Calculating Relative Air Mass

Purpose

To introduce students to the concept of relative air mass and demonstrate how solar elevation angle affects the intensity of sunlight that reaches an observer on the ground.

Overview

Students work in teams to calculate relative air mass using simple geometry.

Student Outcomes

Students understand the relationship of solar elevation angle to relative air mass.

Science Concepts

Earth and Space Science

Dynamic processes such as Earth's rotation influence energy transfer from the sun to Earth.

Atmosphere Enrichment

The path length of incident sunlight through the atmosphere (relative air mass) varies as a function of the solar elevation angle.

Scientific Inquiry Abilities

Identify answerable questions.

Use appropriate tools and techniques.

Use appropriate mathematics to analyze data.

Develop and construct models using evidence.

Communicate procedures and explanations.

Time

Morning elevation readings: 5 minutes each; sunny day is necessary

Calculating air mass: 20 minutes

Level

Middle and Secondary

Materials and Tools

Meter stick and/or tape measure marked in centimeters

Pole, at least 50 cm high, to be used as a solar gnomon (e.g. wooden dowel)

Calculating Relative Air Mass Data Sheet

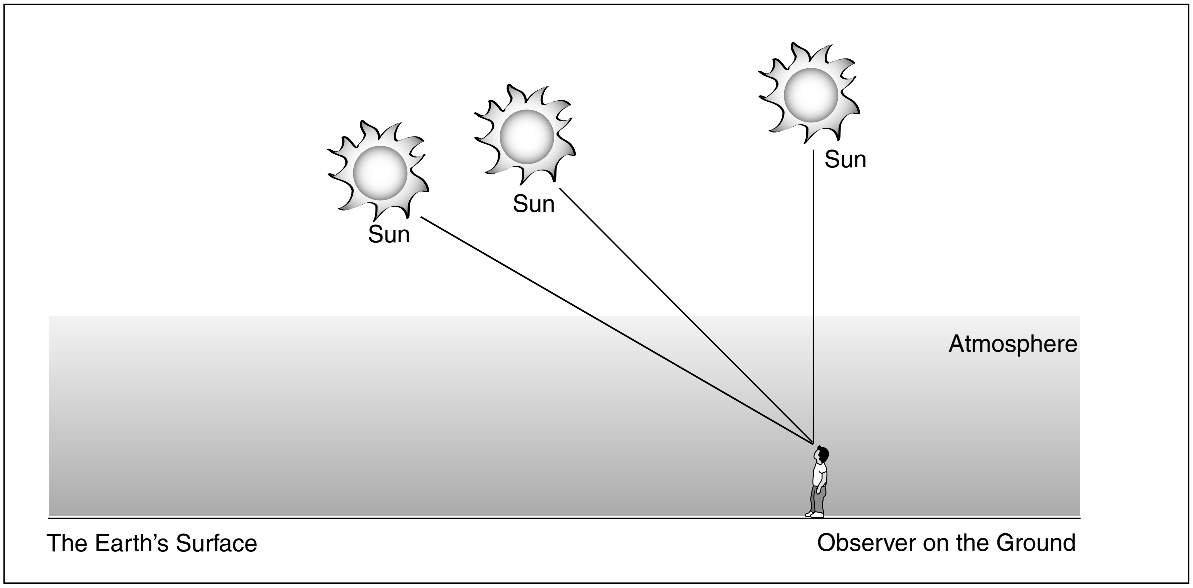
Preparation

None

Prerequisites

Making a Sundial (suggested for younger students)

Figure AT-AM-1



Teacher Support

Background

Relative air mass is a ratio indicating the amount of atmosphere that light must pass through before reaching an observer on the ground. When the sun is directly overhead, sunlight passes through the least amount of atmosphere to reach the ground. This is defined as a relative air mass of 1.0. In this case, the sun is 90˚ above the horizon. When the Sun is 30˚ above the horizon, sunlight passes through twice as much atmosphere to reach an observer on the ground, and the relative air mass is 2.0. Thus, the relative air mass is a function of the solar elevation angle.

In the *Aerosol Protocol*, the amount (the intensity) of sunlight reaching the instrument depends on the amount of atmosphere between the instrument and the sun as well as the amount of aerosol in the atmosphere. So, the relative air mass you calculate in this activity is important for interpreting data obtained using the GLOBE sun photometer. In *Looking At the Data* for the *Aerosol Protocol*, the technique is given for calculating aerosol optical thickness from the voltage readings of the photometer. This calculation requires knowing the relative air mass at the time of observation.

