

What Causes Tides?

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Abstract

It has been known for thousands of years that the waters of coastal seas ebb and flow on a daily basis. This rhyme is widely thought to be from the gravitational pull of the Moon and Sun. Here we propose that, the Earth's curved motions about the barycenter of the Earth-Moon system and about the Sun may generate centrifugal effect to stretch the Earth, the resulting deformation, together with the Earth's daily rotation and the globally water covering, makes land regularly rise from and fall into water. The rise and fall of land lead water to recede and advance, and also the fall and rise of water level at local.

1 A brief introduction of tidal ideas

From antiquity it has been familiar that coastal seas always perform daily regular movements of water rise and fall. Since these movements are closely related to the frequently coastal activities, explaining them has undoubtedly tested human wisdom for millennia. Aristotle (384-322 BC) was highly perplexed and vaguely attributed it to the rocky nature of the coast. Galileo asserted that the Earth in the curved orbit is alternately accelerated and retarded to induce the sea to move and form tide. Early Chinese considered tides as the beating of the Earth's pulse and alternatively, it was believed to be caused by the Earth's breathing. Some people thought tides were caused by the different depths of ocean water. However, the majority certainly linked tidal action to the influence of the Moon and of the Sun. Seleucus (lived in the 2nd century BC) was the first to consider this connection. He concluded the height of tide was correlated with the Moon's position relative to the Sun. However, the exact determination of how the Moon and Sun cause tides is unknown. A few Arabic explanations proposed that the Moon uses its rays to heat the water and then expand it. Descartes argued that space was full of ethereal substance and the resulting stresses between the ether and the Earth's surface gave birth to tides when the Moon travelled round the Earth. In contrast, Kepler and Newton represent those who expressly define this influence as the attraction of the Moon and Sun on the water. Newton formulated an equilibrium mechanism to account for the tide, within it the Earth is supposed to be an ocean planet with no land, and the influence of inertia and currents are fully ignored. The gravity gradient of the Moon produces a pair of bulges of water on Earth (that is in the line of the Earth-Moon system) to form tides. As Newton and the well known 1740's Essayists (such as Daniel Bernoulli, Leonhard Euler, Colin Maclaurin, and Antoine Caverri, for instance) had assumed the oceans' response to the tidal driving force to be quasi-static, considering the complexity of actual oceans and currents, Laplace developed a set of hydrodynamic equations of continuity and momentum for a fluid on a rotating earth. Together with the following endeavors (including William Thomson, Baron Kelvin, Henri Poincaré, Arthur Thomas Doodson, etc.), the idea of gravitation as the cause of tide (we name it the attractive mechanism in the following sections) was increasingly strengthened and became the cornerstone of modern tidal theory. A fuller review of the tidal history may be found in these works (Pugh 1987; Cartwright 1999).

2 Why is the attractive mechanism infeasible?

Logic

The attractive mechanism may be approximately expressed with such a paradigm (Pugh 1987; Stewart 2008): within the Earth-Moon system the two bodies revolve about their common centre of mass. As the two bodies rotate in the system, each particle of the Earth moves in a circle which has the same radius. The force necessary to maintain this revolution of each particle is the same as for the particle at the centre of the Earth. The difference between the

force necessary to maintain the revolution of a particle and the Moon's gravitational pull on the particle is the tide producing force at the particle. In detail, as shown in Figure 1, a particle of mass m located at P_1 of the Earth's surface, the Moon's gravitational pull on this particle is $Gmm_1/(R-a)^2$, the force necessary for its revolution is the same as for a particle at O , which is Gmm_1/R^2 , the difference between these two is $Gmm_1[1/(1-a/R)^2-1]/(R)^2$, which is treated as the tide producing force at P_1 . Due to $(a/R)^2 \ll 1$ and expanding $[1/(1-a)^2] \approx 1+2a$ for small a , this finally results in a net tidal force (towards the Moon) of $2Gmm_1a/R^3$ at P_1 , where m_1 , a , R , G are respectively the Moon's mass, the Earth's radius, the distance between the Earth and Moon, and gravitational constant. Similar work for a particle located at P_2 results in a net tidal force (away from the Moon) of $-2Gmm_1a/R^3$. The net force at P_3 , directed towards the Earth's center, is given as Gmm_1a/R^3 under a consideration that approximately treats $\sin(\angle P_3O) = a/R$ and the force along P_3M is given as Gmm_1/R^2 . The net effect is for particles at both P_1 and P_2 to be displaced always from the centre of the Earth, whereas particles at P_3 are displaced towards the centre. This leads to an equilibrium shape (two bulges) for a fluid Earth which is slightly elongated along the axis between the centers of the Moon and the Earth.

