AMERICAN METEOROLOGICAL SOCIETY

The Maury Project

Ocean Tides

TEACHER'S GUIDE

The Maury Project

This guide is one of a series produced by The Maury Project, an initiative of the American Meteorological Society and the United States Naval Academy. The Maury Project has created and trained a network of selected master teachers who provide peer training sessions in precollege physical oceanographic education. To support these teachers in their teacher training, The Maury Project develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

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Forward

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities and in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further reading.

If we except the tides, and ... those that may be created by the wind, we may lay it down as a rule that all the currents of the ocean owe their origin to difference of specific gravity between sea water at one place and sea water at another; for wherever there is such a difference, whether it be owing to difference of temperature or to difference of saltiness, etc., it is a difference that disturbs equilibrium, and currents are the consequence.

Matthew Fontaine Maury
from The Physical Geography of the Sea. 1855.

Introduction: Ocean Tides and the Moon

Tides are the periodic rise and fall of sea level resulting from the gravitational interaction and motions of the Sun, Moon and Earth. Tidal currents are associated horizontal water movements. Although the impact of tides on local water levels and currents is predictable, the combination of factors influencing local tides is complex. Once formed by astronomical factors, tides are modified by many other factors including the ocean bottom, coastlines, and weather.

Of the astronomical factors, the influence of the Moon is greater than the Sun because it is closer to the Earth. The Moon's gravitational attraction and the inertia of the water contributes to the formation of two bulges which tend to make the surface of the ocean egg-shaped. One bulge is towards, and the other away from, the Moon. A place on the Earth rotating daily through these two ocean bulges experiences two high and two low tides.

Since the Moon revolves around our planet monthly in an elliptical orbit that is inclined to Earth's equatorial plane, there is a wide range of astronomical tidal variables possible. It takes about 18.6 years to experience most of the effects of the various configurations of the Earth-Moon-system generating the tides. The most notable of these effects are that the Moon-based day and tidal day are both 50 minutes longer than the Sun-based day.

With an influence about 45% of the Moon's, two smaller Sun-associated bulges tend to modify the dominant lunar tidal bulges. Since the Earth revolves around the Sun yearly in an elliptical orbit inclined to Earth's rotational plane, there is a wider range of astronomical variables possible. It takes over a thousand years to experience most of the effects of the configurations of the Earth-Moon-Sun system generating the tides. The most notable of these effects are the extreme tides occurring twice monthly when the Earth, Moon and Sun, and their associated tidal bulges, are aligned during the New and Full Moon phase.

Once formed by astronomical factors, the tides can be thought of as moving through the ocean as global-scale ocean waves. These waves can be resolved into various periodic components, called partial tides which are forecasted for a future date and then added together to predict the resulting local tide. In order to predict the tides accurately, each tide station must first gather data for a minimum of the 18.6 year period covering most major tide-generating configurations of the Earth-Moon system.

In the past, tides have been investigated because of their local impact on navigation, engineering, legal boundaries, commerce and recreation as well as their potential as a renewable energy source. Current research is more involved with the global nature of tides, including their influence on other physical processes such as circulation, mixing, and the generation of waves.

Basic Understandings

Tide Characteristics

1. The tides are the regular rise and fall of the ocean surface that occur over a period of several hours or more each day.

2. Tides are measured at coastal locations as local changes in sea level. The difference in height between water levels at high and low tide is called **tidal range** and the time between successive high tides is called **tidal period**.

3. Although the effects of the tide are observed along the shore as local changes in sea level and water currents, the tides develop from the gravitational interaction and motions of the Sun, Moon, and the Earth acting on the ocean waters.

4. Once formed by astronomical factors, the tides are modified by many nonastronomical influences including water depth, bottom topography, coastline configuration and the weather, to produce the observed local tide.

5. Local tides, although resulting from a complex interplay of astronomical and nonastronomical factors, can be predicted with a high degree of accuracy from detailed analysis of the long-term local tide record.

Astronomical Factors

1. Fundamental to the formation of the tides is the gravitational attraction between the Earth and the Moon and Sun, with this attraction being determined by both the masses of these objects and the distance between them. The greater the masses, the greater is the attraction, while the greater the distance, the smaller is the attraction.

2. The magnitude of the gravitational attraction of the Sun or the Moon will not be the same at all places on Earth's surface because not all these places are the same distance away from the attracting body. Places on the Earth nearest to the body will experience a greater gravitational attraction towards the Sun or the Moon than will places on the opposite side of the Earth.

