally leads to stable weather conditions while low pressure can result in storms.

Atom is the smallest unit of a chemical element that can take part in a chemical reaction. An atom is composed of a nucleus containing protons and neutrons, and is surrounded by electrons.

AVHRR stands for Advanced Very High Resolution Radiometer; the imagery produced by NOAA (National Oceanographic and Atmospheric Administration) satellites. Pixel size is 1km x 1km for local area coverage ('AC) and 2km x 2km for global area coverage (GAC).

Barometer is an instrument used to measure atmospheric pressure.

Biodiversity refers to the total number of biological species in a particular area.

Biomass is the total dry weight of living material in a particular area.

Biome is a distinctive ecological system, characterized primarily by the nature of its vegetation.

Biosphere refers to the region on land, in the oceans and in the atmosphere inhabited by living things.

Biota refers to all living things, including animal and plant life.

Blizzard is snow falling with winds faster than 35 miles per hour and visibility of a quarter mile or less over an extended time period.

Business-as-usual, in the context of global climate change, refers to a scenario for future world patterns of energy use and greenhouse gas emission which assumes that there will be no significant change in people's attitudes and priorities.

Carbon cycle is the exchange of carbon between land, atmosphere and oceans. About one quarter of the total carbon (in the form of carbon dioxide) in the atmosphere is cycled in and out each year; half of this is exchanged with the land biota, and the other half, through physical and chemical processes, across the ocean's surface.

Carbon dioxide ($C0_2$) is one of the major greenhouse gases. Anthropogenic $C0_2$ results mainly from burning fossil fuels (coal, oil, gas) and from deforestation.

Celsius is a temperature scale, also called the Centigrade scale. Its fixed points are the freezing point of water (0°C) and the boiling point of water (100^0C). To convert from Celsius to Fahrenheit, multiply the Celsius temperature by 1.8 and add 32°.

Chlorofluorocarbons (CFCs) are synthetic compounds which destroy stratospheric ozone and are also greenhouse gases. The primary use of CFCs today is as a coolant in refrigerators and air conditioners. CFCs are also used as solvents, foam blowing agents and aerosol propellants, though the use of CFCs in aerosol cans in the U.S. was outlawed 15 years ago. Substitutes for CFCs are under development, and some are already available. The Montreal Protocol for the Protection of the Ozone Layer is an international agreement that requires that parties to the convention in developed nations phase out CFCs by 1996.

Climate refers to the temperature, humidity, precipitation, winds, radiation, and other meteorological conditions characteristic of a locality or region over an extended period of time. Compared to weather; climate involves longer times and deals not only with the atmosphere, but also with oceans, land and biosphere.

Climate Sensitivity refers to the size of the climate change expected to result from a change in external influences. One description of climate sensitivity is the global average temperature rise expected to result from a doubling of carbon dioxide in the atmosphere.

Cloud is a visible mass of condensed water vapor (liquid or ice) particles.

Compound is a substance formed from two or more elements chemically combined in fixed proportions.

Condensation is the process of changing state from gas to liquid.

Condensation Nuclei are small particles in the air that attract water and encourage condensation.

Convection generally refers to vertical motion in the atmosphere or ocean generated by temperature difference and resulting in the transfer of heat.

Cryosphere is one of the five interrelated components of the Earth system. It is that portion of the Earth's surface with average temperatures below the freezing point of water. The bulk of the cryosphere is at or near the poles, but cryospheric regions also exist atop high mountain ranges on all continents. The cryosphere is composed of snow, permanently frozen ground (permafrost), floating ice, and glaciers.

Deforestation is destruction of forests, usually by cutting or burning. Deforestation enhances the greenhouse effect in two ways. First, when wood is burned or decomposes, it releases carbon dioxide. Second, trees which are destroyed can no longer serve their function of removing carbon dioxide from the atmosphere in the process of photosynthesis.

Demography is the study of the nature and structure of human populations including their distribution, age structure, composition, life styles, and change.

