Vertical Challenge

Overview: Students create a scale model depicting the vertical distance from Earth's surface to various features and objects, including Earth's atmospheric layers, the Van Allen Radiation Belts, and geocentric satellites. Students also compare the vertical distances to these features and objects with distances from their classroom to other common points on the ground.

Target Grade Level: 5-8

Estimated Duration: About 90 minutes

Learning Goals: Students will…

- estimate the altitude of layers and objects above Earth's surface, and then place them at the correct vertical distance.
- better appreciate how solar events can impact communications and navigation on Earth.
- create scale model from Earth's surface to various atmospheric layers, radiation belts, and the Moon.
- compare vertical and ground-based distances to better understand the distance from Earth to its layers and satellites.

Standards Addressed:

Next Generation Science Standards ©

MS-ESS1 Earth's Place in the Universe; DCI: MS-ESS1.B: Earth and the Solar System; S&EP: Developing and Using Models

Benchmarks (AAAS, 2009)

Common Themes; B: Models, D: Scale

National Science Education Standards (NRC, 1996)

Unifying Concepts and Processes: Evidence, models, and explanation

Principles and Standards for School Mathematics (NCTM, 2000)

Number and Operations; Representation

Contents:

Background Science:

When we talk about the distance to a nearby town or a city across the country, most of our students have a framework of understanding based on their everyday experiences. However, when we talk about vertical distances or altitudes, such as how far away the Moon is from Earth, we venture into concepts and scales that are less familiar. In this activity we will build on familiar experiences and models to help students better understand what layers and objects are "up" above their heads and how far away those layers and objects are from Earth's surface. In addition, after completing this activity students will better appreciate how solar events can affect communications and navigation on Earth.

Vertical distance and altitude are simply the distance in the "up" direction from a reference point, such as sea level or Earth's surface. Many of your students have likely heard a pilot announce the altitude at which a commercial airplane is cruising, which is roughly 35,000 feet (about 11 km). It might be surprising to students to compare that altitude to a distance on the ground, such as from your school to a familiar landmark.

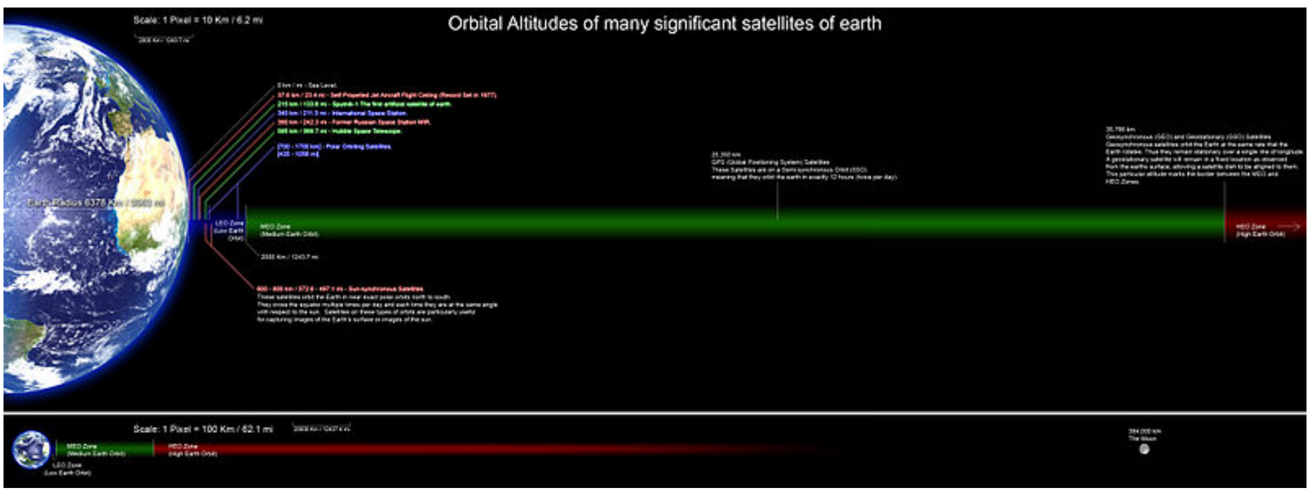


Figure 1. A scaled diagram showing the orbital altitudes of several significant satellites of Earth. For a larger version, please visit the source: http://upload.wikimedia.org/wikipedia/commons/8/82/Orbitalaltitudes.jpg (Image courtesy: Mark Mercer, Wikipedia Commons).

What is up there? Satellites!

Up in the sky one might see objects that fly close to Earth's surface, such as hot air balloons, prop planes, and commercial airplanes. In areas with dark skies at night, if you look long enough, you can often see dim satellites travelling across the sky in their orbit about Earth. We have many man-made satellites orbiting Earth, but only one natural satellite—the Moon.

Table 1. Altitude Classifications

Low Earth Orbit (LEO): 0 – 2,000 km (0 – 1,240 miles)

Medium Earth Orbit (MEO): 2,000 – 35,785 km (1,240 – 22,235 mi)

Geosynchronous Obit (GEO)/Geostationary Orbit: 35,786 km (22,236 mi)

High Earth Orbit (HEO): Above 35,786 km (22,236 mi)

Again, it might be surprising to students that the International Space Station and the Hubble Space Telescope orbit Earth within the same zone that airplanes travel (see Table 1). The International Space Station orbits between 309 and 436 km (192-288 mi) above Earth and the Hubble Space Telescope orbits at an altitude of 595 km (370 mi). Also within this zone are polar orbiting satellites that provide long-term weather forecasting, environmental monitoring, and general Earth observing.

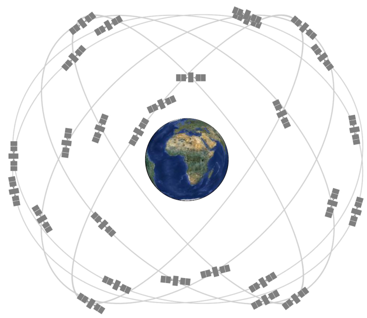


Figure 2. The expandable 24-slot Global Positioning System (GPS) satellite constellation. (Image courtesy: GPS)

In the Medium Earth orbit (MEO) zone are the group of at least 24 satellites that are likely most common to you and your students: the Global Positioning System. Each of these satellites orbits at about 20,200 km (12,550 mi), circling the Earth twice a day. They are configured such that at least four are in view from anyplace on Earth at any given time.

Separating MEO from High Earth orbit (HEO) is the Geosynchronous and, a special case of that, the Geostationary orbit. This very unique altitude of 35,786 km enables satellites to orbit at the same rate as the Earth rotates—24 hours in both cases. Therefore, satellites in geosynchronous orbit remain at the same longitude over Earth *all the time*. If a satellite is in a geosynchronous orbit directly over the equator the satellite appears to be motionless above a point on Earth or *geostationary*. This is helpful for communication satellites, such as the DISH® Network, where the users on the ground mount a dish in a fixed orientation, which is aimed at the geostationary satellite overhead. When you check your favorite weather web site you are probably accessing data and images from the Geostationary Operation Environmental Satellites (GOES). GOES satellites monitor Earth weather and solar activity or "space weather."