3. Because of gravitational attraction, the Earth's ocean facing (and nearer) the Moon is pulled more strongly by the Moon than is the ocean on the more distant opposite side of the Earth. A similar effect on ocean water is produced by the Sun.

4. Earth and Moon revolve around a common center of mass once each lunar month. This turning motion, combined with the Moon's gravitational attraction, causes egg-shaped bulging of the ocean surface. One ocean bulge is towards the Moon and the other is on the opposite side of the Earth. A similar interaction between the Earth and Sun produces ocean bulges on Earth that line up towards and away from the Sun.

5. On a theoretical Earth with no friction, the ocean bulges would remain aligned with the celestial body contributing to their formation. A place on the coast that is moved by the Earth's rotation through the bulges would experience rising and falling sea level. These changes in sea level are the tides produced under theoretical conditions by astronomical factors acting alone.

6. The large range of astronomical variables involved in the production of the theoretical tides is dominated by the changing alignment of the Moon, Sun and Earth, including the changing positions of the Moon and Sun relative to the Earth's equator and the changing distances of the Moon from the Earth, and the Earth from the Sun, due to their elliptical orbits.

Role of the Moon

1. Although its mass is considerably smaller than that of the Sun, the Moon has a greater influence on the tides because it is so much closer to Earth than is the Sun.

2. Because the Moon's monthly revolution about the Earth is in the same direction as Earth's daily rotation, a point on the Earth must make a full rotation and more (with about 24 hours and 50 minutes elapsing) to catch up with the advancing Moon. This Moon-based day is also called the **tidal day**.

3. The ocean tidal bulges produced by the Moon remain in the same alignment relative to the Moon, but change their latitudinal positions on Earth from day to day as they follow the Moon during its monthly revolution about the Earth. This occurs because the Moon's orbit is inclined to the Earth's equatorial plane.

4. During one lunar month the Moon's latitudinal position moves from being directly over the equator to within five degrees of the Tropic of Cancer (23.5 degrees North), back to the equator, on to within five degrees of the Tropic of Capricorn (23.5 degrees South), and then back to the equator where another cycle begins.

5. When the Moon is directly over the equator, its associated tidal bulges are centered on the equator. In theory, almost all coastal locations would rotate through the two tidal bulges and experience two equal high tides and two equal low tides per tidal day. This is known as a **semidiurnal tide**.

6. Different tidal patterns exist when the Moon, and the midpoints of its associated tidal bulges, are either north or south of the equator. While semidiurnal tides are observed at the equator at all times, most locations between the equator and the high latitudes experience two unequal high tides and two unequal low tides per tidal day. This is known as a **mixed tide** and this difference in heights between successive high (or low) tides is called the **diurnal inequality**.

7. When the Moon is above or nearly above the Tropic of Cancer or Capricorn, the diurnal inequality is maximum, and the tides are called **tropic tides**. When the Moon is above or nearly above the equator, the diurnal inequality is minimum and the tides are known as **equatorial tides**.

8. When the Moon and its associated tidal bulges are either north or south of the equator, most points at high latitudes would in theory experience one high and one low tide per tidal day. This is known as a **diurnal tide**.

Role of the Sun

1. The Sun produces ocean tidal effects that are about 45% of those related to the Moon, due to the much greater distance between the Sun and Earth.

2. Sun-related ocean tidal bulges are produced the same way as those resulting from Earth-Moon interactions. The gravitational attraction between the Earth and Sun and Earth's annual revolution around the mutual center of mass of the Sun and Earth produce a second set of similar but smaller tidal bulges aligned with the Sun.

3. The mid-points of Sun-related tidal bulges follow the Sun just as Moon-related bulges track the Moon. Their latitudinal positions go through a yearly cycle.

4. The separate sets of ocean bulges related to the Moon and Sun act at times together and at times in opposition as they produce the astronomical component of the tides. These tides are dominated by the Moon-related bulges while the Sun-related bulges play a modifying role.

5. Twice monthly the positions of the Sun, Moon, and Earth are along a straight line. At these times of new and full Moon phases, as viewed from Earth, the lunar- and solar-related ocean bulges also line up to produce tides having the greatest monthly range. These are called **spring tides**.

