NOVA

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PBS

Dimming the Sun

PROGRAM OVERVIEW

NOVA investigates the evidence for a little-known phenomenon called global dimming and explores its potential impact on climate worldwide.

The program:

- relates how the first signs of global dimming came in the 1980s when one scientist—who measured sunlight amounts over Israel in the 1950s—found a 22 percent drop in sunlight 20 years later.
- reports that scientists were at first skeptical of global dimming, which indicated Earth was getting cooler, because it conflicted with evidence supporting global warming.
- explains how a decline in pan evaporation rates worldwide, and correlation of the evaporation rates with measured declines in sunlight, further supported the hypothesis of global dimming.
- describes an experiment measuring the atmosphere over the Maldives that revealed polluted air was causing global dimming.
- details how polluted air was creating clouds with 10 times more particles than naturally occurring clouds, and that the polluted clouds were both preventing sunlight from getting through and reflecting more sunlight back into space.
- reports on research indicating that global dimming may have affected normal weather patterns, including altering rainfall patterns that led to a 20-year drought in sub-Saharan Africa.
- notes how global dimming may be masking the full effects of global warming.
- presents research showing that vapor trails left behind by high-flying aircraft have a significant impact on daily temperature range.
- provides estimates for the impacts of global warming and global dimming.
- predicts what may happen to parts of the world if revised global warming estimates are true.
- describes a new controversial climate analysis that predicts that temperatures could rise by as much as 10 degree Celsius by 2100.
- emphasizes the urgent need to address the causes of global warming.

BEFORE WATCHING

1 Ask students to explain what they know about global warming and global dimming. Review these climate phenomena with students, including how the phenomena are believed to occur and what their effects may be. (See Background on page 2 for more information.)

2 Organize students into three groups to take notes on the following topics as they watch the program: the possible causes of global dimming, the evidence that global dimming occurs, and the tools and techniques used to study global dimming.

AFTER WATCHING

1 Have groups present their notes. Why does global dimming occur only during the daylight hours, while global warming occurs both during day and night? How is global dimming causing scientists to re-evaluate current climate models? *(Because global dimming seems to have been reducing the global temperature, the actual effect of global warming may be much stronger than predicted by current models.)* Based on evidence presented in the program, what is the confidence level among students concerning current and future models of global dimming and global warming? Have students defend their reasoning.

2 Ask students what can be done to reduce global dimming. *(The particulate pollutants that block infrared and visible light can be reduced.)* Should these steps be taken without also addressing global warming? Why or why not? *(No, it seems most important to lessen both effects. Decreasing global dimming may increase the impact of global warming.)* If what is depicted in the program is true, what steps would students be willing to take to reduce global dimming? Global warming?

CLASSROOM ACTIVITY

Activity Summary

Students will set up pan evaporation devices and for four uninterrupted days will measure and record pan evaporation amounts, air temperature, relative humidity, wind speed, solar radiation, and precipitation.

Materials for Teacher

- copy of "Class Charts" teacher sheet

Materials for Each Team

- copy of "Investigating Evaporation" student handout
- copy of "Data Sheet" student handout
- copy of "Graphing Data" student handout (2 pages)
- pencil or pen
- calculator
- graph paper

Materials for Pan Setups

- 2 stainless steel or galvanized pans of equal size (at least 25 cm x 25 cm x 6 cm)
- 2 wood blocks (same or greater perimeter as pan bottom)
- two 2L containers
- room temperature water
- masking tape
- 2 metric rulers with millimeter graduations
- level
- 2 rain gauges with millimeter graduations
- 1 opaque shading device, if necessary
- waterproof marker
- 1 thermometer (optional)
- 2 anemometers (optional)
- 2 hygrometers (optional)
- magnifying glass (optional)
- graph paper (optional)

Background

Earth's temperature rises when the sun heats the surface and when sun rays reflected off the planet are absorbed and re-emitted by greenhouse gas molecules in the atmosphere. While naturally occurring atmospheric greenhouse gases such as water vapor and carbon dioxide provide a beneficial warming effect, some scientists believe that human-generated greenhouse gases are contributing to increased global warming. Some scientists fear that a continued accelerated warming of Earth's surface may lead to climate changes that melt polar ice caps, raise sea levels,

LEARNING OBJECTIVES

Students will be able to:

- collect, interpret, and analyze weather variable data.
- describe atmospheric variables that affect evaporation.

