Title:
What Orbital Dynamic Variables Are Responsible For Earth's Weather?

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Background:
A common misconception of an introductory astronomy student is that the changing distance of Earth from the Sun (an elliptical orbit) is responsible for Earth's changing seasons. Using an Earth/Sun orbit model, the student will determine which of two orbital dynamic variables - eccentric orbit or inclined axis of rotation, is responsible for Earth's changing seasons.

Pre-Lesson Vocabulary & Concept Introduction

- Plane of the Ecliptic - The plane of the Earth's orbit around the Sun.
- Conical Orbit Paths as defined by Kepler
- Eccentricity - The elliptical motion of the Earth about the Sun
- Perihelion – The closest distance of Earth from the Sun. For Earth this occurs about January 3, at which time Earth is some 1.55 10^6 mi (2.5 10^6 km) closer to the Sun than its mean distance of 93.0 10^6 mi (149.6 10^6 km).
- Aphelion – The farthest distance of Earth from the Sun. When Earth is only 1.55 10^6 mi (2.5 10^6 km) farther from the Sun than at its mean distance of 9.3 10^6 mi (1.496 10^6 km).
- Polaris - The star Ursae Minoris, also known as the North Star or Pole Star. Earth's northern hemisphere is always pointed at the North Star.
- Axis of inclination - The 23.5˚ angle at which Earth's rotation axis deviates from the ecliptic plane
- Equator
- Hemisphere
- Tropic of Cancer-23.5 degrees south of the equator
- Tropic of Capricorn – 23.5 degrees south of the equator
- Solstice - When the sun nadir intersects the latitudes of either the Tropic of Cancer or Capricorn
- Equinox - When the sun nadir intersects the equator
- Sun ray travel paths – The discussion will demonstrate why the area on Earth's surface that receives the maximum solar input corresponds the shortest travel path vector of a sun ray.
- May include a discussion of the effects of atmospheric deflection of sunlight. This introduction can be introduced in order to ask higher order questions of why it is colder in regions away from the Earth's surface that is receiving the maximum levels of solar input.

Objectives:
- The student will construct an Earth/Sun model of planet revolution that incorporates the previously introduced orbital geometry concepts identified above.
- The student will record Earth/Sun relative distance and Sun nadir observations acquired from model simulation of Earth's relative position and geometry at each solstice and equinox.

- The student will compare the solstice/equinox orbital position observations in order to determine which orbital position variable controls Earth's changing seasons.

Standards:

Standard 1: Science as Inquiry

1SC-E1. Identify a question, formulate a hypothesis, control and manipulate variables, devise experiments, predict outcomes, compare and analyze results, and defend conclusions

- Conduct an experiment using a scientific method
- Analyze the results of an experiment
- Defend conclusions drawn from the analysis

1SC-E2. Create a model (e.g., a computer simulation, a stream table) to predict change

- Construct a model that demonstrates change within a system
- Describe variables that cause change
- Explain cause and effect of variables within a system

1SC-E3. Organize and present data gathered from their own experiences, using appropriate mathematical analyses and graphical representations

- Construct a representation of data (e.g., histogram, stem-and-leaf plot, scatter plot, circle graph, flow chart)
- Interpret patterns in collected data

Standard 2: History and Nature of Science

2SC-E3. Provide different explanations for a phenomenon; defend and refute the explanations

- Analyze different theories to explain a phenomenon
- Defend or refute the explanation of a phenomenon

Standard 6: Earth and Space Science

6SC-E1. Describe and model the motion of earth in relation to the sun, including the concepts of day, night, season and year

Materials:

- 4 to 5 inch diameter Styrofoam ball (Earth), thin gauge wire, 2 to 3 inch thick Styrofoam block, a light source (flashlight or light bulb, see Figure 1 in Appendix i), ~ 20,,x30,, foam board, string, push tacks, toothpicks, rubber bands and marker. The above materials can be found at craft and hardware stores.
- Datasheets and questions (Appendix ii)

Time:

3-4 days

Grade Level:

6-8th grade

Procedure:

- Students will be assigned to groups of four. All work is to be completed as a group.
- Using two push tacks, string and marker, each group will draw an ellipse onto the foam board (i.e., http://www.nasaexplores.com/lessons/01-079/k-4_1-t.html) in order

to demonstrate Earth’s elliptical orbit path. The ellipse perimeter at the short axis should touch the perimeter of the foam board.