6. Twice monthly, at the first and third quarter Moon phases, the Sun is pulling on the Earth along a line that is at right angles to the pull of the Moon. At this time the tides have the least monthly range. These are called **neap tides**.

Nonastronomical Factors

1. Once formed by astronomical factors, the tides can be thought of as global-scale ocean waves moving across the ocean, with high tide being the crest of the wave and low tide the trough of the wave.

2. For a semidiurnal tide at the equator, the wave would have a period of about 12.5 hours and a length that approaches 20,000 km, or half the circumference of the Earth.

3. As ocean waves, the tides are modified by many nonastronomical factors including friction, water depth, bottom topography, coastline configuration, and the weather.

4. Because of their size and shape, many ocean basins have natural periods that equal tidal periods. This helps to explain why many locations on the U.S. Atlantic Coast have a predominantly semidiurnal tide, while many locations on the Gulf Coast have a predominantly diurnal tide, and many locations on the Pacific Coast have a predominantly mixed tide.

Tide Prediction

1. Treated as a wave, the local tide is resolved into various components, called **partial tides**. These are forecasted individually and added together to predict the future local tide.

2. Although as few as four partial tide components can account for 70% of the total tidal range, some 60 components are commonly used. More than 100 must be considered to predict the tides along complex irregular coasts such as that of Alaska.

3. In order to predict the local tide, tide stations must gather data for a minimum of 18.6 years to experience most of the astronomical configurations of the Earth-Moon-Sun system generating the tides.

Tide Investigations

1. Tides are investigated because of their impact on local navigation, moorings, coastal structures, legal boundaries, fishery, and recreation.

2. Today, considerable research focuses on the global nature of tides, including their influence on other physical processes such as ocean circulation, mixing, and the generation of waves.

3. In some areas, research is concerned with how storm-driven ocean waves and storm surges combine with tides to affect the rate of coastal erosion.

4. Tides are a potential energy source. Limitations to widespread development of tidal power facilities include the difficulty of finding a site with sufficiently large tidal range plus a nearby energy market, the dependency of tidal power on a lunar day whereas power demand depends on a solar day, and the challenge of producing and storing tidal energy without adverse environmental impact.

Activity: Gaging the Moon Tide

Introduction

Ocean tides are the periodic rise and fall of sea level observed along coasts. While tides are most often viewed from their local impact on water levels and currents, their origins are astronomical. They form as a result of the complex interaction of the gravitational attraction of the Moon and the Sun on the Earth's water surface, with the influence of the Moon being dominant due to its closeness.

This activity investigates the role of the Moon in generating the ocean tides. Many other influences build on these astronomical foundations to produce the tides actually observed at any specific location. These include such factors as the Sun, shape of the ocean bottom, coastline irregularities, and weather.

Materials

Tide Gages Diagram (with cut out or copied ***Tide Gages***), ***Equatorial Tide Diagrams, Tropic Tide Diagrams,*** and a pencil.

Objectives

After completing this investigation, you should be able to:

- Describe the role of the Moon in generating the ocean tides.

- Explain some of the different types of ocean tides the Moon helps generate.

Method

1. Examine the ***Earth Cross-Sections and Tide Gages Diagram*** (page 11). The top drawing is a side-view of an imaginary Earth (not to scale) representing the solid planet as a smooth sphere (white) completely covered by a uniformly deep ocean (gray). There is no friction acting between the ocean bottom and the water and no Moon or Sun to produce tides. Marked are positions of three cross-sectional slices that are oriented perpendicular to the Earth's rotational axis at high and middle latitudes in the Northern Hemisphere and at the equator. These slices, as viewed from above the North Pole, are shown in the lower left three drawings of the figure. The slice with the largest cross-sectional area of the Earth is found at the (***high latitudes***), (***middle latitudes***), (***equator***).

2. **Tide Gages** are presented to the right of each Earth cross-sectional slice. These will be used in this activity to measure the height of the ocean's surface. Note that each tide gage is firmly attached to a solid Earth slice at the particular latitude. Each tide gage is marked to indicate low (L), medium (M), and high (H) ocean levels. Cut out the three tide gages with their Earth slices (or make a clear plastic overlay via a photocopy machine).