KEY TERMS

climate: The weather conditions in a given location averaged over a long period of time.

pan evaporation rate: The amount of water that evaporates from a pan in a given period of time.

relative humidity: The amount of water in the air compared with how much water the air can hold at a given temperature.

weather: Meteorological conditions such as temperature, wind speed, relative humidity, and precipitation at a given time and place.

CLASSROOM ACTIVITY (CONT.)

change rainfall, and impact local climate conditions.

Other scientists believe they have found evidence that shows Earth is cooling. Global dimming, as it is known, is a phenomenon believed to cause a reduction in the amount of sunlight reaching Earth's surface. This is thought to occur when pollution particles create dense clouds that prevent sunlight from getting through and reflect sunlight back into space. Some scientists believe global dimming is altering rainfall patterns worldwide and is masking the true impact of global warming. There is still much scientific debate about the extent and impact of both global warming and global dimming.

One of the ways that scientists determine energy changes in the environment is by looking at water evaporation rates. Evaporation rates can be measured by calculating the change of depth of water in a container over a given time period. Evaporation rates are mainly influenced by sunlight, relative humidity, and wind speed.

Evaporation rates have been calculated worldwide for hundreds of years and are used to determine the approximate amount of water loss from lakes or crops. They are also used to help calculate the amount of water needed for irrigation. Many U.S. weather stations determine evaporation rates using a U.S. Class-A pan, which is a stainless steel pan, 25.4 centimeters high and 1.2 meters in diameter. The pan, which is normally installed on a wooden platform set on the ground in a grassy open area, is filled with water to within 6.35 centimeters of the top and left exposed. The pan evaporation rate is simply the amount of water that evaporates from the pan in a given period of time. This rate is measured by manual readings or using an evaporation gauge. Water is added to the pan to bring it back to its original level each day.

In the 1990s, scientists worldwide started noticing the pan evaporation rate was falling, despite an overall rise in global temperature. The decrease in the pan evaporation rate is a key piece of evidence used to support the hypothesis of global dimming. In this activity, students will set up their own pan evaporation experiments and determine which variables affect evaporation.

Procedure

1 Before class, identify level, outside locations in an open area (such as a field or blacktop) where the pan evaporation devices can be set up and left undisturbed for four uninterrupted days. Pan 1 will be placed on wood in an unsheltered location; pan 2 will be placed on wood in a shaded location. Try to place the pans close to one another. If there is no appropriate shaded location, use a shading device, such as an umbrella or an opaque fabric or cardboard overhang, to shelter the pan.

STANDARDS CONNECTION

The "Investigating Evaporation" activity aligns with the following National Science Education Standards (see books.nap.edu/html/nses) and the Principles and Standards for School Mathematics (see standards.nctm.org/document/index.htm).

GRADES 5–8
Science Standard A
Science as Inquiry
Abilities necessary to do scientific inquiry

Mathematics Standard
Statistics

GRADES 9–12
Science Standard A
Science as Inquiry
Abilities necessary to do scientific inquiry

Mathematics Standard
Statistics

Video is not required for this activity.

Classroom Activity Author
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CLASSROOM ACTIVITY (CONT.)

2 In the classroom, set up the pans. Use a permanent marker to number each pan and place a mark two centimeters from the top of the pan.

3 Organize the class into four teams and number them one through four. Distribute and review the handouts with teams. Have students write their team number on their "Data Sheet" handout. Tell students that they will collect data from an unsheltered and sheltered pan for four uninterrupted days to learn about the variables that affect pan evaporation.

4 Make a schedule, and assign Teams 1 and 2 to take morning measurements (at about the same time but Team 1 always measures first) for both pans and Teams 3 and 4 to take afternoon measurements (at about the same time but Team 3 always goes first) for both pans. Try to have students take measurements as early and as late in the day as possible.

