What causes tides? How are tides predicted?

1. Tides are the regular rise and fall of sea level that occurs either once a day (every 24.8 hours) or twice a day (every 12.4 hours).

   - Tides are waves with very long periods (24.8 or 12.4 hours) and wavelengths (thousands of km)
   - Tides are shallow-water waves (that is, their speed is slowed by friction with the ocean bottom) even in the deepest parts of the ocean.
   - Tidal range is the vertical distance between high and low tide, the height of the wave.

2. Equilibrium tidal theory:

   - Suppose the Earth were a ‘water world,’ with no land masses and especially no large continents to divide the ocean basins.

   Tides on the ‘water world’ are caused by

   - gravitational attraction between the Earth and Moon, and between the Earth and the Sun

   and by

   - centrifugal "forces" that result from the Moon orbiting around the Earth (29.5 days), and the Earth orbiting around the Sun (1.0 years), and the Earth spinning on its axis (24 hours).

   Note:

   - The Moon, because it is closer, is responsible for most of the tide (68.5%, or about twice as much tidal forcing as the sun). These are the lunar tides.
   - The Sun creates tides, also (about 31.5% of the total).

   Lunar tides:

   Although we usually think of the Moon orbiting around the Earth, actually they are both orbiting around the center of gravity of the total Earth-Moon pair. (This center of gravity is a point within the Earth, but not at its center.)

   At all points of the Earth's surface, there are two forces acting to produce lunar tides: the gravity of the moon, and a centrifugal force that acts parallel to the Earth-moon axis, but away from the moon.

   NOTE: the centrifugal “force” is not a real force. It is an apparent force, in the same sense as the Coriolis Effect (often called the Coriolis Force).
There are two ways to explain how the Moon generates tides. First explanation:

- Gravity becomes weaker with distance, so the gravitational attraction of the Moon is strongest for the side of the Earth closest to the Moon, and weakest for the opposite side. Because there is a slight excess of gravity on the side of the Earth nearer the Moon, the ocean "bulges" toward the moon on that side.

- Because there is a slight deficiency of gravity on the side of the Earth which faces away from the moon, the ocean "bulges" away from the moon on that side. These "bulges" in the surface of the ocean are high tides.

Alternative explanation:

- Gravity becomes weaker with distance, so the gravitational attraction of the Moon is strongest for the side of the Earth closest to the Moon, and weakest for the opposite side.

- In contrast, the centrifugal force is the same everywhere.

- The stronger gravity on the side of the Earth facing the Moon causes the ocean to “bulge” on the near side.

- The centrifugal force of the Earth moving through space tends to pull it away from the Moon, creating another “bulge” on the far side.

The Earth rotates once a day beneath the two bulges. So, we would expect 2 high and 2 low tides each day. This in fact occurs in most places (semidiurnal tide).

However, some places have only 1 high and 1 low tide a day (diurnal tide).

Why?

The Earth’s spin axis is tilted by 23.5 degrees from its orbit around the Sun. It takes (of course) one year to complete its orbit.

The Earth’s spin axis is tilted 28.5 degrees off of the Moon’s orbit around the Earth. The Moon is almost in the plane of the Earth’s orbit around the Sun. However, its orbit oscillates over 18.6 years, from an orbit 5 degrees above the Earth-Sun plane to an orbit 5 degrees below it.

There are other complications, too.

Bottom line: sometimes, the tidal pull of the Sun and Moon are in the same direction, and reinforce each other. At other times, they partly cancel each other out.

Because the Earth’s spin axis is at an angle to the Moon’s orbit, the “bulge” created by the Moon’s gravitational attraction is not necessarily centered on the equator.

For example: The "bulge" may move north into the mid-latitudes. However, the corresponding “bulge” on the other side of the Earth will move south of the equator. The northern mid-latitude will see only one “bulge” during a full day’s rotation. Diurnal tide.

Diurnal and semidiurnal tides are ‘end member’ concepts, but real tides are rarely one or the
other. Real tides are often called diurnal or semidiurnal, but that is a convenient approximation. Strictly speaking, they are typically semidiurnal mixed tides. Likewise, the two semidiurnal tides are not EXACTLY the same size. This is also an approximation.

*Note:* 

The Earth-Sun system acts like the Earth-Moon system, except that the tide generated is smaller.

The observed tide is the sum of lunar and solar tides.

3. The relative positions of the Earth, Sun, and Moon change in a regular pattern during a (lunar) month.

- When the Earth, Sun, and Moon are aligned (new moon and full moon), the tidal forces reinforce each other and there are unusually large spring tides.