Desertification is degradation of land characterized by reduced soil moisture and vegetation including crops, and by soil erosion. Like deforestation, desertiflcation can affect climate in several ways, including by altering the water cycle.

Developing Countries, sometimes called less developed countries (LDCs) or "Third World," generally means low-income nations, usually with little industrialization, often accompanied by high rates of illiteracy and pool public health. Most developing countries are in the southern hemisphere.

Dew Point is a measure of humidity, given in terms of the air temperature at which dew begins to form, as water vapor condenses into liquid.

Dobson Units (DU) is the standard way to express ozone amounts. Ozone varies with latitude and season, typically ranging from about 250 to 460 Dobson units. Dobson was a researcher at Oxford University who, in the late 1920s built the first instrument, now called the Dobson meter, for measuring total ozone from the ground.

Drought is a period of abnormal dryness for a particular region.

Drylands are areas of the world where precipitation is low and where rainfall consists of small, erratic, short, high-intensity storms.

Ecology is the science that deals with the study of the interrelationships between living organisms and their environments.

Ecosystem refers to a distinct system of interdependent plants and animals, along with their physical environment. An ecosystem may be as large as the entire Earth, or as small as a pond.

Earth Observing System (EOS) refers to a series of small- to intermediate- sized spacecraft that is the centerpiece of NASA's Mission to Planet Earth. Planned for launch beginning in 1998, each of the EOS spacecraft will carry a suite of instruments designed to study global change.

El Niño is a warming of the surface waters of the eastern equatorial Pacific that occurs at irregular intervals of 2 to 7 years, usually lasting 1 to 2 years, which has a significant influence on regional and glob4 climate. El Niño has been linked to colder; wetter winters in parts of the U.S., drier hotter summers in South America and Europe, and drought in Africa, as well as reduced numbers of fish in South American coastal waters.

El Niño-Southern Oscillation (ENSO) refers to the combined effects of El Niño (see above) and a global-scale shift in atmospheric pressure called the Southern Oscillation. In the warm phase of ENSO, El Niño warming extends over much of the tropical Pacific and becomes clearly linked to the SO pattern. Many of the countries most affected by ENSO events are developing countries with economies that are largely dependent upon their agricultural and fishery sectors as a major source of food supply, employment and foreign exchange. New capabilities to predict the onset of ENSO events can thus have important human impacts. While ENSO is a natural part of Earth's climate variability, whether its intensity or frequency may change as a result of global warming is a concern.

Electromagnetic Spectrum is a continuum of all kinds of electric, magnetic, and visible radiation.

Electron is a negatively charged component of an atom.

Element refers to any substance that cannot be separated by chemical means into two or more simpler substances.

Endemic means naturally occurring *only* in a certain region, as in a species that is endemic to a particular place.

Environment is the complex of physical, chemical and biological factors in which a living organism or community exists.

Environmental refugees are people obliged to leave their traditional or established homelands due to environmental problems (deforestation, desertification, floods, drought, sea-level rise, nuclear plant accidents), on a permanent or semi-permanent basis, with little or no hope of ever returning. Though no formal accounting has been taken, there may currently be about 25 million environmental refugees in the world, according to one estimate.

Equator is an imaginary circle around the Earth that is equally distant from the North and South Poles and defines the latitude 00.

Eutrophication is the process by which a body of water becomes rich in dissolved nutrients through human-created or chemical processes (such as runoff laden with chemical fertilizers used in agriculture). This often results in a deficiency of dissolved oxygen, producing an environment that favors plant over animal life.

Evaporation is the process of changing state from liquid to gas.

Evapotranspiration is the discharge of water from Earth's surface to the atmosphere by evaporation from bodies of water, or other surfaces, and by transpiration (the process by which water is taken up by roots and released as water vapor by leaves) from plants.

Exotic means originating outside of an area, such as an exotic species.

Fahrenheit is a temperature scale based on water freezing at 32^0F and boiling at 212^0F under standard atmospheric pressure. To convert from Fahrenheit to Centigrade, subtract 32º from the
Fahrenheit temperature and divide the resulting quantity by 1.8.