5 After taking the daily morning measurement, Team 2 needs to refill the pans to the *exact level* of the original water mark with room temperature water (and/or remove any rainwater so that the water is at the original starting line). After taking the late afternoon measurement, Team 4 needs to refill the pans in the same manner.

6 Using the "Class Charts" teacher handout as a guide, transfer the "Measurements Chart," the "Daily Averages Chart," and the "Averages for Graphing Chart" onto chart paper so students can enter their data, and the results can be analyzed and graphed by the class. Students will be entering their data into the all-class "Measurements Chart" in the correct space next to their teams' number each day.

7 Demonstrate how to read the instruments and have teams practice until they are proficient. Have teams practice using the ruler to measure water loss from a pan. Emphasize the importance of taking an accurate ruler reading (eyes looking straight at the ruler rather than looking at an angle) when measuring water evaporation. Students should measure water depth from the same place in the pan each time. Practice refilling the pan with students. If an anemometer and/or a hygrometer are not available, students can obtain wind speed and humidity data from NOAA's National Weather Service Web site (see sidebar) or local news outlets.

8 Take the pans, containers of room temperature water, wood blocks, and instruments to the predetermined locations with students the day before the first measurements will be taken. Fill each pan *exactly* to the marked line with water. Make sure the pans are level and cannot be easily bumped or disturbed. Measure the initial pan water level to the nearest millimeter. Have students write this number on their "Data Sheet" handout. Place a rain gauge next to each pan and place a thermometer next to the sheltered (shaded) pan. (Air temperature is measured in the shade.) Make sure that the water in the pan is at the

NOAA's National Weather Service
www.nws.noaa.gov/organization.php
Students can find local weather information for their city by typing in their city and state in the box on the left-hand side of the page. Once students have chosen their city, the "Current Conditions" box below the map will show current conditions, including temperature, relative humidity, wind speed, and visibility. The "2-Day History" link provides students with hourly information for weather variables for the past two days.

CLASSROOM ACTIVITY (CONT.)

original starting level at the time that Team 4 would be taking its afternoon measurement.

9 Have students collect and record their data for four days, entering their data into the class chart daily. Monitor measurements each day and consider deleting outliers when data is averaged. At the end of the data collection period, and after all student data has been posted, hang the "Daily Averages Chart" and the "Averages for Graphing Chart" next to the "Measurements Chart."

10 Have Teams 1 and 2 calculate a.m. averages and Teams 3 and 4 calculate p.m. averages for sheltered and unsheltered locations for the four variables—air temperature, relative humidity, average wind speed, solar radiation (amount of shade for sheltered, clouds or sun for unsheltered) and for the evaporation amounts. Enter these into the "Daily Averages Chart."

11 Then, as a class, calculate daily averages for both unsheltered and sheltered locations for the four variables (air temperature will be the same for both) and enter the averages into the "Averages for Graphing Chart." Add together the a.m. and p.m. evaporation amounts for each day and enter these amounts into the "Averages for Graphing Chart." Round up all numbers to one decimal point for graphing.

12 Have teams work together to complete the graphs on their "Graphing Data" handouts or have students use graph paper to create their graphs. There are eight graphs for each location. The evaporation results that students obtained for the Unsheltered Location will be the same for all four graphs. The evaporation results that students obtained for the Sheltered Location will be the same for the four graphs related to *that* location.

Unsheltered

Graph 1a: average air temperature	**1b:** evaporation amount
Graph 2a: average relative humidity	**2b:** evaporation amount
Graph 3a: average wind speed	**3b:** evaporation amount
Graph 4a: average solar radiation	**4b:** evaporation amount

Sheltered

Graph 1a: average air temperature	**1b:** evaporation amount
Graph 2a: average relative humidity	**2b:** evaporation amount
Graph 3a: average wind speed	**3b:** evaporation amount
Graph 4a: average solar radiation	**4b:** evaporation amount

13 Analyze the data with students and discuss the results. Based on the data, which variables seem to most affect water evaporation? Ask students how results might differ if they were collected in more locations and/or over a longer period of time.