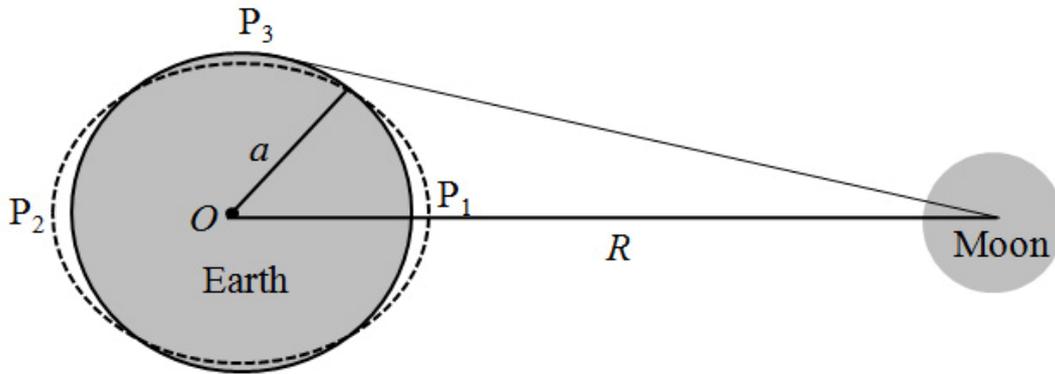


Figure 1: The dynamics frame of the attractive mechanism. R and a represent the distance between the Earth and Moon and the Earth's radius, O is the centre of the Earth. Dashed lines are the resulting bulges due to the Moon's gravitational pull.

At first glance, this argument is considerably self-contained, but it misses a crucial point. As described above, "The net effect is for particles at both P_1 and P_2 to be displaced always from the centre of the Earth", "to be displaced" means a tendency only. In fact, in another work of the attractive mechanism (Sawicki 1999) the effect of the tide producing force is also considered as a tendency for object to move. What is a tendency? A tendency represents a possibility. It means an event may occur and also may not occur. This is determined by a condition. For instance, if we use a force to push a building. Under the effect of this force the building has a tendency to move (to be displaced). But whether the building really moves away is determined by whether this force is stronger than the ground's friction acting on the building. Also, if we use a force to lift an object, the force we exert on the object is necessarily greater than the Earth's gravitational pull on the object. Go back to the event of the Moon's gravitational pull on these particles at both P_1 and P_2 , to make these particles really move away from the surface of Earth, at least, the tidal producing force should be greater than the Earth's gravitational pull on them. According to the established parameters, the tidal producing force gives these particles just an acceleration of about $11.2 \times 10^{-8} g$, an extremely infinitesimal amount, where g is the Earth's gravitational acceleration. Therefore, the tidal producing force is unable to displace these particles away from the surface of Earth. One should be aware, these particles and other parts of the Earth are gravitationally fixed together, when an external force (the Moon's gravitation, for instance) attempts to pull any of them, it inevitably works on all of them. In addition to those, from the view of an earthly observer, the displacement of these particles that is asserted is unobservable. We temporarily allow that these particles due to the tidal producing force have been displaced away from the

surface of the Earth. So, how to measure this displacement? An observer can never stay at the Earth's centre, and he also cannot stay beyond the Earth. In everyday life the observer often stays at/near seaside viewing a tide. If the tidal producing force may displace these particles away from the Earth's surface, inevitably, it also may displace the observer away from the Earth's surface. Physical knowledge shows that, within an identical reference frame, the observer cannot discern the displacement of these particles.

Expectation

The attractive mechanism results in two symmetric tidal bulges and asserts that the effect of the Moon's declination is to produce an asymmetry between the two high and the two low water levels as a site rotates on the surface of solid Earth within the two bulges. Namely, a site at P is experiencing a much higher water level than it will experience about 12 hours later when the Earth's rotation brought it to P' (Figure 2). This is not the matter, because the two bulges also generate an equality of two low water levels when they generate the inequality of the two high water levels. For example, we conclude that, for a spherical Earth, the middle of the two bulges will be a belt (marked with dashed lines) of the lowest water level, the site at P will inevitably pass through this belt at P_1 and P_2 per day as the Earth rotates, two low water levels of same size are formed. From the view of the globe, other sites (N and Q , for instance) at different latitudes also will pass through this belt of the lowest water level (at N_1, N_2 , and Q_1, Q_2) to form two low water levels of same size. On the whole, the attractive mechanism will request the high water levels of these sites to be different in size but the low water levels to be same in size. This is evidently against the observed tides.