Feedback refers to a sequence of interactions in which the final interaction influences the original one. In such a sequence, a cause produces a result, and the result then in turn influences its cause. For example, by one estimate, global warming is expected to increase air conditioner use in the U.S. enough to require 86 additional power plants by the year 2010. The burning of fossil fuels in those power plants would in turn cause more global warming, causing more air conditioner use, causing more warming, and so on, in a positive feedback loop. As a system changes, it may generate processes that affect the original change. If one of these processes amplifies the change (such as increasing global warming in the above example) we call it a positive feedback. If it dampens the change, we call it a negative feedback.

Food Chain refers to a series of plants and animals that depend upon each other as food sources (i.e., a plant is eaten by a small fish, which is eaten by a larger fish, which is eaten by a bird, and so on).

Fossil is the hardened remains or traces of plant or animal life from a previous geological period preserved in the Earth's crust.

Fossil Fuels such as coal, oil, and natural gas are created by the decomposition of ancient animal and plant remains. They are finite (limited) resources, and release carbon dioxide and other gases when burned.

Gaia Hypothesis is the idea, developed by James Lovelock, that Earth's systems behave as a single living entity striving to maintain health and stability conducive to the existence of life.

General Circulation Models (GCMs) are computer models of Earth's climate that are used to improve our understanding of factors that influence climate and enhance our ability to forecast future climate patterns. One reason GCMs are so useful is that they allow researchers to turn individual variables on and off and observe the results, isolating factors in a way that is not possible in the physical world.

Geoengineering refers to artificial modification of Earth systems to counteract anthropogenic effects such as global warming or stratospheric ozone depletion. An example of geoengineering aimed at reducing global warming is the "iron hypothesis," which suggests that adding iron to the oceans could stimulate the growth of algae which would photosynthesize, thus taking carbon dioxide from the atmosphere. In general, geoengineering proposals would be costly and logistically difficult, and before they were undertaken, it would be prudent to be certain that unanticipated adverse consequences would not occur.

Geographic Information System (GIS) uses computers to combine remote sensing data with other information (e.g., topographic, political, cultural, economic, ground truth). In essence, a GIS is a way of managing Earth science data to bring out geographical interrelationships.

Geosphere refers to the physical elements of the Earth's surface, crust and interior.

Geostationary or geosynchronous describes an orbit in which a satellite is always in the same position with respect to the Earth. The satellite travels around the Earth, in the same direction and at the same speed as the Earth's rotation, completing one orbit in a 24-hour period. All geostationary satellites are directly above Earth's equator and are at the same altitude.

Geothermal Energy is energy obtained by the transfer of heat to Earth's surface from its depths. A natural hot spring is one such example.

Glacier is a multi-year accumulation of snowfall in excess of snow melt on land, resulting in a mass of ice covering at least a tenth of a square kilometer, that shows some evidence of movement in response to gravity Glacier ice is the largest reservoir of fresh water on Earth, and second only to the oceans as the largest reservoir of total water. Glaciers are found on every continent except Australia.

Global Change refers to change to the Earth system which is either a global phenomenon or that occurs regionally, but strongly enough and often enough to be of global significance. The leading current global change issues include climate change due to an enhanced greenhouse effect, stratospheric ozone depletion, acid precipitation, urban air pollution, and loss of biodiversity.

Global Positioning System (GPS) is a constellation of satellites whose purpose is to provide accurate position location and navigation anywhere on Earth.

Global Warming is a term used to describe a predicted warming of Earth's climate due to increased concentrations of greenhouse gases in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC), composed of many of the world's leading authorities on the subject, estimates that if atmospheric $C0_2$ doubled, global average temperature would eventually increase by 1.5º to 4.5^0C (about 3^0-8^0F) with a "best guess" of 2.5^0C (4^0F). The IPCC also estimates that about half of this warming will have occurred by the year 2030:

Green Revolution refers to a dramatic increase in food production, primarily as a result of the development of new strains of crops.