14 As an extension, have students work in teams and design and write an indoor pan evaporation experiment.

ACTIVITY ANSWER

Student results should reflect that differences in relative humidity, wind speed, and sunlight affect the pan evaporation. In general, when relative humidity increases, the pan evaporation decreases. It is also common to see an increase in pan evaporation with an increase in wind speed, especially if the wind is moving away moist air and bringing in dry air. Solar radiation (the amount of sunlight) has the greatest impact on pan evaporation. Though students may see little change in pan evaporation due to changes in air temperature, measuring solar radiation includes a consideration of day length, air temperature, and cloud cover. Results will vary depending on local weather conditions.

Student Handout Questions

1. How did the pan evaporation amounts change in relation to air temperature? Relative humidity? Wind speed? Solar radiation? *Answers will vary some depending upon location. In general, when relative humidity increases, the pan evaporation decreases. When wind speed increases, the pan evaporation increases. When solar radiation increases, evaporation increases.*
2. Which variables seem to most affect the evaporation amounts? *Explain your answer. Student results should reveal that wind speed, relative humidity, and solar radiation most affected evaporation amounts. Sample results showed that wind speed and relative humidity affected evaporation amounts even in the sheltered area.*
3. What difference, if any, was there in the amount of evaporation that occurred in the unsheltered location compared to the sheltered location? What might account for any differences? *Students will most likely find more evaporation in the unsheltered location on sunny days (due to more solar radiation). This may vary depending upon humidity levels—if humidity is high, evaporation may be less.*
4. If the amount of sunlight reaching Earth's surface were to decrease, would you expect the evaporation rate on Earth's surface to increase, decrease, or stay the same? Why? *If the amount of sunlight were to decrease, the evaporation rate would likely decrease.*
5. What are the limitations of the experiment? *Some limitations include lack of sophisticated instrumentation, reader error, and water loss due to unmeasured variables such as air pressure differences or animals drinking from the pan. In addition, data used from a local weather source may not reflect microclimate conditions at pan setup locations.*
6. What could the class do to have more confidence in the conclusions drawn from this experiment? *Carry out the experiment in more locations for a longer period of time.*

LINKS AND BOOKS

Links

NOVA—Dimming the Sun
www.pbs.org/nova/sun
Find out more about aircraft contrails and their impact, read the producer's take on why some people remain skeptical about global warming, see a time line of global dimming discoveries, and learn about tools to reduce and prevent air pollution.

U.S. Global Change Research Information Office
www.grcio.org/index.html
Features general information, resources, and links to other organizations dealing with global change. Also includes an e-mail service, Ask Dr. Global Change, where readers can send questions about global environmental change.

What's Up With the Weather?
www.pbs.org/nova/warming
Provides interviews with proponents and skeptics of global warming, shows how ice cores reveal climate data, takes a look at home energy consumption, and reviews alternative energy sources.

Books

Global Warming
by Fred Pearce and John Gribben.
Dorling Kindersley, 2002.
Examines the causes and effects of global warming.

Weather
by Brian Cosgrove.
Dorling Kindersley, 2004.
Includes information about designing a weather station.

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ExxonMobil David H. Koch HHMI

cpb Corporation for Public Broadcasting

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Class Charts

Transfer these onto chart paper so students can enter their data and the results can be analyzed and graphed by the class.

Measurements Chart	DAY 1				DAY 2				DAY 3				DAY 4			
	U		S		U		S		U		S		U		S	
	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm
Air Temperature	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4
Relative Humidity	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4
Wind Speed	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4
Solar Radiation	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4
Evaporation Amount (in mm)	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4	1 2	3 4

Daily Averages Chart	DAY 1				DAY 2				DAY 3				DAY 4			
	U		S		U		S		U		S		U		S	
	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm
Air Temperature																
Relative Humidity																
Wind Speed																
Solar Radiation																
Evaporation Amount (in mm)																

Averages for Graphing Chart	DAY 1		DAY 2		DAY 3		DAY 4	
	U	S	U	S	U	S	U	S
Air Temperature								
Relative Humidity								
Wind Speed								
Solar Radiation								
Evaporation Amount (in mm)								

Key:
U (unsheltered location), **S** (sheltered location)

Investigating Evaporation

Certain weather variables influence the amount of water that evaporates each day from a standing body of water. In this activity, your team will collect and analyze weather data to find out what variables affect water evaporation amounts.

