WHY ARE THERE TWO TIDES A DAY, INSTEAD OF JUST ONE?

Those who live in the Bosham area are usually very well aware of the rise and fall of the tide. Neglecting this knowledge, and parking on Shore Road, can be an expensive mistake! Most people know that the tides are 'something to do with the moon and the sun', but few really understand what is going on. I have puzzled for some time as to why there are two tides a day. If the complete explanation is that the water is pulled towards the moon, there should only be one tide!

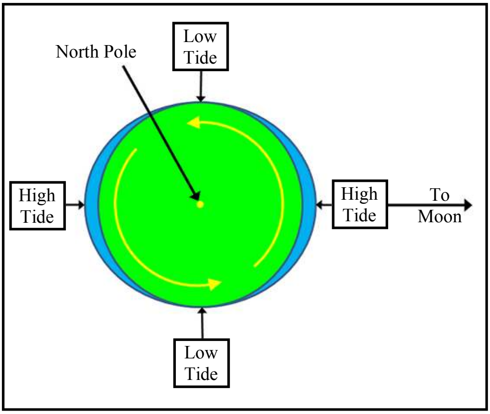


Figure 1: Tides are caused by bulges in the oceans, one on each side of the earth

The simple answer is that the oceans bulge out on both sides of the earth. As the earth rotates, each point on the coastline passes through these two bulges, in turn, and also through the low points between them (Figure 1). This causes two high tides and two low tides per day. However, that only replaces the question of 'why there are two tides?' by 'why are there two bulges?'!

The answer, unfortunately, is not particularly easy to understand! Forgetting the (minor) effect of the sun, the tides are caused by two things—the pull of the moon's 'tidal force', and centrifugal force. The moon's 'tidal force' is the difference between the moon's gravity on the side of the earth facing the moon and the moon's gravity on the opposite side of the earth. For those who have forgotten about centrifugal force, it is what causes things to fly outwards from something which is spinning. For you physicists out there, I *know* there is really no such thing as centrifugal force—it is actually an object's inertia reacting against a centripetal force—but it doesn't affect the explanation, and centrifugal force is a lot easier to understand!

The moon in its orbit goes around the earth once every four weeks. This has two effects on the earth's oceans. Firstly—the easy one—the moon's tidal force pulls the water in the direction of the moon, causing it to bulge out on the side of the earth facing the moon.

The second bulge is on the side of the earth opposite the moon, which is where the centrifugal force comes in. It is not strictly true to say that the moon revolves around the earth. What actually happens is

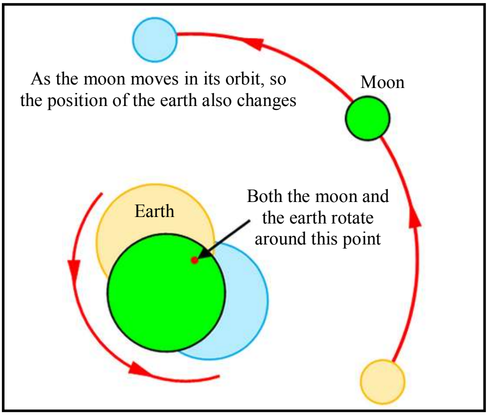


Figure 2: Both the moon and the earth rotate about the centre of gravity of the earth-moon system

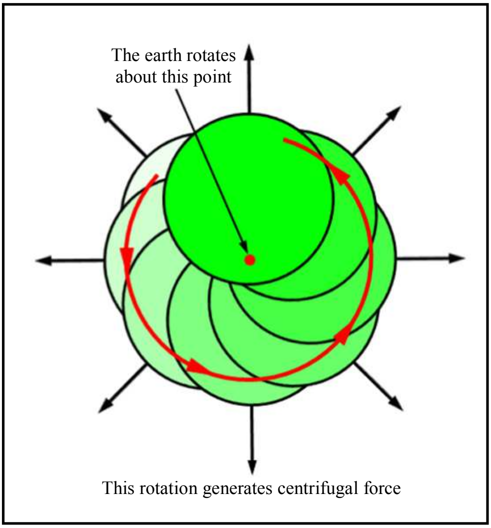


Figure 3: The rotation of the earth about the centre of gravity of the earth-moon system produces a centrifugal force