- When the Moon is off to the side of the Earth-Sun axis (first quarter moon, last quarter moon), the lunar and solar tides partly cancel out, so tides are smaller than average neap tides.

4. The equilibrium model of tides is not useful for actually predicting tides. Instead, use a dynamic model.

- Laplace developed a model that describes tides in terms of a large number (>400) of factors that influence them. These factors include the primary tide-producing forces, but also many others such as the shape of the basin. The factors are called partial tides.

- Four partial tides (four factors) describe about 70% of tidal variation.

*Note*, the best way to figure out the tide at a given location is to go out and measure it. (using tide gauges, TOPEX/Poseidon radar altimetry satellite) Tide predictions are made from a combination of theory and observations.

- Laplace’s dynamic model of tides considers the fact that the tide is trapped within each ocean basin. It acts like a standing wave which rotates around a node. In the case of tides, the node is called an amphidromic point.

  a. In the northern hemisphere, the currents (water motion) due to tides run clockwise due to the Coriolis effect. But the crests of tides progress counterclockwise.

  b. In the southern hemisphere, tides progress clockwise.

  c. Some ocean basins, due to their shape, have more than one amphidromic point. There are about 12 in the world’s oceans.

Tides can be considered a combination of
 Rotary standing waves (currents created by progression of high tide crests)

Deflection of water movement by the Coriolis effect.

5. There are three major types of tides:

Diurnal tides have 1 high and 1 low per day. They are found in Australia, Antarctica, and the Gulf of Mexico.

Semidiurnal tides have 2 equal highs and lows each day. They are found in the Atlantic and Indian Oceans. Note that the two semidiurnal tides are not EXACTLY the same size. This is an approximation.

Semidiurnal mixed tides have two unequal highs and lows each day. They are found in the Pacific Ocean.

6. Tides have important effects on marine organisms and on human activities.

- Tidal currents are often the strongest currents in coastal areas.

  Special type of tidal current: a tidal bore. In locations with a high tidal range and a long, narrow inlet or bay. Example: upper Cook Inlet -- as the inlet narrows into Knik Arm and Turnagain Arm, the huge volume of rising tide is forced into the shallow areas and river channels (arms). It forms a breaking wave front that travels rapidly up the inlet.

- Tidal currents affect navigation of ships.

- They are also important to certain migrations of animals. For example, larvae may rely on such currents to move them toward or away from the coast.

- Intertidal organisms are strongly influenced by the periodic advance and retreat of the ocean. They are often arranged in patterns (intertidal zonation) which depend on the amount of time the area of beach is exposed to the air.

Where are the highest tides? Mean tidal range:

<table>
<thead>
<tr>
<th>Location</th>
<th>Tidal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bay of Fundy, Nova Scotia</td>
<td>38.4 feet</td>
</tr>
<tr>
<td>Ungava Bay, Quebec</td>
<td>32.0 feet</td>
</tr>
<tr>
<td>Port of Bristol, England</td>
<td>31.5 feet</td>
</tr>
<tr>
<td>Turnagain Arm, Cook Inlet, AK</td>
<td>30.3 feet</td>
</tr>
<tr>
<td>Knik Arm, Cook Inlet, AK</td>
<td>26.2 feet</td>
</tr>
<tr>
<td>Fire Island, Cook Inlet, AK</td>
<td>24.4 feet</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Compare with Bristol Bay</td>
<td>5-7 feet</td>
</tr>
</tbody>
</table>
Why are the tides so high in these locations?

In a funnel-shaped coastline with the right curvature, e.g., southern Alaska and British Columbia, the tide wave can be focused into the narrow end. In Alaska, the tide is focused into Cook Inlet, especially into the inner end of the fjords. The same is true in the Bay of Fundy.

Also, in a large, deep ocean (Pacific), the tide wave itself is larger and higher.

Also, the natural period of oscillation in a long, narrow bay can be similar to that of the tides – so the oscillation amplifies the tide. Like pushing someone on a swing at just the right moment. The Bay of Fundy has a natural oscillation of 12 hours.

The standing tide wave has a node (minimum tidal range) at the entrance of the bay, and antinode (maximum tidal range) at the upper end of the bay. Bay of Fundy: tidal range at entrance = 6.6 ft, upper end = 35 ft.

EUROPA: a moon of Jupiter, a ‘water world.’ Detailed images of Europa were acquired by the Galileo spacecraft in 1996-1997 (see NASA web site). Surface deformation of the icy crust is due to TIDAL forces, not plate tectonics. The tides are caused by Jupiter, and by two other moons near Europa (Io, Ganymede).