Procedure

1. Your team will be collecting data once a day for four uninterrupted days. Your teacher will provide you with the initial pan water level. Record that depth on your "Data Sheet" handout.
2. Each day, gather and record the following measurements for both pans on your "Data Sheet" handout.
   - **Air Temperature (in °C):** Read the thermometer that is next to the sheltered pan or find the temperature for your appointed time from another weather source.
   - **Relative Humidity (in percent):** Read the hygrometer or record from another weather source.
   - **Wind Speed (in km/hr):** Read the anemometer or record from another weather source.
   - **Solar Radiation:** Note the amount of cloud cover. For the **unsheltered pan: 1**=all cloudy, **2**=mostly cloudy, **3**=equal mix of sun and clouds, **4**=mostly sunny, **5**=all sunny; for the **sheltered pan**, rate the amount of shade: **1**=fully shaded, **2**=mostly shaded, **3**=partly shaded.
   - **Water Depth (in mm):** Use the ruler to measure the water depth. Measure from the same place each time. If you are a member of Team 2 or Team 4, take your reading, and then fill the pan with room temperature water to the *exact level* of the original water mark. If it has rained during the day or night, remove water from the pan until the water line is at the *exact level* of the original marked starting point.
   - **Precipitation (in mm):** Record any water that has collected in the rain gauge. If you are a member of Team 2 or Team 4, empty the gauge after you take your reading.
3. When all your data has been gathered for the day, perform the following calculations:
   [Water Depth - Precipitation = Adjusted Water Depth]
   [Initial Pan Water Level - Adjusted Water Depth = Evaporation Amount]
4. Use the "Data Sheet" handout to record your data for four consecutive days. Also enter each day's data into the all-class "Measurements Chart."
5. After all the data has been recorded, you will work as a class to analyze it. When you are done, answer the questions on this page.

Questions

Write your answers on a separate piece of paper.

1. How did the pan evaporation amounts change in relation to air temperature? Relative humidity? Wind speed? Solar radiation?
2. Which variables seem to most affect evaporation amounts? Explain your answer.
3. What difference, if any, was there in the amount of evaporation that occurred in the unsheltered location compared to the sheltered location? What might account for any differences?
4. If the amount of sunlight reaching Earth's surface were to decrease, would you expect the evaporation rate on Earth's surface to increase, decrease, or stay the same? Why?
5. What are the limitations of the experiment?
6. What could the class do to have more confidence in the conclusions drawn from this experiment?

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Data Sheet

Name: _____

Team Number: _____

Time of Measurement: _____

Initial Pan Water Level (in mm): _____

	Day 1		Day 2		Day 3		Day 4	
	U	S	U	S	U	S	U	S
Air Temperature (in °C)								
Relative Humidity (in percent)								
Wind Speed (in km/hr)								
Solar Radiation*								
Water Depth (in mm)								
Precipitation (in mm)								
CALCULATE								
Adjusted Water Depth (in mm) [Water Depth - Precipitation]								
CALCULATE								
Evaporation Amount (in mm) [Initial Pan Water Level - Adjusted Water Depth]								

enter data into the class "Measurement Chart"

enter data into the class "Measurement Chart"

Key:
U (unsheltered location), **S** (sheltered location)

*** Solar Radiation**

Unsheltered:
1=all cloudy
2=mostly cloudy
3=equal mix of sun and clouds
4=mostly sunny
5=all sunny