Greenhouse Effect is the natural process whereby gases in Earth's atmosphere act like the glass in greenhouse, letting the Sun's energy in, but keeping some of it from going back out. Were it not for this natural effect, Earth's climate would be about 33^0C (60^0F) colder, and life as we know it would not exist. The "enhanced greenhouse effect" refers to an increase in this natural heat-trapping phenomena caused by anthropogenic emissions of greenhouse gases.

Greenhouse Gases are water vapor, carbon dioxide, methane, tropospheric ozone, nitrous oxide, CFCs, and other gases which absorb some of the long wave thermal radiation emitted from Earth's surface, thereby warming the atmosphere. With the exception of water vapor, these are also called "trace gases" since they total less than 1% of the atmosphere.

Ground Truth is the collecting of information on Earth's surface at the same place and time as a remote sensor gathers data. Ground truth information is used to interpret and calibrate remotely sensed data from satellites.

Gulf Stream is a warm, swift ocean current that flows from the Gulf of Mexico, along the coast of the Eastern U.S., across the Atlantic to the European coast, and makes Ireland, Great Britain and the Scandinavian countries warmer than they would be otherwise.

GWP stands for Global Warming Potential, and is the ratio of how much a gas contributes, molecule for molecule, to enhancing the greenhouse effect compared to carbon dioxide.

Habitat refers to the environment in which an individual or population occurs.

Hail is precipitation composed of lumps of ice. Hail is produced when large frozen raindrops or other particles in cumulonimbus clouds, grow by accumulating supercooled liquid droplets. Violent updrafts in the cloud carry the particles up through the freezing all; allowing the frozen core to accumulate more ice. when the piece of hail becomes too heavy to be carried by rising air currents, it falls to the ground.

Halocarbons are halons, chlorofluorocarbons, hydrochlorofluorocarbons, and other chemicals that deplete the stratospheric ozone layer. The term halocarbons is used in the Montreal Protocol on Substances that Deplete the Ozone Layer

Humidity is the amount of water vapor in the air. The higher the temperature, the greater the number of water molecules the air can hold. "Relative humidity" describes the amount of water in the air compared with how much the air can hold at the current temperature. For example, 50% relative humidity means the air holds half the water vapor it is capable of holding.

Hurricane is a severe tropical storm whose winds exceed 74 miles per hour. Hurricanes originate over the tropical and subtropical North Atlantic and North Pacific oceans, because high sea surface temperatures are essential to their formation.

Hydrochlorofluorocarbons (HCFCs) are replacements for chlorofluorocarbons (CFCs) which are less ozone-depleting than CFCs but not totally ozone-safe. HCFCs are also greenhouse gases, contributing to global warming.

Hydrologic Cycle refers to the natural sequence through which water evaporates from the ocean, land surface, and plants into the atmosphere as water vapor, falls to Earth as precipitation, and largely returns to the ocean through pathways including rivers and ground water.

Hydrosphere is one of the five interrelated components of the Earth system and consists of all of Earth's waters including the oceans, fresh waters, and water vapor in the atmosphere.

Ice Age is a geological time period during which sheets of ice cover extensive parts of the Earth.

Image resolution has to do with the level of detail in an image and is determined by the area represented by each pixel (picture element). The smaller the area represented by a pixel, the more detailed the image. For example, if a U.S. map and a world map are printed on the same size paper, one square inch on the U.S. map will represent far less area and provide far more detail than one square inch of the world map. The U.S. map would thus be said to have higher resolution.

Indigenous means naturally occurring in an area, such as an indigenous species.

In Situ is Latin for "in original place" and usually refers to data collected at the actual location of the object or material measured, as opposed to remote sensing.

Insolation is the solar radiation falling upon a particular horizontal surface on or above Earth's surface.

Ion is an atom or molecule that has acquired an electric charge by the loss or gain of one or more electrons.