3. Place the high latitude tide gage directly over the high latitude cross-section so the solid Earth portion of the cross-section is covered. Use a pencil to hold the two together at the axis point. Then, starting with the tide gage at the zero (0) position, turn the tide gage with its Earth slice to simulate the Earth's counterclockwise rotation by quarter turns as marked around the edge of the cross-section. Note the water level on the tide gage as you proceed. Do the same for the other two Earth cross-sections using the appropriate tide gages. This demonstrates that over the course of one Earth rotation, if there were no Moon or Sun, there would be (***tides***), (***no tides***).

4. Turn to the ***Equatorial Tides Diagram***, (page 12) and examine the top drawing. It is similar to the previous top drawing with a very important addition, the Moon, that is located to the far right, directly over the equator. Interactions between the Earth and Moon cause a small, but significant, egg-shaped bulging of the ocean surface. One bulge is on the side towards the Moon (where the Moon's gravitational pull is strongest) and the second occurs on the opposite side of the Earth (where the Moon's gravitational pull is weakest). The top view of the three Earth cross-sections in the lower left of this diagram each have (***no***), (***one***), (***two***) bulges.

5. These bulges remain fixed in position relative to the Moon. A coastal locality, as it is moved by the Earth's rotation through the bulges, experiences their effects in the form of high tides. To demonstrate this, place the high latitude tide gage device on the high latitude cross-section so the gage is at the zero (0) position. Measure the height of the water level and plot the value on the graph to the right. Time is shown on the graph as fractions of a **tidal day**. A tidal day is the amount of time it takes for the Earth to rotate once with respect to the Moon. The tidal day used in this activity is actually almost an hour longer than our common 24-hour day. Simulate Earth rotation by turning the device, held in the center by your pencil point, counterclockwise. Record water levels measured with the tide gage as the Earth turns, including values at the 1/4, 1/2, 3/4, and full rotation (plotted at 1 on the graph) positions.

6. Draw a smooth curve connecting the points you plotted. You have drawn a **Tide Curve**. It depicts a high latitude location's changes in water level as that location rotates through the bulges caused by the Moon's tidal pull. Follow the same procedure and construct tide curves for the Northern Hemisphere middle latitude and equatorial locations. All three tidal curves show that during one complete rotation of the Earth (or tidal day), locations at any of the three latitudes would experience (***0***), (***1***), (***2***) high tide(s) and (***0***), (***1***), (2) low tide(s).

7. Tides are often distinguished by their cyclical patterns. One **tidal cycle** is the sequence from one high tide to the next high tide. Tides that go through one cycle during a single Earth rotation are described as **diurnal**, or daily tides. Those that go through two cycles are described as **semidiurnal**, or semi-daily tides. A third common category is **mixed tides**. Mixed tides have characteristics intermediate between the other two. They usually show two unequal high waters and two unequal low waters each tidal day. With the Moon located directly above the equator, as shown in the ***Equatorial Tides Diagram***, all the observed tides are (***diurnal***), (***semi-diurnal***), (***mixed***).

8. The time between successive high tides is called the **tidal period**. With the Moon directly over the equator, the tidal period is (***one quarter***), (***one half***), (***one***) tidal day.

9. **Tidal Range** is the difference in the ocean surface height between high and low tides at any one location. When the Moon is directly above the equator, the tidal range is (***maximum***), (***minimum***) at the equator and (***increases***), (***decreases***) with increasing latitude.

10. When the Moon is directly above the equator, tidal curves for places at middle and high latitudes in the Southern Hemisphere would show characteristics that are (***the same as***), (***different from***) tidal curves for places at equivalent latitudes in the Northern Hemisphere.

11. The Moon is not always directly above the Earth's equator. It revolves around our planet in an orbit that is inclined to the Earth's equatorial plane. Just as the Sun appears to move in the sky north and south of the equator over the course of a year so too does the Moon, but over the course of a month. The Moon is directly over the equator only twice a month. The rest of the time it is either north or south of the equator. Turn to the ***Tropic Tides Diagram*** (page 13). **Tropic tides** refer to tides that occur when the Moon's position in the sky is farthest from the equator. This position of the Moon is close to the Tropic of Cancer (23.5 degree N Latitude) or the Tropic of Capricorn (23.5 degrees S Latitude). The top drawing in this diagram is a side-view of the Earth showing the tidal bulges when the Moon is nearly overhead at the Tropic of Cancer. With the tide gage devices used earlier, proceed to measure ocean levels and construct tide curves for all three latitudes.