Satellites in HEO, beyond geosynchronous orbit, include the network of Cluster II, which is a joint mission between the European Space Agency (ESA) and NASA. The four Cluster II satellites are providing a detailed three-dimensional map of Earth's magnetosphere as they orbit the poles at a distance of between 19,000 and 119,000 km (11,800-73,900 mi).

Last, but not least, far beyond the artificial satellites that orbit Earth resides our only natural satellite, the Moon. The average distance from Earth to the Moon is about 384,430 km (238,870 mi).

What is up there? Layers!

In addition to many objects orbiting Earth, we are surrounded by atmospheric layers. Many of your students will already be familiar with the atmospheric layers, which could be helpful scaffolding as we explore the vertical distance to the Van Allen Radiation belts and other objects to which students are likely less familiar. A full discussion of Earth's atmospheric layers is beyond our scope, but if you want a review see this resource: http://www.srh.noaa.gov/jetstream/atmos/layers.htm.

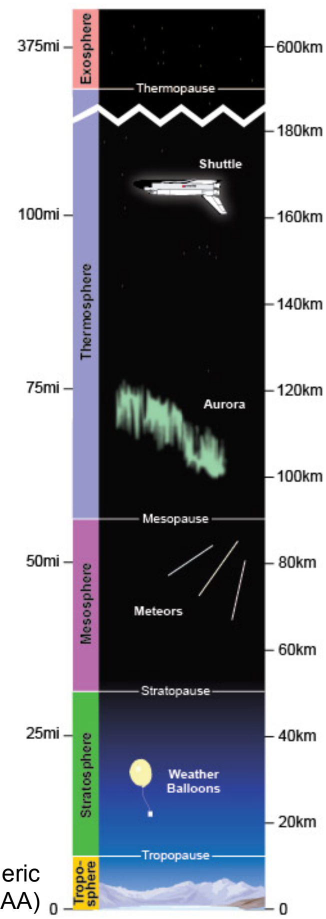


Figure 3. Earth's atmospheric layers. (Image courtesy: NOAA)

What is up there? Belts!

Often overlooked, yet near-neighbors with the atmospheric layers are the Van Allen Radiation belts. They are modified donut-shaped regions encircling Earth, where high-energy (i.e. fast-moving) particles such as protons and electrons are trapped by Earth's magnetic field. The Van Allen belts also happen to span a region that includes the orbit of many satellites. From Earth's surface at the equator the inner belt can span from about 600 -6,000 km (370 – 3,700 mi) and the outer belt spans from roughly 10,000 – 65,000 km (6,200 – 40,000 mi).

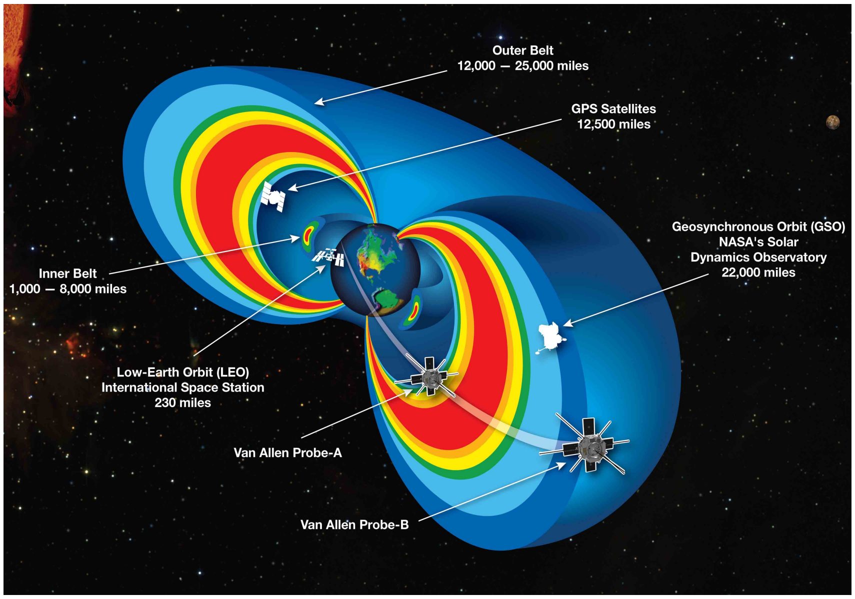


Figure 4. A cutaway model of the Van Allen radiation belts. The graphic also includes the Van Allen Probes and other satellites near the region of trapped radiation. NOTE: This image is not to scale! (Image courtesy: NASA)

Are the radiation belts brightly colored? No! The colors here are used to represent conditions that are not actually apparent visually; red indicates areas where there are a lot of high-energy particles, yellow areas are a little less intense, and green and blues have the least radiation. In reality, if you were to stand in the middle of the radiation belts, you wouldn't be able to see them at all!

Watch a video of these dynamic belts, "Van Allen Probes Reveal A New Radiation Belt Around Earth": http://vanallenprobes.jhuapl.edu/gallery/video.php

While the Sun may look the same every day to us from Earth, in fact the Sun's surface is quite dynamic and so is the steady stream of particles, such as electrons and protons, that is constantly released from the Sun's surface. Sometimes the Sun releases a lot of these particles at once in an event called a Coronal Mass Ejection (CME). The Van Allen belts response to these solar storms is variable. For example, sometimes after a solar storm the number of particles can increase dramatically, and their speeds can become close to the speed of light. Other times after similar space weather events the particles decrease in number and speed, and sometimes conditions seem to stay the same. The Van Allen Probes have even recorded the formation of a capricious third belt that persisted for about a month.

Figure 5. The source of space weather, our dynamic Sun, shown with a coronal mass ejection that will interact with the Earth's magnetosphere producing geomagnetic storms. (Image courtesy: NASA)

What is radiation?

You may have heard the term radiation used in different ways, such as in relation to medicine, to the Sun, or even to heat. Sometimes it refers to electromagnetic waves of energy like x-rays or gamma rays in the electromagnetic spectrum, other times to fast moving particles. When we talk about radiation in the Van Allen belts we are referring to electrically charged particles such as protons and electrons moving very fast. Sometimes these particles move close to the speed of light, about

300,000 km/s (186,000 miles per second). The faster something moves the more energy it has. Even tiny particles like electrons that are moving close to the speed of light have so much energy that they can cause electrical damage or degrade any materials they encounter.

Why do we want to study the Van Allen belts?
The Van Allen Probes are exploring this mysterious space weather that can impact our way of life as we become increasingly dependent upon space-based infrastructure. Many of the Earth-orbiting satellites that we depend on for communication, GPS navigation, weather forecasting, and much more are within the Van Allen belts. Extreme space weather can disable these satellites, cause power grid failures, harm astronauts, and disrupt GPS services. If you think this doesn't apply to you, think again! GPS navigation is used in precision agriculture, transporting food to a grocery store, and in your automobile navigation system. Communication satellites help transmit news, cellular phone data and voice, and long distance service. What we learn will be used by engineers to design radiation-hardened spacecraft and satellites and will be used by forecasters to warn astronauts and spacecraft operators of hazardous conditions.