Isothermal means of or indicating equality of temperature. Isotherms are lines connecting points of equal temperature on a weather map.

Kilometer is a metric unit of distance equal to 3,280.8 feet or 0.621 miles.

Landsat is the name for a group of five satellites dedicated to applying remote sensing techniques to the inventory, monitoring, and management of Earth's natural resources. The Landsat system currently uses two sensors: multispectral scanner (MSS) and thematic mapper (TM).

Lightning is a discharge of atmospheric electricity accompanied by a vivid flash of light. During thunderstorms, static electricity builds up in clouds. A positive charge builds in the upper part of the cloud, while a negative charge builds in the lower portion. When the difference between the charges becomes great, the charge jumps from one area to another, creating a lightning bolt. Most lightning bolts strike from one cloud to another but they can also strike the ground. Such bolts occur when positive charges build up on the ground. A negative charge or "leader" flows from the cloud toward the ground and then a positively charged leader (called the return stroke) runs from the ground to the cloud. what appears as a lightning bolt is actually a series of downward and upward strokes, all taking place in less than a second.

Magnetosphere is the region surrounding a celestial body where its magnetic field controls the motions or charged particles. Earth's magnetosphere is dipolar, meaning it behaves as if it were produced by a giant magnet located near the center of the planet with its north pole tilted several degrees from Earth's geographic north pole.

Mean is the scientific term for average as in "global mean temperature."

Milankovitch Theory states that major ice ages of the past may be triggered by regular variations in Earth's orbit around the Sun, leading to changes in incoming solar radiation.

Modeling is an investigative technique which uses a mathematical or physical representation of a system or theory to test for effects that changes in system components may have on the overall functioning of the system. Mathematical modeling using computers plays a major role in climate research, by simulating how Earth's climate will respond to changes in atmospheric concentrations of greenhouse gases.

Molecule means two or more atoms of one or more elements chemically combined in fixed proportions. For example, atoms of the elements carbon and oxygen, chemically bonded in a 1:2 proportion, create molecules of the compound carbon dioxide ($C0_2$). Molecules can also be formed of a single element, as in ozone (03).
Monsoon refers to a particular seasonal weather pattern in subtropical regions, especially when characterized by periods of heavy winds and rainfall. Monsoons are caused by a pronounced seasonal change in wind direction. Winds usually blow from land to sea in winter, while in the summer this reverses, bringing precipitation. Monsoons are most typical in India and southern Asia.

Montreal Protocol on Substances that Deplete the Ozone Layer is an international agreement that prescribes a timetable for ending the production of chlorofluorocarbons (CFCs) and related compounds. Begun in 1987, this unprecedented international treaty is a unique example of scientists and industry working with governments to seek a global solution to the human-caused environmental challenge of ozone depletion. After the original agreement was signed, new evidence arose proving that deeper cuts in CFC production were necessary to protect the ozone layer. The 1990 London amendments and the 1992 Copenhagen amendments sped up the halocarbon phase out and controlled several other chemicals that were not in the original agreement: methyl chloroform, carbon tetrachloride, methyl bromide, and HCFCs. The revised agreement now calls for the phase-out of CFCs to be complete by 1996. The treaty also attempts to make the phase-outs fair to developing countries by setting up a fund, paid for by developed nations, to assist developing countries in making the switch to ozone-safe chemicals.

Multispectral Scanner (MSS) is a sensor system carried on Landsat satellites (add info about bands and pixels size)

Neutron is a component of most atomic nuclei, without electric charge, and of approximately the same mass as the proton (positively charged component).

Orbit is the path of a body, such as a planet or satellite, in its periodic revolution around another body in space. For example, satellites which orbit Earth near latitude 0~ are said to have equatorial orbits, since they remain above the equator. Satellites with inclinations near 900 are said to be in polar orbits because they cross over or near Earth's north and south poles as they revolve around the planet.