In order to help students understand how the solar elevation angle affects relative air mass, make some sketches on the board like those shown above or use an overhead projector to project the figure onto a board or wall. Invite students to use a meter stick to measure the distance from the top of the atmosphere to the observer for solar elevation angles of 90, 45, and 30 degrees. The students should see that as the elevation angle of the sun decreases, the pathlength of sunlight through the atmosphere increases. Have the students find the ratio of each pathlength to the 90 degree pathlength. These ratios are the relative pathlengths through the atmosphere and are the same as the relative air masses.

Relative air mass can be calculated in the field using the length of the shadow cast by a vertical pole. A pole used for this purpose is called a *solar gnomon*. In Figure AT-AM-2A, the pathlength through the atmosphere (p) is a function of the elevation angle (e). The distance from the ground to the top of the atmosphere (d) may be assumed to be constant.

As shown in Figure AT-AM-2B , sunlight shining on the solar gnomon casts a shadow creating a right triangle. The three sides of this triangle are: the height of the gnomon (h), the length of the pole's shadow on the ground (r), and the hypotenuse (c).

The solar elevation angle (∠e) is the same in the right triangles in both figures, making them similar triangles where the ratio of the hypotenuse to the side opposite ∠e is the same in both cases. Therefore you can determine relative air mass (p/d) by measuring the triangle formed by the solar gnomom and its shadow.

There are several ways to find relative air mass depending on the mathematical sophistication of your students. If your students only know arithmetic, have them measure c directly as suggested in the steps below.

Equation 1 Relative Air Mass = $\frac{c}{h}$

If your students know a bit of geometry and understand square roots, then you can measure the length of the shadow (r) and the height of the gnomon (h), and:

Equation 2 Relative Air Mass = $\frac{c}{h}$

$$= \sqrt{\frac{h^2 + r^2}{h^2}} \qquad = \sqrt{1 + \frac{r^2}{h^2}}$$

If your students understand trigonometric functions, you can measure ∠e, and:

Equation 3 sin(e)=h/c

Equation 4 Relative Air Mass = c/h = 1/sin(e)

Ask the students to speculate about how the relative air mass will affect the intensity of the sunlight that an observer on the ground would see. The important concept for the students to understand is that the longer the pathlength, the less sunlight shines through. This happens even in a clear atmosphere, as students can see by observing that sunlight is not as strong near sunrise and sunset as it is at noontime.

Also note that outside the tropics, the sun is never directly overhead and the relative air mass is always greater than one.

Students may ask why the sun looks redder at sunrise and sunset than at noontime. Sunlight's path through the atmosphere is longest at sunrise and sunset, so the number of gas molecules and particles that can scatter the sunlight is greatest at these times. The gases in the atmosphere scatter blue light more strongly than red light. At sunset, when the relative air mass is high, the orange and red color dominates because almost all the violet, blue, green, and yellow light has been scattered leaving only the red and orange hues (wavelengths). The relative amounts of different wavelengths in sunlight combined with the relative amount of scattering by gases in the atmosphere gives us our blue sky. During most of the day when we look at the sky and not at the sun, the light reaching our eyes is scattered sunlight, and blue is the predominant color. Aerosols in the sky tend to make the sky look less blue and more milky.

What To Do and How To Do It

1. Organize the class into working groups of three students per group.
2. Select a day that is sunny. Unless your school is at relatively high latitude (higher than ~ 50˚ N or S), this activity is best done before mid morning or after mid afternoon.
3. Find a flat site outside that will not be shaded during the activity. Place a solar gnomon (wooden dowel or other straight object) at least 50 cm in height in the ground. Use a string with a weight on the end or a level to make sure that the pole is perpendicular to the ground. Measure the length of the gnomon above the ground and record it on the *Calculating Relative Air Mass Work Sheet*. Next, measure the distance from the top of the pole to the end of the shadow. This is the hypotenuse of the triangle. Use a tape measure or a string to measure the distance. Have the three students in each group do this reading independently and record the readings on the *Calculating Relative Air Mass Work Sheet.*
4. Have students average the hypotenuse lengths.