Earth's radiation belts also provide a perfect laboratory to understand many other places in the universe that are known to have similar processes but are farther away and therefore more difficult to study. We have a place in Earth's own back yard that can provide answers to some of the mysteries of our galaxy and beyond.


Figure 6. The identical Van Allen Probes follow similar orbits that take them through both the inner and outer radiation belts. (Image courtesy: JHU/APL)

The Van Allen Probes
To help us understand how the Earth responds to changes in the Sun's energy, and how that response affects life and society, NASA launched the twin Van Allen Probes on August 30, 2012. The Van Allen Probes spacecraft will investigate this extreme region of space for a minimum of two years, searching for answers to critical questions about the behavior of the Van Allen Radiation Belts. The spacecraft chase each other in nearly the same orbit, investigating the storms in the radiation belts caused by our Sun, gathering data to better understand this region and how it affects our modern way of life.

To learn more about the Van Allen Probes mission, check out some of these links:

- What are the Van Allen Radiation Belts and how did they get their name? Who is Van Allen?: http://vanallenprobes.jhuapl.edu/science/overview.php
- Van Allen Probes Mission Goals or "Science Questions": http://vanallenprobes.jhuapl.edu/science/questions/questions.php
- Learn from some of the Mission Scientists via these questions and video responses: http://vanallenprobes.jhuapl.edu/mission/conversation/overview/index.php
- How does the spacecraft detect invisible particles?: http://vanallenprobes.jhuapl.edu/spacecraft/instruments/index.php

Materials:

- What's Up There? Student Reading (3 pages, 1 per student)**
- Vertical Challenge worksheet (4 pages, 1 per student)
- Vertical Distance chart (6 pages, 1 set per group)
- Layers and Objects cut-outs (1 set per group)**
- Clear tape (1 roll per group)
- Masking tape (1 roll per group)
- Scissors (1 per student)
- Colored pencils (1 set per group)
- Altitudes Table (1 per group, cut on dotted line) NOTE: Do not distribute with above materials. See In-Class Procedure step 5.

** Save paper and create one classroom set for re-use with each period!

NOTE: You could laminate the Vertical Distance chart pages and students could use transparency markers to indicate layers

Procedure:

Generally speaking…

The teacher will: Introduce students to the activity by talking about vertical distances, using concepts from the Background section (p. 2) as desired and assigning **What's Up There** student reading (p. 7). Divide the class into groups and allow groups to gather and assemble materials, as outlined in the Procedure section, below. Groups will spend 5 minutes placing **Layers and Objects** cut-outs on the **Vertical Distance** charts, followed by a teacher-led discussion of group choices. Then distribute the **Altitudes Table** and allow groups to move the **Layers and Objects** cut-outs to the correct location on the **Vertical Distance** chart (5 minutes). Lead the class in a discussion about observations and conclusions, based on questions and answers provided in the Procedure section, below. Finally, assign students to complete Part 2 of the **Vertical Challenge** worksheet as homework (which can also be used for assessment).

The students will: Read **What's Up There** student reading and then gather and assemble materials as instructed by the teacher and as indicated in the "Assembly Instructions" of the **Vertical Challenge** worksheet. Groups will estimate where **Layers and Objects** cut-outs should be placed on their **Vertical Distance** chart based on group consensus and record the estimated altitudes in their **Vertical Challenge** worksheets. After a class discussion about estimated altitudes, the students will be given the **Altitudes Table** and move their **Layers and Objects** cut-outs accordingly. Students will use vertical lines and arrows to indicate layers or features that span across multiple altitudes. As homework, students will complete Part 2 of the **Vertical Challenge** worksheet, in which they look for features on the surface of the Earth that are equal in distance to many of the vertical distances they explored in Part 1 of the activity using Google Earth.

<u>**In-Class Procedure**</u>

PART 1: Vertical Challenge

1. **WARM UP** Distribute and ask students to read What's Up There student reading (p. 7). Ask students what all of these have in common: long distance phone communications, television broadcasts, weather forecasting, cell phone communications, and GPS navigation. Answer: they all use satellites for some part of their functions. Discuss how

we don't often think about satellites, even though many of our every-day activities use satellites. Use information in the Background section to talk about how many of these satellites orbit Earth within an area of high radiation known as the Van Allen Belts. Explain that we will be looking at where satellites and other objects orbit with respect to the Earth's atmospheric layers and the Van Allen Belts. Be sure students are familiar with vertical distance or altitude, which is the distance in the "up" direction from a reference point, such as sea level or Earth's surface.

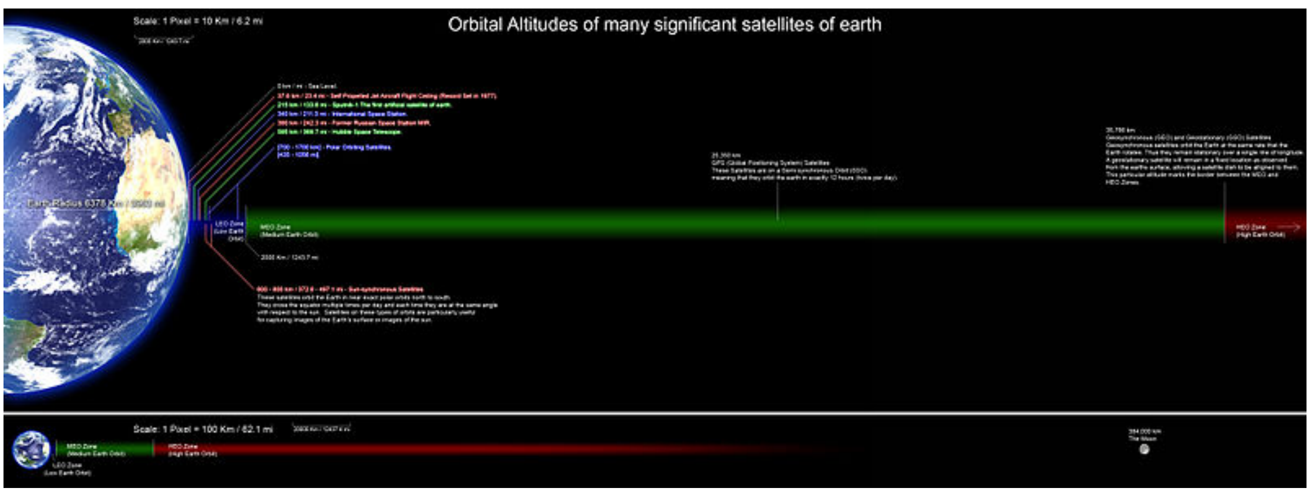
2. Assign students to groups of about 5 and provide each group with the materials listed in the Materials section, above. Each group should have all of the materials listed *except* the Altitudes Table, which you will hand out mid-way through the activity.
3. After students have gathered materials, have each group assemble their Vertical Distance chart and cut out the Layers and Objects, as indicated in the "Assembly Instructions" section of their Vertical Challenge worksheet.
4. Once ready, the teacher will help groups tape their Vertical Distance charts to the wall and then travel between groups, helping where necessary, as students estimate the placement of the Layers and Objects cut outs on the Vertical Distance chart. Remind students to record their estimated elevations for Layers and Objects in their Vertical Challenge worksheets. Allow about 5 minutes for this step.
5. When groups appear to be wrapping up, lead the class in a discussion about why groups chose the placement they did, allowing groups to justify their estimations. Then distribute an Altitudes Table to each group and allow groups to move the Layers and Objects cut outs to the correct locations, coloring in features, such as the Van Allen Belts, that span a vertical distance, as indicated in the Vertical Challenge worksheet.
6. After the Vertical Distance charts are complete, with the corrected placement of Objects and Layers (and features that span altitudes are indicated with colored arrows), allow students a few minutes to complete their Vertical Challenge worksheet questions and then lead a class discussion about where many of the satellites are with respect to the Van Allen Belts. Use the Background information to help guide your students to appreciate the significance of this fact. Here are some sample discussion questions:
   - "Where do many of the satellites appear to be with respect to the Van Allen Belts?" (A: Within the Belts).
   - "What do we know about the Van Allen Belts?" (A: They are doughnut-shaped regions around Earth with high-energy particles, such as protons and electrons.)
   - "What are the satellites within the Van Allen Belts used for?" (A: Communication, navigation, weather prediction, etc.).
   - "Why do you think it is important to learn more about how space weather events can affect the Van Allen Belts?" (A: Because then we can better understand how space weather events will affect our satellites and we can build satellites that will better withstand the space weather events and the environment of the Van Allen Belts).