Ozone is a gaseous molecule consisting of three atoms of oxygen (03). Ozone in Earth's stratosphere forms a protective layer that shields Earth's inhabitants from damaging ultraviolet radiation from the Sun. Ozone in the troposphere, near Earth's surface, on the other hand, is a harmful pollutant resulting from the interaction of anthropogenic emissions of nitrogen oxides and volatile organic compounds and sunlight.

Ozone Depletion refers to the thinning of the stratospheric ozone layer which protects life on Earth from excess ultraviolet radiation from the sun. Human-made halocarbons are primarily responsible for this reduction in the amount of ozone in the stratosphere.

Ozone Hole refers to a region of the atmosphere over Antarctica where, during springtime in the Southern Hemisphere, up to three quarters of the stratospheric ozone disappears. Anthropogenic halocarbons are the primary cause of this phenomenon.

Paleoclimatology is the reconstruction of ancient climates by using evidence such as tree rings and air trapped in ice cores. Researchers use such evidence to understand natural climatic shifts which can help us in understanding and eventually predicting future climate trends.

Passive Solar Design refers to designing buildings to maximize the use of solar radiation to warm and light the interior. Passive solar design criteria include properly siting the building, using energy efficient windows, and providing for both appropriate levels of insulation and thermal mass (material in the walls or floors of the building which stores heat and thereby helps to moderate temperature variations).

Pedosphere is one of the five interrelated components of the Earth System, and consists of the solid portion of the Earth. The pedosphere rides on continental structures that evolve over millions of years as a consequence of the tectonic motions of Earth's land masses.

pH is a measure of the acidity or alkalinity of a solution. A value of 7 is neutral, values less than 7 are acid, and values over 7 are alkaline or basic. A change of one unit on the pH scale represents a factor of ten in acidity. For example, a solution with a pH of five is ten times as acid as one with a pH of six.

Phenology is the science dealing with the relationships between climate and periodic biological phenomena that are related to or caused by climatic conditions, such as the seasonal budding of trees and migration of birds.

Photochemical Smog, present in many large cities, is formed by chemical reactions involving nitrogen oxides and hydrocarbons (from human activities including automobile use) taking place in the presence of sunlight. The principle component of photo-chemical smog is tropospheric or ground-level ozone.

Photosynthesis is the series of chemical reactions by which plants use the sun's energy; carbon dioxide and water vapor to form materials for growth, and release oxygen.

Phytoplankton are minute forms of plant life in the oceans at the base of the marine food chain.

Pixel is the smallest element of an electronically-coded image. Pixel is a contraction of the words "picture element." See image resolution.

Plate Tectonics is the concept that Earth's crust is composed of rigid plates that move over a less rigid interior. The movements of these plates cause geological events such as earthquakes and continental drift, and over long periods of time, can cause significant shifts in Earth's land masses.

ppbv stands for parts per billion by volume, a measure of concentration

ppmv stands for parts per million by volume, a measure of concentration

Precipitation is moisture that falls from clouds. Raindrops form around particles of salt or dust. Water or ice droplets stick to these particles, the drops attract more water and continue to grow until they are large enough to fall out of the cloud.

PV stands for photovoltaic. A photovoltaic or solar cell is a device, often made of silicon, which converts solar radiation directly into electricity.

Radiation Budget is an accounting of the radiation which enters and leaves a planet's atmosphere. The quantity of solar radiation entering the atmosphere from space should be balanced by the thermal radiation leaving the Earth's surface and atmosphere.

Rainforest is an evergreen woodland of the tropics distinguished by a continuous leaf canopy and an average rainfall of about 100 inches per year. Rainforests play an important role in the global environment for several reasons. They are the most biologically diverse biome on the planet, encompassing just 6-7% of Earth's land, but thought to house nearly half of its species. Rainforests also take up carbon dioxide, helping to balance anthropogenic emissions. When rainforests are cut or burned, the opposite occurs: they release stored carbon dioxide, adding to the greenhouse effect.

Rain Gauge is a calibrated container that measures the amount of rainfall occurring during a specific period of time.