that both the moon and the earth revolve around a single point—their common centre of gravity—which is 2900 miles away from the centre of the earth, in the direction of the moon. Figure 2 shows the positions of the moon and the earth at three times during the month. The movement of the moon in its orbit is obvious, but the movement of the earth is more subtle. If you want a way to visualise this, think of the sporting event of hammer throwing. As the hammer spins around in a circle, the competitor spins around in a smaller circle. Both the hammer and the thrower rotate about a single point, which is between them, but closer to the thrower.

Because the earth is moving around in a circle, it produces a centrifugal force (Figure 3), which causes the oceans to bulge out on the side away from the moon. Hence the second tidal bulge, and the second tide in the course of a day.

The description given above only seeks to explain why there are two tides per day, and not just one. The actual height of those two tides, and when they occur, depends on a large number of factors, including the phase of the moon, the position of the sun, the depth of the ocean, and the shape of the coastline. These factors will be examined in further articles. The height of a particular tide also depends on the atmospheric pressure, and the direction and strength of the wind. On 10th March 2008, a particularly high tide coincided with especially low air pressure and a southwest gale, causing serious flooding in Bosham, the flood waters coming up Bosham Lane (Figure 4) as far as Bosham Walk!

(*Revised February 2015*)

Figure 4: Floods in Bosham Lane on 10th March 2008— Photo by Barry Colgate

WHY AREN'T ALL TIDES THE SAME HEIGHT?

My previous article explained why there are two high tides a day, when logic would dictate that there should be only one. I now want to explore the changes in the height of the tide, over the course of the month, and over the course of a year.

In order to understand the pattern of the tides, it is first necessary to understand the phases of the moon. Figure 1 shows the positions of the sun and the moon at three times during the month. When the moon is on the same side of the earth as the sun, the dark side of the moon faces the earth, and only a thin crescent of the moon's disk is visible. This is a 'new moon', which is mainly visible during the daytime. At the time of the full moon, the sun and the moon are on opposite sides of the earth, so that the whole disk of the moon is sunlit, when seen from the earth. The full moon is highest in the sky in the middle of the night. Between the full moon and the new moon, the moon is around the 'side' of the earth, and a 'quarter' moon is visible—the 'first quarter' occurs after the new moon,

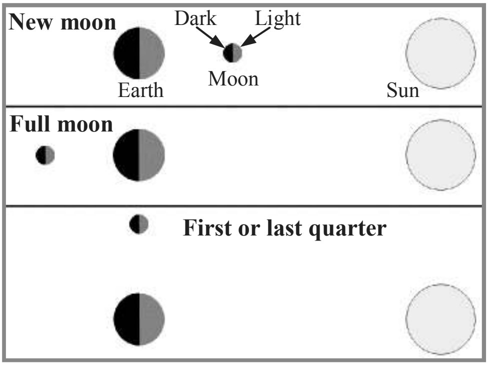


Fig 1: Relative positions of the moon, earth and sun at new moon, full moon and first and last quarters

and the 'last quarter' after the full moon. In both cases, the moon is lit from the side, so that half of the disk is illuminated. The moon is at its highest around dusk (first quarter) or dawn (last quarter).