   7. Finally, ask students to complete Part 2 of the Vertical Challenge worksheets as homework. This worksheet can also be used as an assessment tool. NOTE: you may wish to assign specific cities and states for the "Google Earth" portion of the homework. Also note that if internet access could be a problem for students you should do Part 2 in a computer lab or as an in-class demonstration.

What's Up There?

How far is your home from school or a neighboring city? You can probably estimate these distances in miles fairly easily. But do you know the distance between your home and central Australia? Probably not, although you likely know how to find such a number! When we talk about distances to objects in the solar system, such as the Moon, it is difficult to grasp because they are so much greater than our everyday experience here on Earth. And rather than distances across the ground, they are distances in the "up" or vertical direction. What can we use to help us make exceptionally large numbers seem more human-sized? A model!

In this activity we are going to use a *scale model* to explore the vertical distances to various objects and layers up above our heads. You might be asking, "Why should I care about the satellites and stuff above Earth?" Well it turns out that "stuff" is rather important for your everyday life! If you have used a cell phone, watched satellite television or a special news broadcast, looked up the weather predicted for today or next week, used a navigation system to get to a destination, or bought food at a grocery store from a far-away source, you have had help from a satellite!



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What's up there? Satellites!

Much like different seats in a stadium offer unique views of the game, satellites orbit at different vertical distances to offer unique perspectives of Earth. Orbiting close to Earth are the International Space Station, the Hubble Space Telescope, satellites that provide long-term weather forecasting, environmental monitoring, and general Earth observing.

If you have ever used a navigation system you have had help from a group of at least 24 satellites called the Global Positioning System. Each of these satellites orbits at about 20,200 km (12,550 mi), circling the Earth twice a day. They are configured such that at least four are in view from anyplace on Earth at any given time.

Sort of like 50 yard-line seats close to the field, there is a special altitude of 35,786 km (about 22,236 mi) where the speed of the satellite orbits at the same rate the Earth rotates—24 hours in both cases. Therefore, satellites in this *geosynchronous orbit* remain at the same longitude over Earth *all the time*. If a satellite is in a geosynchronous orbit directly over the equator the satellite appears to be motionless above a point on Earth or *geostationary*. This is helpful for communication satellites, such as the DISH® Network, where the users on the ground mount a dish in a fixed orientation, which is aimed at the geostationary satellite overhead. When you check your favorite weather web site you are probably accessing data and images from the Geostationary Operation Environmental Satellites (GOES). GOES satellites monitor Earth weather and solar activity or "space weather."

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What's up there? Layers!

Along with the many satellites orbiting Earth, we are surrounded by atmospheric layers. Hopefully you are already familiar with the atmospheric layers, but if not, you can check out Figure 2 or this website for a refresher: http://www.srh.noaa.gov/jetstream/atmos/layers.htm.

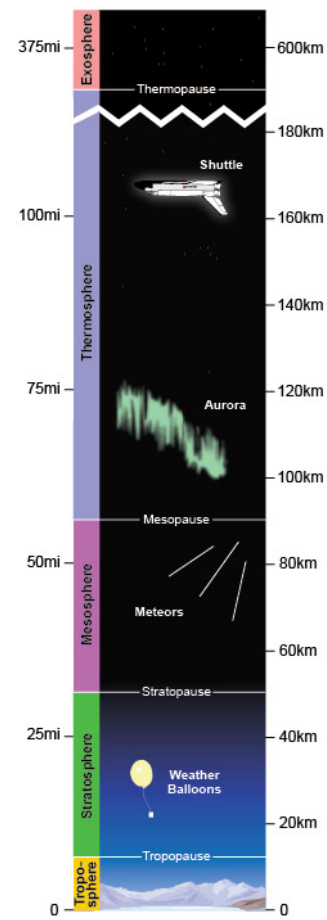

Figure 2. Earth's atmospheric layers. (Image courtesy: NOAA)

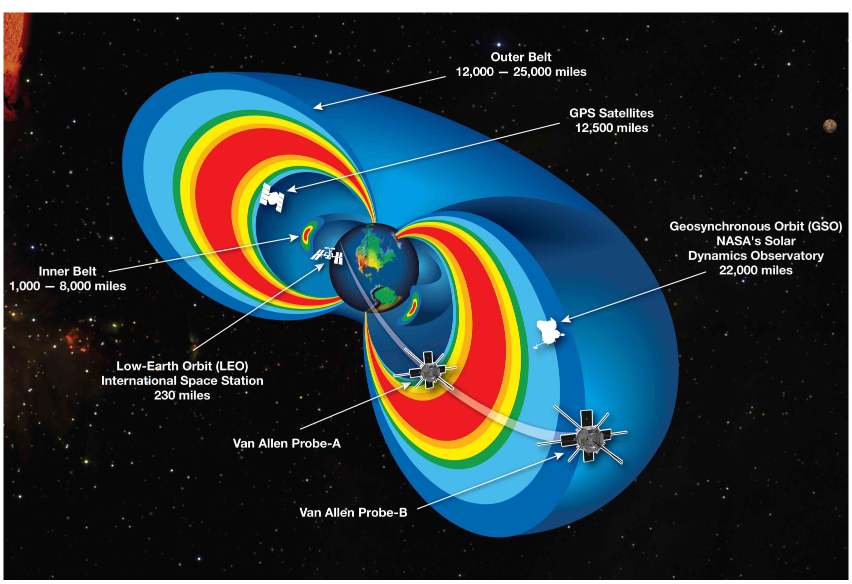

Figure 3. A cutaway model of the Van Allen radiation belts. The graphic also includes the Van Allen Probes and other satellites near the region of trapped radiation. NOTE: image not to scale. (Image courtesy: NASA)

Are the radiation belts brightly colored?
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Why should we care about these Van Allen belts? Well, if you care about the internet, your cell phone, or the power grid that makes those and other things you use work, then you might want to know a bit about solar storms and the radiation belts! Because many of the satellites that help your gadgets function spend some time within the harsh environment of the radiation belts.