- Beginning at a point along the perimeter of the ellipse that intersects the ellipse’s short-axis, write on the foam board the constellation Cancer. Fill in the remaining constellations of Libra, Capricorn and Aries as shown in Figure 1. Tell the students where the position of the North Star is relative to the constellations.
- For each Styrofoam ball, place three rubber bands onto the ball such that the rubber bands are all at right angles with respect to each other. At two of the rubber band intersections, insert a toothpick into each rubber band intersection such that the toothpicks simulate a rotational axis.
- Using the marker and the rubber band equator as a guide, draw on the ball the latitudes that correspond to Cancer and Capricorn.
- Insert a short piece of wire into the Styrofoam block and mount the globe onto the remaining end of wire. The globe should be mounted such that its rotational axis is at a ~23.5˚ tilt relative to the mounting wire.
- Position the light source on the foam board along the ellipse long axis and slightly closer to the constellation of Libra. Position Earth along the ellipse perimeter and in the constellation of Cancer.
- Adjust the centers of the light source and globe such that their centers are at the same height relative to the foam board surface.
- Point the Earth’s north hemisphere rotation axis at the North Star.
- Using the instructions provided within the question hand out sheets, the students will notate orbital position observations at each solstice and equinox.

Evaluation:

- In order that the model be useful, the student will have to have a clear understanding of the introductory concepts (in particular, plane of the ecliptic and position and orientation of the axis of inclination) in order to configure the proper orientations of the Earth/Sun model. During the experiment, the teacher will be able to note the student’s comprehension by visual observation of the model orientation.
- A grading rubric for the attached question sheets is provided (Appendix iii).

Extensions:

- Moon journals- Along with incorporation of a moon in the Earth/Sun model, nightly journal recordings of the moon’s sky position will be used to determine the revolution and rotation direction of the moon around Earth.
- Determine the scale size of the moon and its distance from Earth relative to the size of the Earth model’s Styrofoam ball.

Appendix I

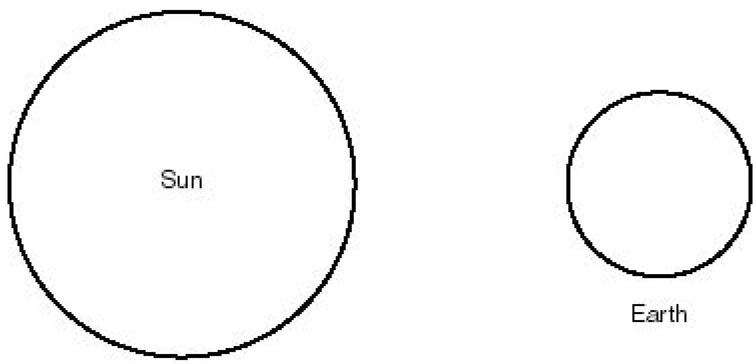
Figure 1. - Student made model based on this lesson. Note optional moon Extension Lesson incorporated into model design.

Appendix ii
Question forms.

In each of the below orbital positions, Earth's orientation will be such that either a solstice or equinox is occurring.

Position 1 (Earth Positioned within Cancer)

1. Using the Sun/Earth diagram below,
    a. Draw the proper orientation of Earth's rotation axis and equator relative to the sun.
    b. Draw the most direct sunray path and at least two longer sunray paths that intersect Earth's surface.
    c. Finally, draw the proper orientation and location of the tropics of Capricorn and Cancer.