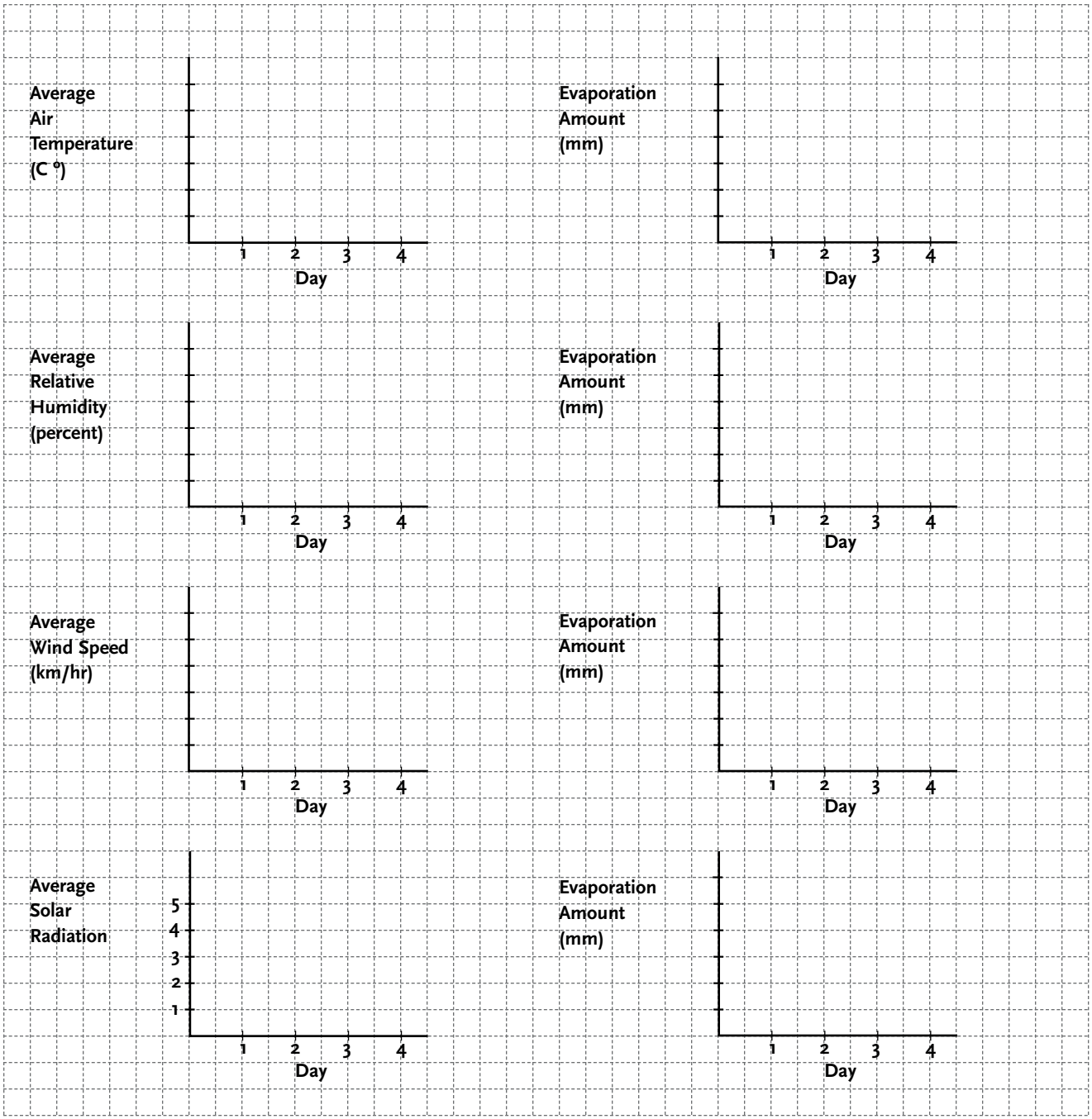
Sheltered:
1=fully shaded
2=mostly shaded
3=partly shaded

NOVA

Graphing Data

Unsheltered Location

On the *y*-axis, write in a range for air temperature, humidity, wind speed, and evaporation amount that correlates with the ranges of your results. The evaporation results for your Unsheltered Location will be the same for all four graphs. The evaporation results you obtained for your Sheltered Location will be the same for the four graphs related to *that* location.



NOVA

Graphing Data

Sheltered Location

On the *y*-axis, write in a range for air temperature, humidity, wind speed, and evaporation amount that correlates with the ranges of your results. The evaporation results for your Unsheltered Location will be the same for all four graphs. The evaporation results you obtained for your Sheltered Location will be the same for the four graphs related to *that* location.