The main factor producing the tides is the moon's 'tidal force', which is the difference between the moon's gravity on the side of the earth facing the moon and the moon's gravity on the opposite side of the earth. The sun's tidal force is much weaker than the moon's (because the sun is much further away), but it also exerts a 'pull', which modifies the effect of the moon's tidal force. At the time of the new moon, the sun's tidal force acts in the same direction as the moon's, causing the tides to be higher. At the time of the full moon, the sun is opposite the moon in the sky, and its tidal force adds to the 'centrifugal force' of the earth's rotation (described in the previous article), again causing the tides to be higher. Both these times of higher tides are called 'springs'. This is nothing to do with the season of the year—the word 'spring' is used as in a 'jump' or 'leap'. At the times of the first and last quarters, the sun's tidal force pulls 'sideways', compared with that of the moon, and it

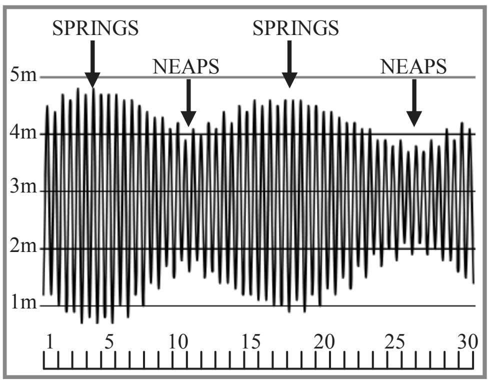


Fig. 2: The rise and fall of the tide at Portsmouth during November 2009

actually reduces, rather than increases, the height of the tide. These lower-than-average tides are known as 'neaps'—the Old English word for 'low'. In the course of a month, there are two spring tides and two neap tides. Figure 2 shows the rise and fall of the tide at Portsmouth during a single month (November 2009). The difference in height between the springs and neaps is clearly visible, but it is also apparent that not all spring (or neap) tides are the same height. This is because of the changing height of the sun in the sky.

Because the earth's axis is tilted relative

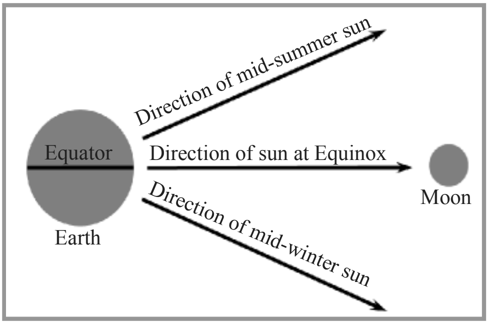


Fig 3: The sun and moon are in line at the equinox; the alignment is poorest at mid-summer and mid-winter

to its orbit, the sun changes its height in the sky over the course of a year. At the latitude of Bosham, the height of the sun above the horizon is 62° at the summer solstice (21 June) and only 16° at the winter solstice (21 December). The sun is exactly opposite the equator at the times of the vernal equinox (20 March) and the autumnal equinox (22/23 September). The highest tides occur when the tidal forces of the sun and moon act in the same direction. Since the moon orbits the earth roughly in line with the equator, the sun and moon are in closest alignment when the sun is also over the equator, which occurs at the equinoxes (Figure 3). Thus, the highest tides of the year occur around the time of

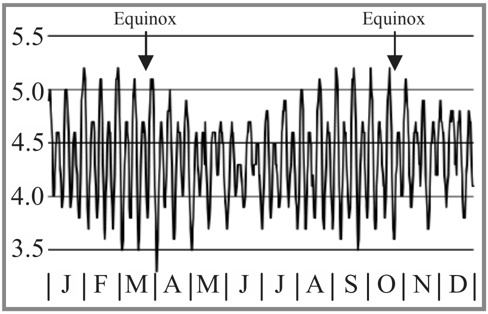


Fig 4: Heights of successive <u>high</u> tides at Bosham during 2010

the equinoxes, and are called (surprisingly enough) equinoctial tides! Figure 4 shows the height of the high tides at Bosham during 2010. The highest tides are in February/March and September/October. There is clearly no exact correspondence between the height of the tides and the dates of the equinoxes, although a general trend can be seen—the highest tides are in the spring and autumn, with lower tides in the summer and winter. The correspondence is not exact because of other factors which affect the height of the tides, including the distance between the moon and the earth, and the distance between the earth and the sun. The third article in this series will examine why the high and low tides occur at the times that they do.