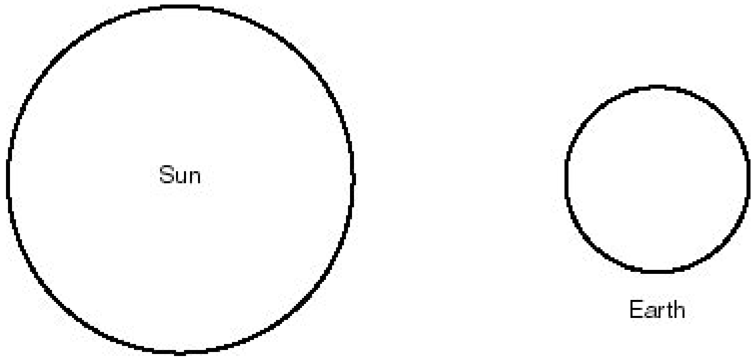


2. Of the three latitudes drawn on the globe (Tropics of Cancer and Capricorn and the equator) which one receives the most direct sunlight path?

3. Does this orientation correspond to an equinox or solstice position of Earth? In Table 1 on page 4, write your answer in Column 1 of the appropriate row.
4. During daylight hours on the two hemispheres, which of Earth's hemispheres receives the majority of the suns energy? In Table 1 on page 4, write your answer in Column 2 of the appropriate row.
5. With respect to Earth's position along its elliptical orbit, is Earth relatively closer to or further away from the sun? In Table 1 on page 4, write your answer in Column 3 of the appropriate row.
6. What astrological sign is blocked from Earth's field of view by the sun?

Position 2 (Earth Positioned within Libra)

7. Using the Sun/Earth diagram below,
    a. Draw the proper orientation of Earth's rotation axis and equator relative to the sun.
    b. Draw the most direct sunray path and at least two longer sunray paths that intersect Earth's surface.
    c. Finally, draw the proper orientation and location of the tropics of Capricorn and Cancer.

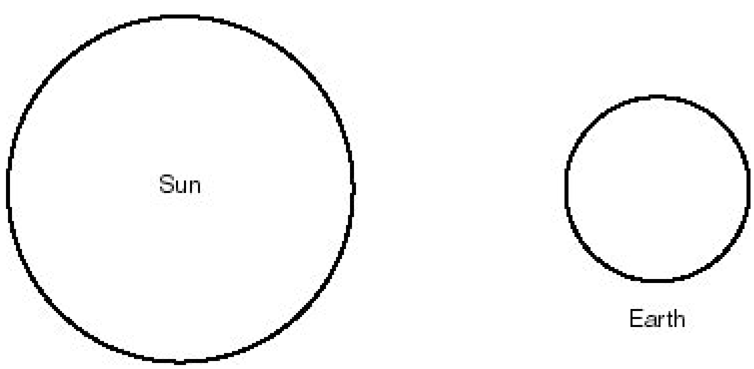


8. Of the three latitudes drawn on the globe (Tropics of Cancer and Capricorn and the equator) which one receives the most direct sunlight path?

9. Does this orientation correspond to an equinox or solstice position of Earth? In Table 1 on page 4, write your answer in Column 1 of the appropriate row.
10. During daylight hours on the two hemispheres, which of Earth's hemispheres receives the majority of the suns energy? In Table 1 on page 4, write your answer in Column 2 of the appropriate row.
11. With respect to Earth's position along its elliptical orbit, is Earth relatively closer to or further away from the sun? In Table 1 on page 4, write your answer in Column 3 of the appropriate row.
12. What astrological sign is blocked from Earth's field of view by the sun?

Position 3 (Earth Positioned within Capricorn)

13. Using the Sun/Earth diagram below,
    a. Draw the proper orientation of Earth's rotation axis and equator relative to the sun.
    b. Draw the most direct sunray path and at least two longer sunray paths that intersect Earth's surface.
    c. Finally, draw the proper orientation and location of the tropics of Capricorn and Cancer.

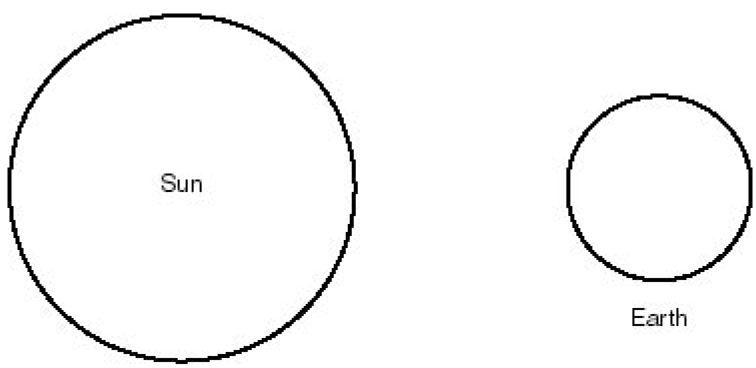


14. Of the three latitudes drawn on the globe (Tropics of Cancer and Capricorn and the equator) which one receives the most direct sunlight path?