12. Examine the tropic tide curves you constructed. By determining the number of high and low tides and by comparing the heights of high and low tides where there are two cycles each tidal day, name the tidal pattern that best fits each of the following latitudes:

    At the high latitude location, the tides are (***semi-diurnal***), (***diurnal***), (***mixed***).
    At the middle latitude location, the tides are (***semi-diurnal***), (***diurnal***), (***mixed***).
    At the equator, the tides are (***semi-diurnal***), (***diurnal***), (***mixed***).

13. By examining the top drawing and the middle latitude tide curve for tropic tides, predict the characteristics of the tide that would be produced at middle latitude in the Southern Hemisphere. On the graph of the Northern Hemisphere middle latitude tide curve, pencil in the Southern Hemisphere middle latitude tide curve using a dashed line. Compare these two middle latitude tide curves. What are the similarities and what are the differences?

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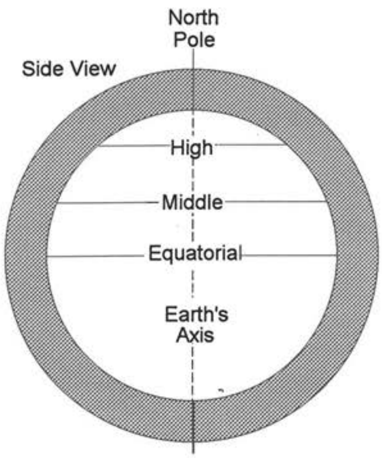
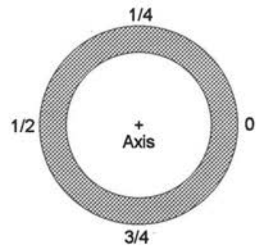
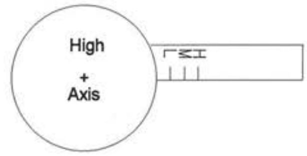
    ____