(*Revised February 2015*)

WHAT CONTROLS THE TIMINGS OF HIGH AND LOW TIDES?

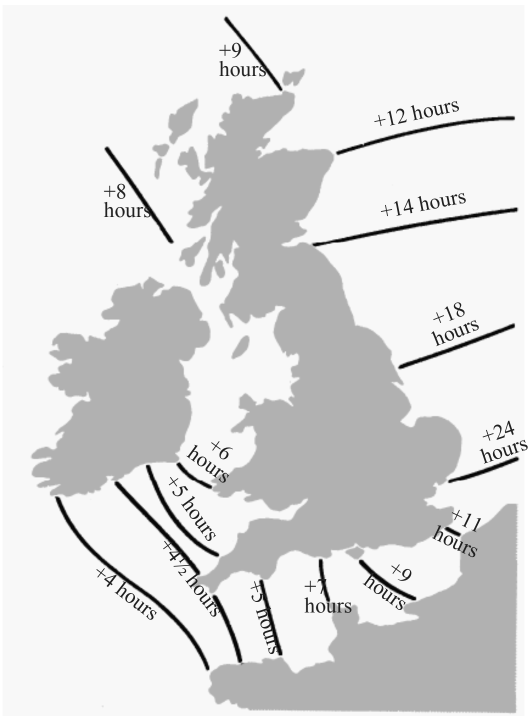
Every month, Bosham Life publishes the times of high tides for Bosham Quay, usually on page 23. Both the Sailing Club 'Red Book' and the 'Village News' give the timings at the harbour entrance. The widely available white booklet gives the timings at Portsmouth. Although the differences are not great enough to matter, these times are not exactly the same, high tide at Bosham being later that at Portsmouth by between 5 and 20 minutes. If high tide occurred when the moon was directly overhead (as you might expect), the speed at which the tide moved around the coastline should equal the rotation speed of the earth—around 1,000 km/hour at the latitude of Bosham. Since Portsmouth is only about 20km from Bosham, and the earth rotates west-to-east, high tide in Bosham should be about one minute earlier than in Portsmouth, not 5-20 minutes later! Thus, it is clear that something else is going on!

That something else is 'tide waves'—not to be confused with 'tidal waves', which are destructive tsunamis! The moon's 'tidal force' is the difference between the moon's gravity on the side of the earth facing the moon and the moon's gravity on the opposite side of the earth. The tidal force moves around the world at the speed of the earth's rotation, but the water itself cannot move at the same speed. There is thus a lag between the cause and the effect. And that lag can be substantial—up to 24 hours around the English coast!

The previous two articles have described how the tidal force of the moon, and to a lesser extent that of the sun, pulls the water into a bulge, which causes a high tide. Although this effect applies to any body of water (even to a glass of beer, if you had equipment sensitive enough to measure it), it only produces a noticeable effect on large bodies of water, such as the Atlantic Ocean. The piling up of water in the Atlantic produces a 'wave', which then radiates out in all directions.

It is well known that as waves reach shallower water, they slow down, allowing the following water to pile up and increase the wave height. Thus, the tide wave in the Atlantic may be only a few centimetres in height, but when it arrives at the coast, it produces the 3-5 metre rise and fall of the tide, with which we are all familiar.

The tide wave reaches the coast of Portugal about two hours after the moon has passed overhead. It reaches western France after three hours, and Lands End after 4½ hours. Having encountered the obstruction of the British Isles, the wave splits, and goes around the island in two



directions. Since it takes a finite time to move large quantities of water, the wave gets later and later as it progresses, as shown in the figure. One part of the wave travels around the north of Scotland, then down the North Sea to East Anglia, by which time it has been delayed 24 hours. There it joins up with the wave which has passed up the English Channel, and accumulated a 12 hour delay.