15. Does this orientation correspond to an equinox or solstice position of Earth? In Table 1 on page 4, write your answer in Column 1 of the appropriate row.
16. During daylight hours on the two hemispheres, which of Earth's hemispheres receives the majority of the suns energy? In Table 1 on page 4, write your answer in Column 2 of the appropriate row.
17. With respect to Earth's position along its elliptical orbit, is Earth relatively closer to or further away from the sun? In Table 1 on page 4, write your answer in Column 3 of the appropriate row.
18. What astrological sign is blocked from Earth's field of view by the sun?

Position 4 (Earth Positioned within Aries)

19. Using the Sun/Earth diagram below,
    a. Draw the proper orientation of Earth's rotation axis and equator relative to the sun.
    b. Draw the most direct sunray path and at least two longer sunray paths that intersect Earth's surface.
    c. Finally, draw the proper orientation and location of the tropics of Capricorn and Cancer.



20. Of the three latitudes drawn on the globe (Tropics of Cancer and Capricorn and the equator) which one receives the most direct sunlight path?

21. Does this orientation correspond to an equinox or solstice position of Earth? In Table 1 on page 4, write your answer in Column 1 of the appropriate row.
22. During daylight hours on the two hemispheres, which of Earth's hemispheres receives the majority of the suns energy? In Table 1 on page 4, write your answer in Column 2 of the appropriate row.
23. With respect to Earth's position along its elliptical orbit, is Earth relatively closer to or further away from the sun? In Table 1 on page 4, write your answer in Column 3 of the appropriate row.

24. What astrological sign is blocked from Earth's field of view by the sun?

Table 1.

Position #	1	2	3	4	5
	Equinox or Solstice?	Hemisphere of maximum solar input.	Earth's relative distance from sun.	Northern Hemisphere Season based on Column 2.	Northern Hemisphere Season based on Column 3.
1					
2					
3					
4					

1. For each Earth orbit position in Table 1, based on your associated answer in Column 2, discuss with your lab partners which season is likely to be occurring in the northern hemisphere. Write your answer in Column 4 of Table 1.
2. For each Earth orbit position in Table 1, based on your associated answer in Column 3, discuss with your lab partners which season is likely to be occurring in the northern hemisphere. Write your answer in Column 5 of Table 1.
3. From your answers in Columns 4 and 5, which column accurately describes Earth's changing seasons? Explain using all of your observations.

4. Of the two orbital variables (eccentricity and axis inclination) which is most important in controlling Earth's seasonal variations?

Example Extension Questions

1. Which direction (clockwise or counter) does Earth need to rotate on its axis in order for the observed rising of the sun in the east and setting in the west?

2. For a given earth orbital position, starting with the moon between the earth and sun, in a counterclockwise fashion rotate the moon a quarter of the way around the earth.
   a. For a person located on the darkside of Earth, how much of the moon is illuminated? In the space provided, sketch a diagram of the moon showing the illuminated and sun-shaded regions.

   b. Rotate the moon another quarter-turn around the Earth. Earth should now be between the sun and moon. How much of the moon is illuminated? Sketch a diagram of the moon showing the illuminated and sun-shaded regions.

   c. Rotate the moon another quarter-turn. How much of the moon is illuminated? Sketch a diagram of the moon showing the illuminated and sun-shaded regions.

   d. Rotate the moon another quarter-turn. How much of the moon is illuminated? Sketch a diagram of the moon showing the illuminated and sun-shaded regions.

3. Relative to the earth and sun, where must the moon be located in its orbit around Earth so that the moon looks full to a person located in the shaded area of Earth?

4. Where must the moon be located so that the moon appears completely dark to a person located in the shaded region of Earth?