Figure AT-AM-2A: Simple Model of Relative Air Mass

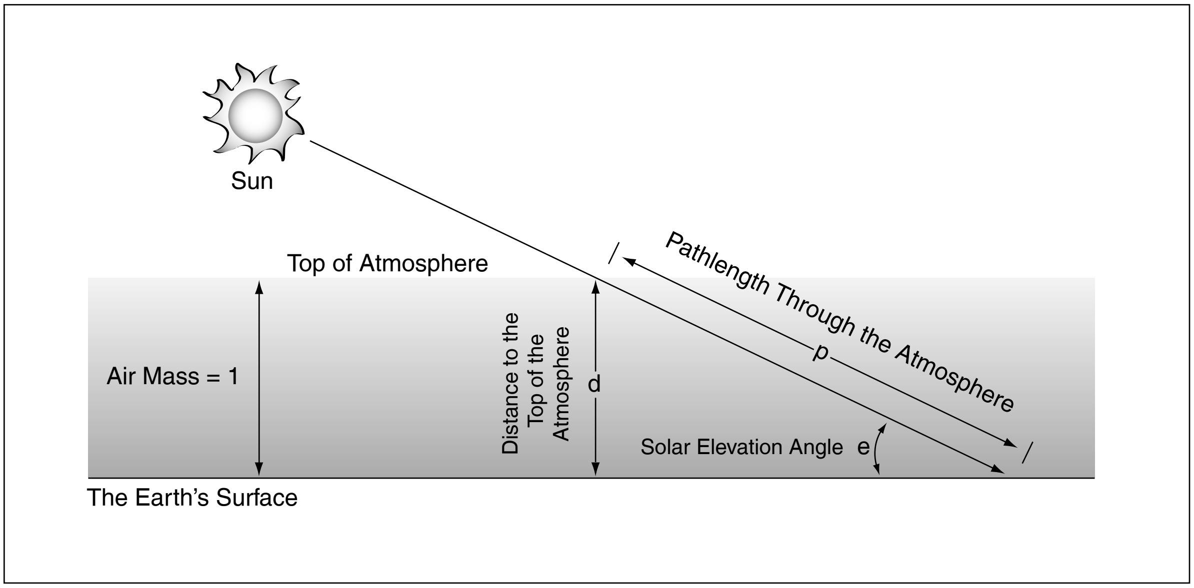
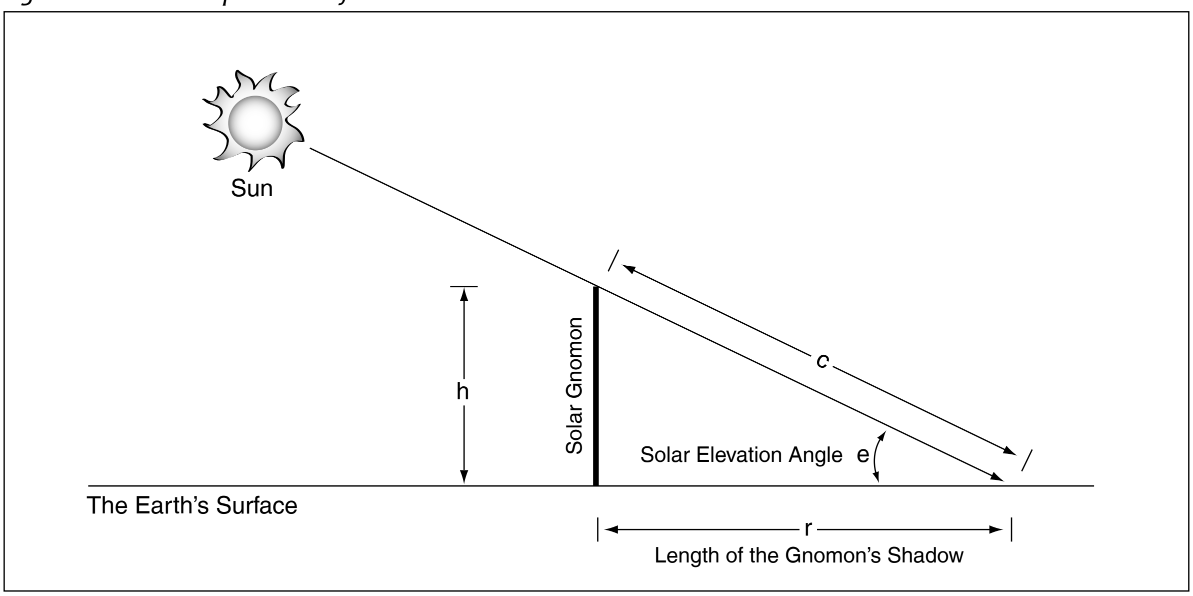