Earth Cross-Sections And Tide Gages

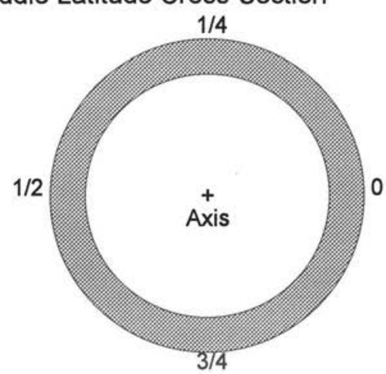


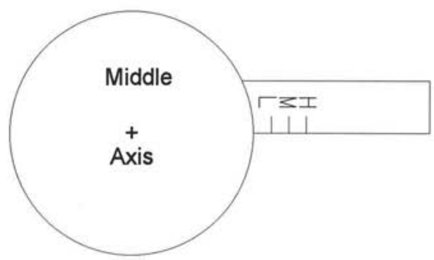
High Latitude Cross-Section



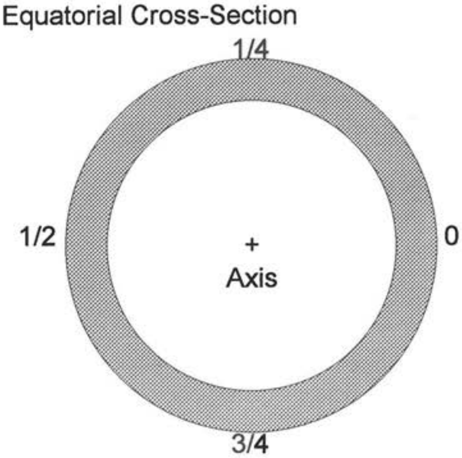


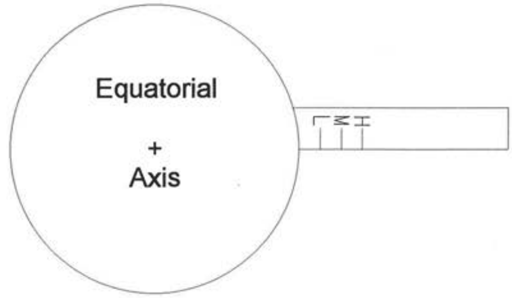
Middle Latitude Cross-Section



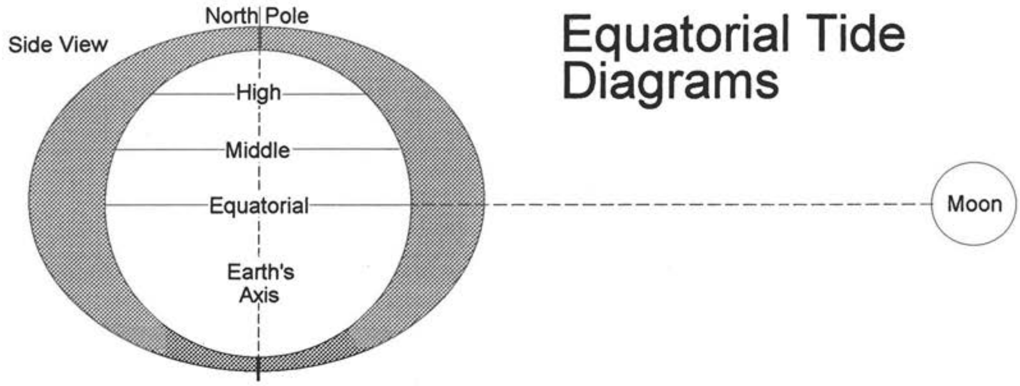


Equatorial Cross-Section





Equatorial Tide Diagrams



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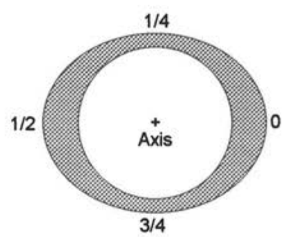

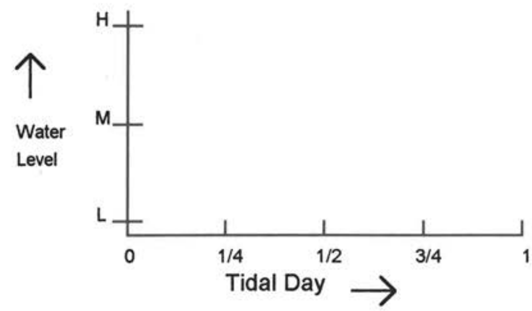

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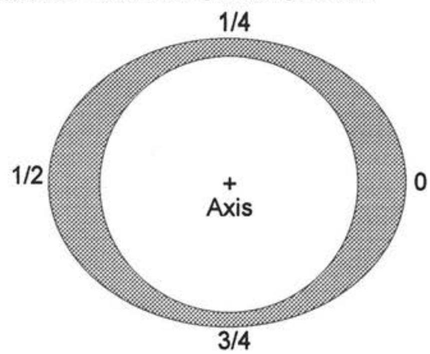
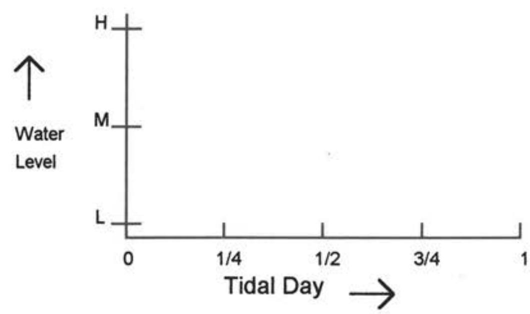
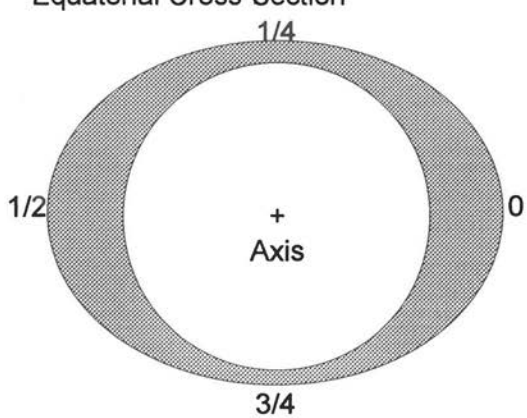
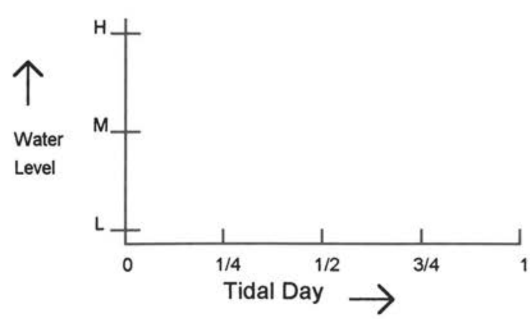