Remote Sensing is the process of obtaining information from a distance, especially from aircraft and satellites. Modern remote sensing technology has greatly expanded our ability to see and understand the Earth and its systems and to observe changes. Remote sensing has become a critical tool in activities ranging from the verification of arms control treaties to the provision of emergency aid to disaster-stricken regions. Through remote sensing we learn about problems such as droughts, famines, and floods; we obtain information about agricultural practices, weather conditions, transportation systems, river flows, and terrain changes. We use remote sensing to locate Earth's natural resources and can then use that information to exploit or protect them.

Renewable Energy refers to energy from sources which are not depleted by use. Examples include using passive solar energy to heat buildings, solar thermal energy to heat water or turn turbines to produce electricity, photovoltaic cells to convert sunlight directly to electricity, wind power, and hydroelectric energy.

Sequestration is removal and storage, as when carbon dioxide is sequestered from the atmosphere by plants via photosynthesis.

Sink is a scientific term for storage or removal of a substance. For example, plants through photosynthesis, transform carbon dioxide from the air into organic matter which is then "stored" in the plant or in the soil. Plants are thus said to be sinks" for carbon. One of the key uncertainties regarding climate is that the quantity of carbon held in the various sinks and the rates of exchange between them are not well known.

Solar Constant is the average total radiation reaching the top of Earth's atmosphere from the sun. The number used for this constant, about 1370 watts per square meter, is not, in fact, truly constant; variations of about a tenth of a percent have been measured during the last two decades.

Solar Radiation is energy from the sun. It is the main energy source for Earth's climate system, heating the surface and driving currents in the oceans and winds in the atmosphere. Ordinary visible sunlight is the most obvious form of solar radiation, but other forms are significant too. For example, see ultraviolet radiation.

Sonde is a device sent up into the air, typically borne on a balloon, to obtain information about atmospheric conditions. Radiosondes, for example, measure temperature, pressure and humidity and then "radio" or transmit these data to Earth.

Spectral Band is a segment of wavelengths within the electromagnetic spectrum.

Stratosphere is the region of the atmosphere between the troposphere and mesosphere, having a lower boundary approximately 8 kilometers above Earth's surface at the poles and 15 km at the equator and an upper boundary of approximately 50 km. This is the region that houses the stratospheric ozone layer which protects Earth from ultraviolet solar radiation.

Sustainable Development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs. Some people also believe that the concept of sustainable development should include preserving the environment for other species as well as for people.

Synoptic means simultaneous. For example, a synoptic weather map displays meteorological conditions observed in different places at a single time. Synoptic also refers to a large or general view of something. For example, an aerial photograph provides a "synoptic," or "bird's eye view" of an area.

Terrestrial means pertaining to the Earth, as distinct from other planets (as in extraterrestrial life). It also means pertaining to the land, as distinct from the water or air (as in a terrestrial, as opposed to aquatic, ecosystem).

Thematic Mapper (TM) is one of the sensor systems carried on Landsat 4 and 5 satellites. The TM acquires surface reflectance (brightness) data in 6 visible and infrared bands, at a pixel size of 30m. A simple thermal band acquires data in 60m pixels.

Thunder is the sound that results from lightning. A lightning bolt produces an intense burst of heat which makes the air around it expand explosively, producing the sound we hear as thunder. Since light travels faster than sound, we see the lightning before we hear the thunder. The difference in time between the two can tell us how far away the clouds producing the lightning and thunder are.

Thunderstorm is a local storm resulting from rising warm humid air, which produces lightning and therefore thunder, usually accompanied by rain or hail, gusty winds, and strong vertical air motion.

Tornado is a strong, rotating column of air extending from the base of a cumulonimbus cloud to the ground. These twisting, spinning funnels of low pressure air are the most unpredictable weather event, created during powerful thunderstorms.

Total Ozone Mapping Spectrometer (TOMS) is an instrument, first flown on NASA's Nimbus-7 satellite, whose primary function is to monitor global ozone. TOMS has been delivering ozone data since 1979, providing high-resolution mapping of total ozone, from the ground to the top of the atmosphere, on a daily basis. TOMS provided the first maps of the ozone hole and continues to monitor this phenomenon.