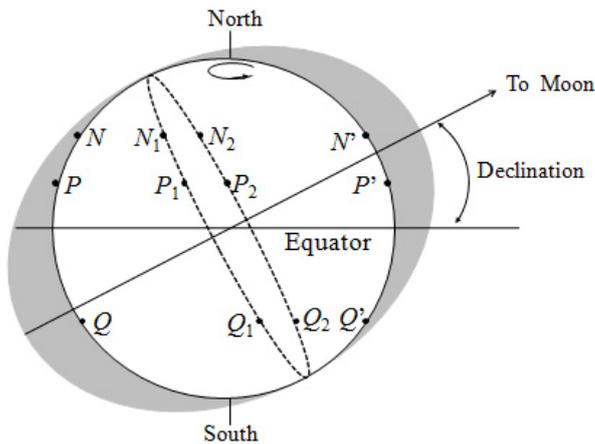


Figure 2: Showing how the unequal semidiurnal tides are determined. O is the Earth's centre. Note the Earth's deformation is exaggerated.

Refer to Pugh's work (1987), the attractive mechanism deduces a formula for the equilibrium model to describe the elevation of the sea surface because of the Moon's gravitational pull.

$$H_m = a(M_m/M_e)[C_0(t)(3\sin^2\varphi_p/2 - 1/2) + C_1(t)\sin 2\varphi_p + C_2(t)\cos^2\varphi_p]$$

$$C_0(t) = (a/R_m)^3(3\sin^2 d/2 - 1/2)$$

$$C_1(t) = (a/R_m)^3(3\sin 2d \cos C_p/4)$$

$$C_2(t) = (a/R_m)^3(3\cos^2 d \cos 2C_p/4)$$

where H_m , a , M_m , M_e , φ_p , R_m , d , and C_p are respectively the elevation of the sea surface, the Earth's radius, the Moon's mass, the Earth's mass, the latitude of a particle at the sea surface, the distance of the Earth and Moon, the declination of the Moon, and the hour angle of the particle.

Replace M_m and R_m respectively with M_s (the Sun's mass) and R_s (the distance of the Earth and Sun), the elevation of the sea surface H_s due to the effect of the Sun's gravitational pull may be obtained. $H_m + H_s$ thus represents the total elevation of the sea surface because of the combination of the Moon and the Sun. Figure 3 compares the expected tides (from the equilibrium mode) with the observed tides. It can be found that there is a significant discrepancy of morphology. The equilibrium mode requests the tide to be asymmetric as latitude increases. This includes two aspects: 1) the variation of tidal amplitude between two

successive high tides is greater than that between two successive low tides; and 2) two successive high tides are reversely developed, namely, the amplitude of one high tide is increased (decreased) as the amplitude of another high tide is decreased (increased). This point may be concluded from Figure 2. For site $N(Q)$, the water level at $N'(Q')$ is increased (decreased) while the water level at $N(Q)$ is decreased (increased) as the bulges turns toward pole. Contrary to this, the observed tides perform symmetric anywhere. On the whole, the equilibrium model requests the diurnal tides to occur in higher latitude regions and the semidiurnal tides to occur in lower latitude regions. We examined hundreds of observed tides around the globe and found no evidence to support this expectation. The semidiurnal and diurnal tides are freely distributed. There are semidiurnal tide at Greenland (76.54° N) and mixed tide at Alert of Canada (82.50° N), and also, there is the diurnal tide at the Karumba Gulf, a relatively lower latitude region.