Figure AT-AM-2B: Simple Model of Relative Air Mass



Deriving Relative Air Mass

1. Calculate the relative air mass value for each of five days using Equations 1 or 2.
2. Ask students the following questions: How do you think the relative air mass readings might change if your readings were taken at different times throughout the day? How might relative air mass readings taken at the same time of the day, differ at different times of year?

Variations for Older Students

Have students measure and average the length of the shadow instead of the hypotenuse and calculate relative air mass using Equation 2.

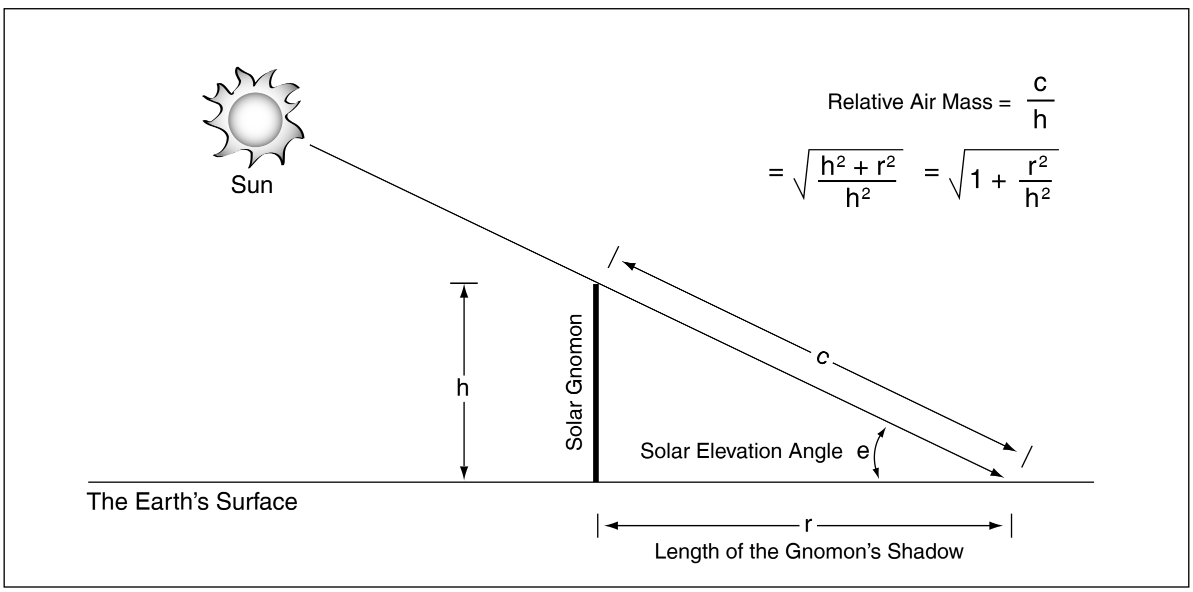
Have students measure the solar elevation angle and use Equations 3 and 4 to calculate relative air mass.

Calculating Relative Air Mass

Data Sheet

1. During a day that will be sunny in the morning, set up a solar gnomon outside. Work in groups of three and measure the height of the gnomon and length of the hypotenuse of the triangle formed by the solar gnomon and the shadow it casts using a meter stick, or if the shadow is very long, a tape measure. Have another member of your group help you by holding the meter stick or tape measure at the top of the pole while you read the length at the end of the shadow. Have each member of your group make these measurements. Record the name of the student in your group and each of your measurements in the table below.

Student Name	Local Time	Universal Time	Pole Height (h)	Hypotenuse Length (c)
1.				
2.				
3.				
		Average		



2. Calculate the average hypotenuse length by taking the sum of the readings from the three partners and dividing by 3. Write the average hypotenuse length value for your group on the table above.

3. Calculate relative air mass (m) from the equation. $m = \frac{c}{h}$

4. How do you think the relative air mass reading might change if you took the measurement at different times throughout the day?

5. How might relative air mass readings taken at the same time of the day, but during different seasons differ? Explain.