The high tide over the Atlantic occurs when the moon is at its highest in the sky, and again 12 hours later. At the time of the full moon and new moon, spring tides occur, around noon and midnight. It takes about 9 hours for the tide wave to reach Bosham. There is also a two-hour time difference between Bosham and the area in the Atlantic where the wave is generated, so at full moon and new moon, the spring tides occur at around 11am and 11pm GMT. When summer time is in force, the corresponding times are noon and midnight. Neap tides occur at 5am and 5pm GMT, or 6am and 6pm in summer time. You should be able to confirm this from the tide tables in this magazine!

Lastly, I have been very casual up to now, in saying that there are 12 hours between one high tide and the next. There are not, of course. Although the time between high tides varies a little, it averages out at 12 hours 25 minutes. The extra 25 minutes per 12 hours, or 50 minutes per day, is due to the changing position of the moon in the sky. If you buy a 'tide clock', it uses this interval to give the current state of the tide, which can be quite useful information if you live in Bosham!

Mike Whittle

(*Revised February 2015*)

HERE COME THE 'SUPERTIDES'

As we all know, the tide comes in and goes out twice a day. How far it comes in, and how far it goes out again, however, varies a great deal. This subject has been explored in three articles in Bosham Life, which may be downloaded from the Bosham Life website: boshamlife.co.uk.

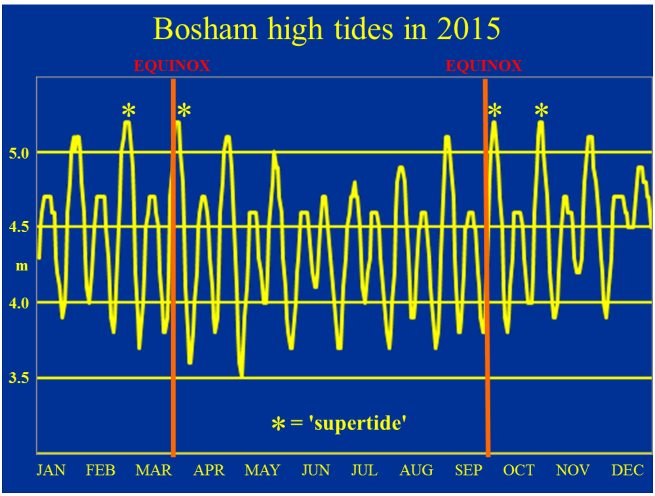
- October 2009: Why are there two tides a day, instead of just one?
- December 2009: Why aren't all tides the same height?
- February 2010: What controls the timings of high and low tides?

But they do not cover a topic which the popular press has dubbed '*supertides*'.

The highest tides are seen:

1) …when the sun, moon and earth are (roughly) in a straight line, which occurs twice a month, at full moon and new moon.
2) …when the sun is over the equator, which occurs twice a year, at the spring equinox in March and the autumn equinox in September.
3) …when the moon is also over the equator. The position of the moon varies between 5° above the equator and 5° below it, over the course of a year.
4) …when the earth, in its elliptical orbit, is closest to the sun. The distance between the earth and the sun varies by about 3% over the course of a year, the distance being shortest around January.
5) …when the moon, which also has an elliptical orbit, is closest to the earth. The distance between the moon and the earth varies by about 11%, over the course of 18 years.

Since these five influences on the height of the tides vary at different rates, for most of the time one or two of them will be high, and one or two will be low, and the resulting tides will be in the 'normal' range. However, if several of these influences coincide, the combined effect produces especially high tides. This occurs about every 18 years, and is happening in 2015. Higher than normal tides can be expected on the following dates: 20-22 February, 20-23 March, 28-30 September and 27-29 October.



So, can we expect to see flooding in Bosham on those dates? The answer is 'no, not necessarily'. The predicted high tides on those dates are only a few inches higher than on many other days throughout the year. It is only when these high tides are combined with two other factors—low air pressure and strong onshore winds—that we are likely to experience flooding. So keep your fingers crossed!

Mike Whittle