Trade Winds are global-scale winds in the tropics that blow generally toward to west in both hemispheres (from the Northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere). These steady winds are called trade winds because they provided trade ships with a sailing route to the *"New* World," America.

Transpiration is the transfer of water from plants to the atmosphere; water is taken up by the roots of plants and released as water vapor by the leaves.

Tropical Cyclone is a low-pressure weather system in the tropics in which the central core is warmer than the surrounding atmosphere. A tropical storm is a tropical cyclone with winds from 39 to 74 miles per hour. When winds exceed 74 miles per hour, the cyclone is called a hurricane.

Tropics refers to the region of Earth from latitude 23.5º north (the Tropic of Cancer) southward across the equator to latitude 23.5º south (the Tropic of Capricorn). This region has relatively small daily and seasonal changes in temperature, but great seasonal changes in precipitation.

Tropospheric Ozone refers to ozone (03) in the region of the atmosphere that extends from Earth's surface to about 7 miles up. As opposed to stratospheric ozone (the "good ozone" that protects us from excess ultraviolet (UV) radiation from the sun), tropospheric ozone or "bad ozone," results from the interaction of nitrogen oxides (NOx), volatile organic compounds (VOCs), and sunlight. Most of the pollutants which lead to the formation of tropospheric ozone come from automobiles, power plants, and other human activities. In many cities, ozone is a significant health problem; 98 U.S. cities have higher concentrations of ozone than the U.S. Environmental Protection Agency finds acceptable. Ozone also causes $3 to 5 billion a year in lost crop production and significant losses in forest products. Tropospheric ozone is also a significant greenhouse gas.

Typhoon is a tropical cyclone with winds 75 miles per hour or greater in the northwest Pacific ocean. In other parts of the world, such storms have different names, such as hurricanes.

Ultraviolet radiation (UV) is the energy range just beyond the violet end of the visible spectrum. Most UV is blocked by earth's atmosphere (particularly the stratospheric ozone layer) but some solar UV penetrates and aids in plant photosynthesis and the production of Vitamin D in humans. Too much UV can burn the skin, cause skin cancer and cataracts, and damage vegetation.

Volatile Organic Compounds (VOCs) are precursors of tropospheric ozone and photochemical smog. They are produced by human activities including the use of dry cleaning solvents.

Volcano is a naturally occurring vent or fissure at Earth's surface through which erupt molten, solid, and gaseous materials. Volcanic eruptions inject large quantities of dust, gas, and aerosols into the atmosphere and can thus cause temporary climatic cooling.

Watershed is a catch basin that guides all precipitation and runoff (water, sediment, and dissolved materials) to a common watercourse or body of water.

Water vapor is the invisible, gaseous form of water.

Wind is a natural motion of the air, especially a noticeable current of air moving in the atmosphere parallel to Earth's surface. Winds are caused by uneven heating and cooling of the Earth and atmosphere.

Wind Shear is a sudden change in wind speed or direction.

Younger Dryas is the name for a cold climatic event lasting about 1500 years which interrupted the warming of the Earth after the last ice age.

Zooplankton are minute forms of animal life in the ocean which feed on phytoplankton (minute plant life).

SOME OFTEN-USED CHEMICAL SYMBOLS

CFCs	chlorofluorocarbons
CH	methane
CO	carbon monoxide
CO_2	carbon dioxide
H_2	molecular hydrogen
H_2O	water
HCFCs	hydrochlorofluorocarbons
N_2	molecular nitrogen
N_2O	nitrous oxide
NO	nitric oxide
NO_2	nitrogen dioxide
O_2	molecular oxygen
O_3	ozone
OH	hydroxyl radical
SO_2	sulfur dioxide

GLOSSARY ACKNOWLEDGMENTS

The definitions and other information in this glossary are derived from many different sources, including:

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