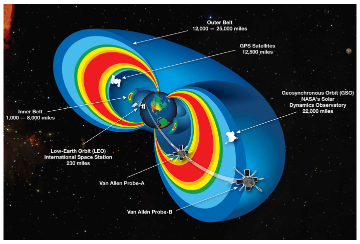
A Scale Model of What's Up There

As promised, to make all of these big numbers more manageable, we are going to use a scale model. Just like a map of the United States can fit on a single sheet of paper, the distant Van Allen Radiation Belts will fit on a few sheets of paper taped together in this activity. If you want to know the distance between two cities on a map, you have to refer to the scale on the map. The scale will tell you how an inch on the map is related to an actual distance, such as 1 inch = 100 miles. Our scale model uses a scale, too. And just like a map is an accurate, yet much smaller representation of real distances, our scale model is accurate, yet much smaller than the real distances.

How do we make a scale model?

In order to keep the proportion the same in the real system and in the scale model of that system, we use a *scale factor*. That means we divide (or multiply) all of the numbers in the actual system by the scale factor to get our numbers for the model. And lucky you…you will calculate the scale factor used for the Vertical Distance chart or model!

Can you think of other models you have used?



Name:____________________

Vertical Challenge

Students: Welcome to the Vertical Challenge, where you will explore what is high in the sky, above Earth's equator.

Assembly Instructions:

After you have gathered your group materials, you have 2 projects to divide and conquer:

1. You need to assemble your Vertical Distance chart (one per group). Have you ever seen a growth chart? The Vertical Distance chart is similar, but instead of using it to measure our height we will use it as a scale model to measure the distance from the Earth's surface to satellites, spacecraft and other objects. This distance happens to be a *vertical distance* or *altitude*. So start with "sea level" at the bottom and, using the clear tape, carefully tape all six pages in order end-to-end so that when you tape them to the wall the top of the chart is 60,000km and "sea level" is at the bottom. Then tape it up!
2. You need to cut out the Layers and Objects (one set per group). You know the drill…cut around each image + label, leaving labels attached to the appropriate image. After you have all of the Layers and Objects cut out, you need to put a little piece of masking tape at the top of each layer/object. (Or, if you want to make it fancy, you can roll up a bit of masking tape and put it on the back of each object/layer).

Part 1:

1. How high do you think these objects and layers are above Earth's surface (at the equator)? Think about it and record your own estimates in the table below in the "My Estimate" column. Remember, some of these might have an altitude range, such as "10-100 km". If you want to write your estimates in miles make sure to save room so you can convert those numbers to kilometers!

2. As a group, compare your individual estimates and come to a consensus to estimate the vertical distance to each object and layer and record it in the "Group Consensus" column. Then tape each object/layer to your Vertical Distance chart (using masking tape). If a layer spans a vertical distance (for example, from 20,000-64,000 km), place the name of the layer somewhere within that range and then draw a horizontal line at the top and bottom of the range, and connect the two by drawing a RED arrow from the bottom to the top of the layer. (Don't forget the units!)

	My Estimate	Group Consensus	Actual Altitude
Troposphere, Stratosphere & Mesosphere			
Hubble Space Telescope			
The Moon			
Van Allen Probes			
Inner Van Allen Belt			

Outer Van Allen Belt			
International Space Station			
Ionosphere			
Weather Satellite			
Communications Satellite			
Thermosphere			
GPS Satellite			
Earth Observing Satellite			

3. After you have received the Altitudes Table from your teacher, move the objects and layers to the appropriate altitude on the Vertical Distance Chart (again using masking tape). As before, make sure you indicate if a layer spans a vertical distance by connecting the top and bottom of the range with a BLUE arrow and place the name of the label within that range. Record the actual altitudes in the table above. Do all of the objects and layers fit on your Vertical Distance chart?

4. Step back and take a look at your Vertical Distance Chart and pay attention the layers and belts that span an altitude to answer the following questions.
   a. A communication satellite orbits within the ________________________.
   b. A GPS satellite orbits within the ________________________.
   c. A weather satellite orbits within the ________________________.

5. The Van Allen radiation belts are sort of doughnut shaped, but as you can see by looking at Figure 3 in "What's Up There?" the inside of these belts is "c" shaped. Near the Earth's poles the radiation belts reach as close as 400km above our surface. Which of the objects from your Vertical Distance chart orbit within this range and possibly at the poles, and therefore need to be concerned about potentially damaging radiation in the belts from active solar storms?

6. Why is it important to learn more about how space weather events affect the Van Allen radiation belts?

Part 2: Homework

At school you made a Vertical Distance chart, which was a scale model depicting the vertical distance from Earth's surface at the equator to various features and objects, including Earth's atmospheric layers, the Van Allen Radiation Belts, and geocentric satellites. Models help make really big numbers smaller and more human-sized (or, in some cases, really small numbers bigger). It is hard for us to image how high above our heads an airplane flies in comparison to the altitude of a GPS satellite, but when we can see them both on a scale model, like our Vertical Distance chart, it is easier to grasp these great distances.

1. In our Vertical Distance chart model, the actual vertical distances were scaled to fit onto 6 pieces of paper. Determine the scale used in this model, assuming the horizontal lines are 2.5 cm apart and represent a 1000 km change in altitude. (Please show your work).

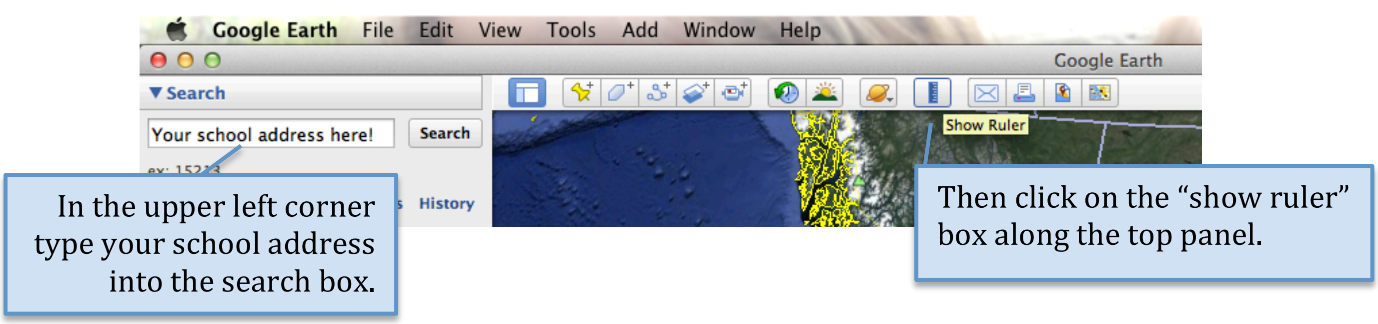
   Scale: 1 cm = _________ km

2. Using the same scale, how many pages would you have to add to the top of our Vertical Distance chart to be able to include the Moon?