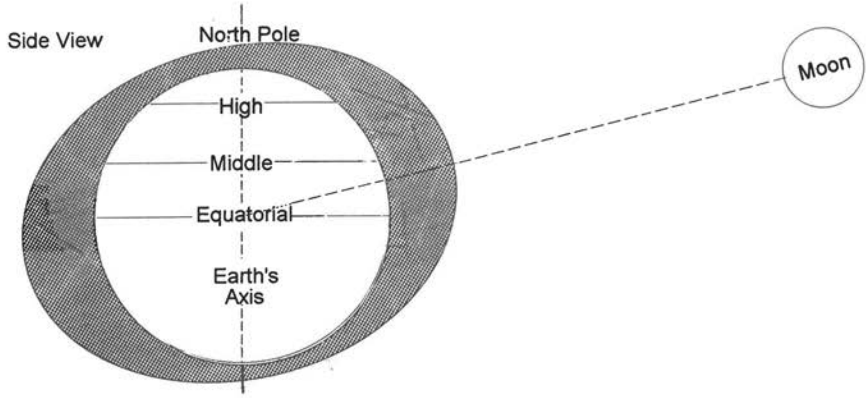


Equatorial Cross-Section

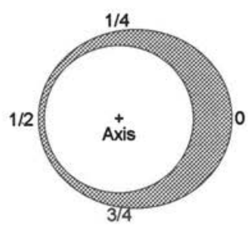


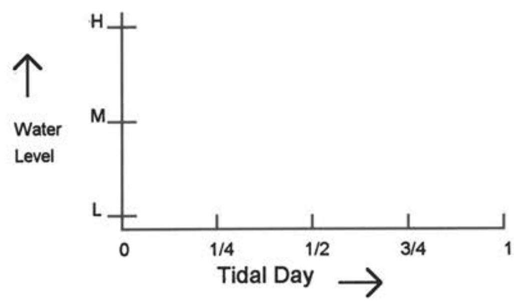


Tropic Tide Diagrams

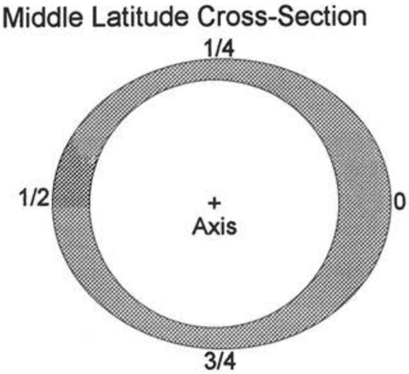


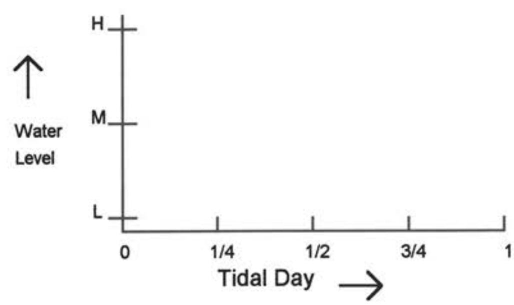
High Latitude Cross-Section



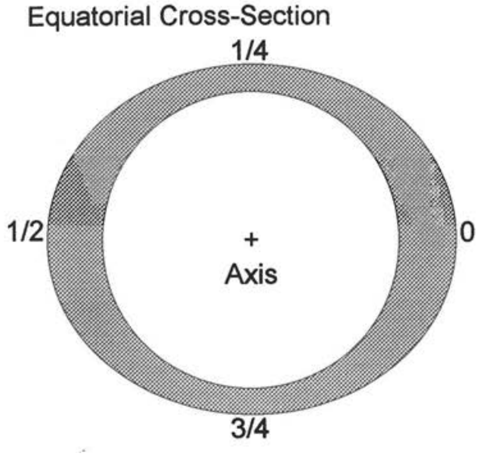


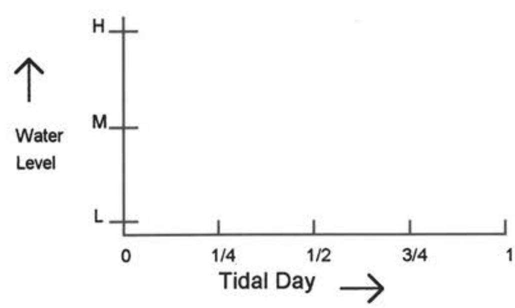
Middle Latitude Cross-Section





Equatorial Cross-Section





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