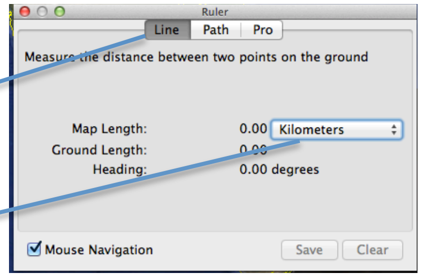
3. Research at least one way that you use information from a satellite orbiting Earth and report your findings here.

4. Our Vertical Distance chart is a model of the layers and objects above the equator. What would change about our model if it were instead depicting the vertical distance from Earth's surface at the NORTH POLE to various features and objects? (Hint: look at a picture of the Van Allen Radiation Belts).

You have been learning a lot about *altitude* and *vertical distance*, whereas normally we talk about distance as a measure between two points on the ground. For example, what is the distance between your home and your school? Let's compare some of the vertical distances you observed on the Vertical Distance chart to distances that might be more familiar to you using Google Earth. If you haven't already, you must download Google Earth (http://www.google.com/earth/). Then get set up, like this:



When you click “show ruler” this box appears. Make sure “line” is selected (tab near top of box) and the Map Length is in units of Kilometers.



Controls

Note: to measure a distance with the ruler tool, click on your starting location once, then click on your ending location once. You should see a line trace with values for the Map Length, Ground Length, and Heading in the Ruler box. You can use the controls at the upper right before clicking on your ending location if it is out of view (for example, you can zoom out or rotate your view before ending your ruler line).

5. Measure the distance from your school to a nearby city.
   City: ______________________ Ground length: _________ km ________ mi

6. Measure the distance from your school to a city in a neighboring state.
   City, State: _______________________ Ground length: _________ km ________ mi

7. Measure the distance from your school to either the Pacific or the Atlantic Ocean, whichever is further from you.
   Ocean: _________________________Ground Length: _________ km ________ mi

8. Measure the distance from your school to Paris, France.
   Ground Length: _________ km ________ mi

9. Measure the distance from Northern Canada to the southern tip of South America.
   Ground Length: _________ km ________ mi

10. Are any of the altitudes for the layers and objects you placed on the Vertical Distance chart similar to the distances you measured using Google Earth? (Note: see altitudes in Part 1, #2).

11. Describe what you have learned about the vertical distances to the layers and objects on the Vertical Distance chart compared to ground-based distances we use on Earth’s surface.

12. Why are models helpful?

13. Why is it important for scientists to improve our model of the Van Allen radiation belts?

65 000 km

64 000 km

63 000 km

62 000 km

61 000 km

60 000 km

59 000 km

58 000 km

57 000 km

56 000 km

55 000 km

54 000 km

53 000 km

52 000 km

51 000 km

50 000 km

49 000 km

48 000 km

47 000 km

46 000 km

45 000 km

44 000 km

43 000 km

42 000 km

41 000 km

40 000 km

39 000 km

38 000 km

37 000 km

36 000 km

35 000 km

34 000 km

33 000 km

32 000 km

31 000 km

30 000 km

29 000 km

28 000 km

27 000 km

26 000 km

25 000 km

24 000 km

23 000 km

22 000 km

21 000 km

20 000 km

19 000 km

18 000 km

17 000 km

16 000 km

15 000 km

14 000 km

13 000 km

12 000 km

11 000 km

10 000 km

9000 km

8000 km

7000 km

6000 km

5000 km

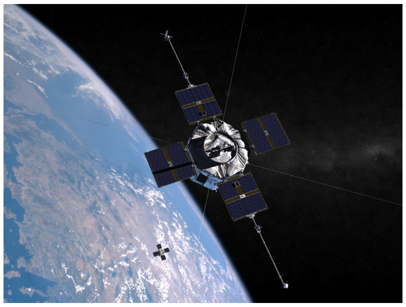
4000 km

3000 km

2000 km

1000 km

Sea Level



Van Allen Probes

Image courtesy: JHU/APL, NASA

GPS Satellite

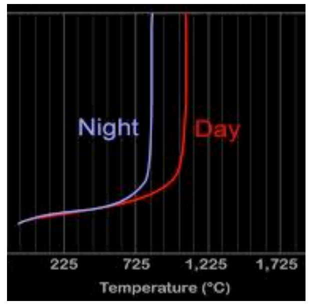
Image courtesy: GPS.gov

The Moon

Image courtesy: NASA

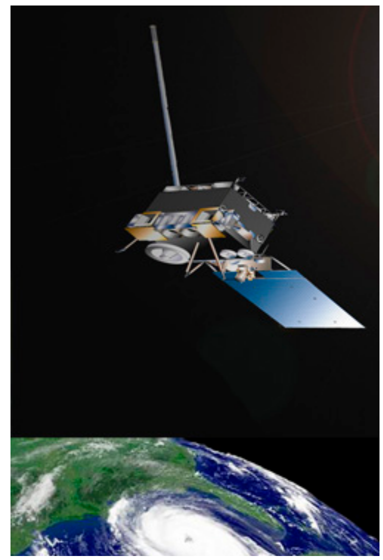
Earth Observing Satellite

Image courtesy: NASA



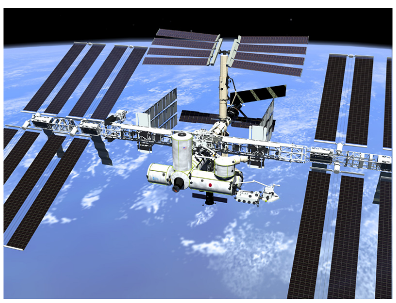
Thermosphere

Image courtesy: Windows to the Universe



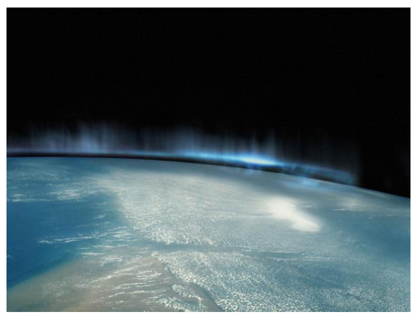
Weather Satellite

Image courtesy: NOAA



International Space Station

Image courtesy: NASA

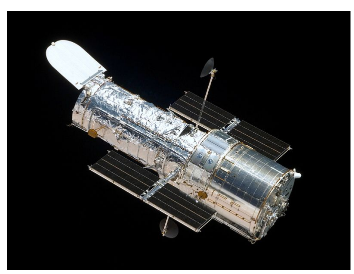


Ionosphere

Image courtesy: NASA

2 mm

Mesosphere
Stratosphere
Troposphere

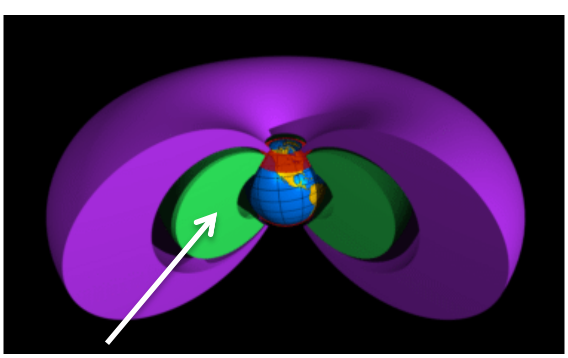


Hubble Space Telescope

Image courtesy: NASA

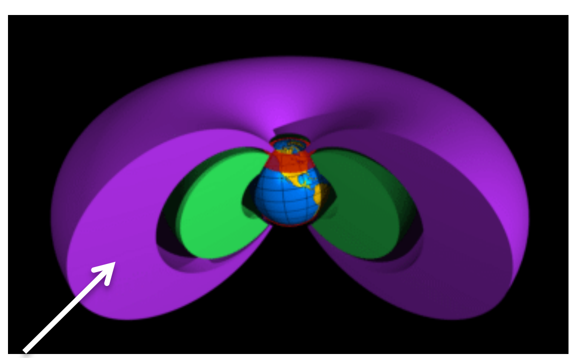
Communication Satellite

Image courtesy: NASA



Inner Van Allen Belt

Image courtesy: NASA, LANL



Outer Van Allen Belt

Image courtesy: NASA, LANL

Altitudes Table

Troposphere, Stratosphere & Mesosphere: 0-12 km, 12-50 km, 50-80 km (respectively)

Hubble Space Telescope: 595 km	The Moon: 384,430 km
Van Allen Probes: 500-30,600 km	Inner Van Allen Belt: 600-6,000 km
International Space Station: 309-463 km	Outer Van Allen Belt: 10,000-65,000 km
Ionosphere: 60-300 km	Thermosphere: 80-500 km
Communications Satellite: 35,786 km	Weather Satellite: 35,786 km
GPS Satellite: 20,350 km	Earth Observing Satellite: 600-800 km

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Vertical Challenge:

TEACHER ANSWER KEY

NOTE: MANY DIAGRAMS AND SOME EXPLANATORY TEXT WERE REMOVED FROM THIS TEACHER ANSWER KEY FOR BREVITY; PLEASE SEE ACTUAL WORKSHEET FOR FULL TEXT

Part 1:

1. How high do you think these objects and layers are above Earth's surface (at the equator)? … **ANSWERS RECORDED IN TABLE, COLUMN 1, WILL VARY, ESTIMATES!**
2. As a group, compare your individual estimates and come to a consensus to estimate the vertical distance to each object and layer and record it in the "Group Consensus" column. … **ANSWERS RECORDED IN TABLE, COLUMN 1, WILL VARY, ESTIMATES!**
3. After you have received the Altitudes Table from your teacher, move the objects and layers to the appropriate altitude on the Vertical Distance Chart (again using masking tape). … **NO; The Moon does not fit on the chart**

VALUES IN COLUMN 3:

0-12 km, 12-50 km, 50-80 km : Troposphere, Stratosphere & Mesosphere

595 km: Hubble Space Telescope

500-30,600 km : Van Allen Probes

309-463 km: International Space Station

60-300 km: Ionosphere

35,786 km: Communications Satellite

20,350 km: GPS Satellite

384,430 km: The Moon

600-6,000 km: Inner Van Allen Belt

10,000-65,000 km: Outer Van Allen Belt

80-500 km: Thermosphere

35,786 km: Weather Satellite

600-800 km: Earth Observing Satellite

4. Step back and take a look at your Vertical Challenge Chart to answer the following questions:
   a. Inside of what region does a communication satellite orbit? **OUTER VAN ALLEN BELT**
   b. Inside of what region does a GPS satellite orbit? **OUTER VAN ALLEN BELT**
   c. Inside of what region does a weather satellite orbit? **OUTER VAN ALLEN BELT**
5. The Van Allen radiation belts are sort of doughnut shaped, but as you can see by looking at Figure 3 in "What's Up There?" the inside of these belts is "c" shaped. … **INTERNATIONAL SPACE STATION, EARTH OBSERVING SATELLITE, HUBBLE SPACE TELESCOPE**
6. Why is it important to learn more about how space weather events affect the Van Allen radiation belts? **SO WE CAN BETTER PREDICT HOW SPACE WEATHER WILL AFFECT THE BELTS AND THEREFORE PROTECT OUR SATELLITES THAT ORBIT THERE FROM THE DAMAGING EFFECTS OF RADIATION**

Part 2: Homework

1. In our Vertical Distance chart model, the actual vertical distances were scaled to fit onto 6 pieces of paper. Determine the scale used in this model, assuming the horizontal lines are 2.5 cm apart and represent a 1000 km change in altitude. (Please show your work).

   Scale: 1 cm = _**400**_ km

   2.5x = 1,000 km
   x = 1,000/2.5 = 400

2. Using the same scale, how many pages would you have to add to the top of our Vertical Distance chart to be able to include the Moon? Assume: the Moon is (on average) 384,430 km from Earth's surface. Assume: a piece of paper is 28 cm long (actual: 11 in = 27.94 cm)

400x = 384,430 km
x = 384,430/400 = 961.075 cm

961.075 cm/28 cm = 34.32 pages

Chart is already 6 pages, so subtract 6 and you would have to add about 28 (28.32) pages to include the Moon

3. Research at least one way that you use information from a satellite orbiting Earth and report your findings here. **POSSIBLE ANSWERS INCLUDE NAVIGATION, WEATHER, COMMUNICATION**

4. Our Vertical Distance chart is a model of the layers and objects above the equator. What would change about our model if it were instead depicting the vertical distance from Earth's surface at the NORTH POLE to various features and objects? (Hint: look at a picture of the Van Allen Radiation Belts). **THE VAN ALLEN BELTS ARE DOUGHNUT SHAPED, SO THEY WOULD NOT APPEAR IN THE MODEL IF IT WERE AT THE NORTH POLE.**

5. Measure the distance from your school to a nearby city. **ANSWERS WILL VARY; YOU CAN DESIGNATE A SPECIFIC CITY FOR EASIER GRADING**
   City: ______________________ Ground length: _________ km _________ mi

6. Measure the distance from your school to a city in a neighboring state. **ANSWERS WILL VARY; YOU CAN DESIGNATE A SPECIFIC CITY/STATE FOR EASIER GRADING**
   City, State: ______________________ Ground length: _________ km _________ mi

7. Measure the distance from your school to either the Pacific or the Atlantic Ocean, whichever is further from you. **ANSWERS WILL VARY; YOU CAN DESIGNATE A SPECIFIC CITY/OCEAN FOR EASIER GRADING**
   Ocean: ________________________Ground Length: _________ km _________ mi

8. Measure the distance from your school to Paris, France. **ANSWERS WILL VARY BASED ON YOUR SCHOOL LOCATION**
   Ground Length: _________ km _________ mi

9. Measure the distance from Northern Canada to the southern tip of South America.
   Ground Length: **~15,000 km ~9,200 mi**

10. Are any of the altitudes for the layers and objects you placed on the Vertical Distance chart similar to the distances you measured using Google Earth? (Note: see altitudes in Part 1, #2). **ANSWERS WILL VARY, BUT GENERALLY YOU WANT TO SEE THAT**

THEY CAN COMPARE THE VERTICAL DISTANCES WITH DISTANCES ON THE GROUND AND SEE THAT MANY OF EARTH'S LAYERS AND THE SATELLITES IN THE LOW EARTH ORBIT ARE COMPARABLE TO DISTANCES WE ARE SOMEWHAT FAMILIAR WITH AS GROUND-BASED DISTANCES.

11. Describe what you have learned about the vertical distances to the layers and objects on the Vertical Distance chart compared to ground-based distances we use on Earth's surface. **ANSWERS WILL VARY, BUT GENERALLY YOU WANT TO SEE THAT THEY CAN COMPARE THE VERTICAL DISTANCES WITH DISTANCES ON THE GROUND AND SEE THAT MANY OF EARTH'S LAYERS AND THE SATELLITES IN THE LOW EARTH ORBIT ARE COMPARABLE TO DISTANCES WE ARE SOMEWHAT FAMILIAR WITH AS GROUND-BASED DISTANCES.**

12. Why are models helpful? **ANSWERS WILL VARY, BUT GENERALLY THEY HELP VERY LARGE/SMALL NUMBERS SEEM MORE "HUMAN-SIZED". THEY CAN ALSO HELP YOU VISUALIZE SOMETHING THAT IS INVISIBLE OR UNDERSTAND CONCEPTS THAT ARE DIFFICULT TO SEE/HEAR.**

13. Why is it important for scientists to improve our model of the Van Allen radiation belts? **ANSWERS WILL VARY, BUT GENERALLY SO THAT WE CAN KEEP OUR SATELLITES, ASTRONAUTS, ETC SAFE FROM HARMFUL RADIATION OR SO WE CAN BETTER UNDERSTAND HOW THE RADIATION BELTS BEHAVE IN RESPONSE TO SOLAR STORMS/ACTIVITY.**

Extensions and Adaptations:

- Create a model of the Earth, the Van Allen Radiation Belts, and the Moon with balls representing Earth and the Moon and string connecting them. Color the string to represent the span of the Van Allen Belts and add dots or the 'cut-outs' provided in this activity at the appropriate distances. For detailed instructions that can be modified to include the Van Allen Belts see pages 11 – 19 here: https://moonkam.ucsd.edu/files/edinst/explore_our_moon/robertson/How%20High%20Is%20It%20Educator%20Guide.pdf
- Students with visual impairment can participate with the group as they estimate the vertical distances to the layers and objects and if another student can read the actual altitudes. Be sure someone in the group talks about some satellites orbit within the Van Allen Radiation Belts. Students with hearing impairment should be able to fully participate in the activity.

Resources:

- Van Allen Probes Mission website, with additional educational materials, science background about the mission, and links to additional resources: http://vanallenprobes.jhuapl.edu
- National Oceanic and Atmospheric Administration (NOAA) National Weather Service "JetStream-Online School for Weather" is a good source for more information on Earth's atmospheric layers: http://www.srh.noaa.gov/jetstream/atmos/layers.htm
- NOAA satellite information: http://noaasis.noaa.gov/NOAASIS/ml/genlsatl.html
- If you want to learn more about the different types of orbits or orbital characteristics, see this "Planetary Orbits" chapter in the online resources, "The Basics of Space Flight": http://www2.jpl.nasa.gov/basics/bsf5-1.php
- Background information about our Global Positioning System (GPS): http://www.gps.gov/
- A great resource about various orbits and why they are useful: http://earthobservatory.nasa.gov/Features/OrbitsCatalog/
- Here are a few articles written about space weather or similar topics for a more general audience:
    - http://www.nasa.gov/content/goddard/ultra-fast-electrons-explain-third-radiation-belt/#.U6xHn6goyEg
    - http://newsroom.ucla.edu/portal/ucla/how-did-a-third-radiation-belt-246861.aspx
    - http://news.nationalgeographic.com/news/energy/2011/08/110803-solar-flare-storm-electricity-grid-risk/
- This activity was adapted from a similar activity created for the GRAIL mission, "How High Is It?". The Educator Guide for that activity and others is available here: https://moonkam.ucsd.edu/files/edinst/explore_our_moon/robertson/How%20High%20Is%20It%20Educator%20Guide.pdf and other GRAIL resources are available here: https://moonkam.ucsd.edu/resources/activities
- Information about using models in the classroom: http://serc.carleton.edu/introgeo/models/index.html

Standards:

Benchmarks (AAAS, 2009)

11. Common Themes

B. Models, 6-8th grades:

- Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly. They are also used for processes that are too vast, too complex, or too dangerous to study.

D. Scale, 6-8th grades:

- Natural phenomena often involve sizes, durations, and speeds that are extremely small or extremely large. These phenomena may be difficult to appreciate because they involve magnitudes far outside human experience.

National Science Education Standards (NRC, 1996)

Unifying Concepts and Processes Standard

Evidence, models, and explanation, Levels 5-8

- Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power.
- Models help scientists and engineers understand how things work.
- Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.

Principles and Standards for School Mathematics (NCTM, 2000)

Number and Operations for Grades 6-8

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems

Representation for Grades 6-8

- Create and use representations to organize, record, and communicate mathematical ideas
- Use representations to model and interpret physical, social, and mathematical phenomena

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MS-ESS1 Earth's Place in the Universe

Disciplinary Core Idea: MS-ESS1.B: Earth and the Solar System

The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. (MS-ESS1-2), (MS-ESS1-3)

- (Performance Expectation) MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system.

Science and Engineering Practices: Developing and Using Models

Modeling in 6-8 builds on K-5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop and use a model to describe phenomena. (MS-ESS1-1), (MS-ESS1-2)

Crosscutting Concepts

- Scale, Proportion, and Quantity: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. (MS-ESS1-3)
- Systems and System Models: Models can be used to represent systems and their interactions. (MS-ESS1-2)

Special thanks to Jane DeLong, Van Allen Probes Ambassador, for creating the original version of this activity! Also thanks to the many Van Allen Probes Science Team members for providing resources, science review, and of course the ongoing support of the Mission, which makes Education and Public Outreach possible!