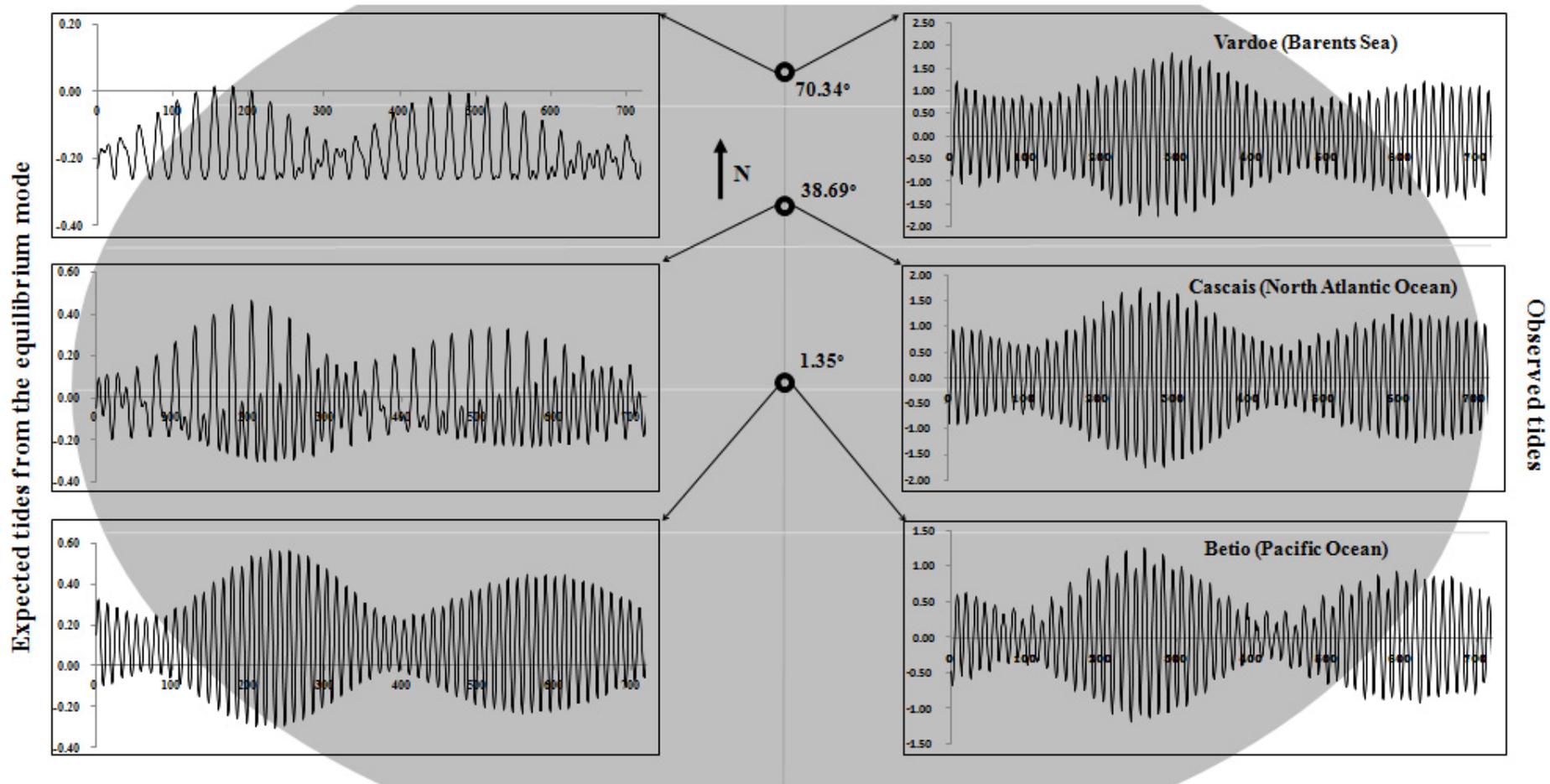


Figure 3: A morphological comparison of the expected tide from the equilibrium mode (left) and the observed tides (right).

3 An analytic treatment of the deformed Earth and the resulting tide

The Earth is an oblate spheroid that is thought to be from a centrifugal effect of the Earth's rotation about its axis. This suggests, the Earth may be stretched by a centrifugal effect. It is already known that the Earth orbits about the barycenter of the Earth-Moon system and the Earth-Moon system orbits about the Sun, these two curved movements generate two centrifugal effects F_1 and F_2 for the Earth at the same time (Figure 3(A)). Practically, F_2 is far larger than F_1 (F_2/F_1 is about 780), but the working point of F_2 (the barycenter of the Earth-Moon system) is not at the Earth's centre, compared to the working point of F_1 (the barycenter of the Earth) that is at the Earth's centre. Even so, the centrifugal effect F_2 still will generate a component $F_2 | \cos\theta |$ directed to the line of the Earth-Moon system. In consideration of the fact that the working point of F_2 is not at the Earth's centre, we suppose the effective part of F_2 , which is able to stretch the Earth, is relatively small. The tidal range of Betio at the time of new Moon or full Moon is about 6 times the tidal range at the time of first quarter or first quarter, the tidal range of Diego Garcia at the time of new Moon or full Moon is about 6.5 times the tidal range at the time of first quarter or first quarter. This ratio may reach 4.0 times at Ecuador, 5.6 time at Mombasa, and 7.5 times at Marshall Islands. From the view of a compromise, we assume the effective part of F_2 to be $4F_1$. Therefore, the combined centrifugal effect that is in the line of the Earth-Moon system may be expressed as $F = F_1 + 4F_1 | \cos\theta |$, where θ is the angle between the Moon and the Sun relative to the barycenter of the Earth-Moon system and may be approximated by the angle between the Moon and the Sun relative to the Earth. We suppose that the Earth's extension in the equatorial direction is more effective than in any other direction and that the centrifugal effect in the line of the Earth-Moon system may further generate a component $(F_1 + 4F_1 | \cos\theta |) \cos\alpha$ to stretch the oblate spheroid along the direction of the equator (Figure 3(B)).

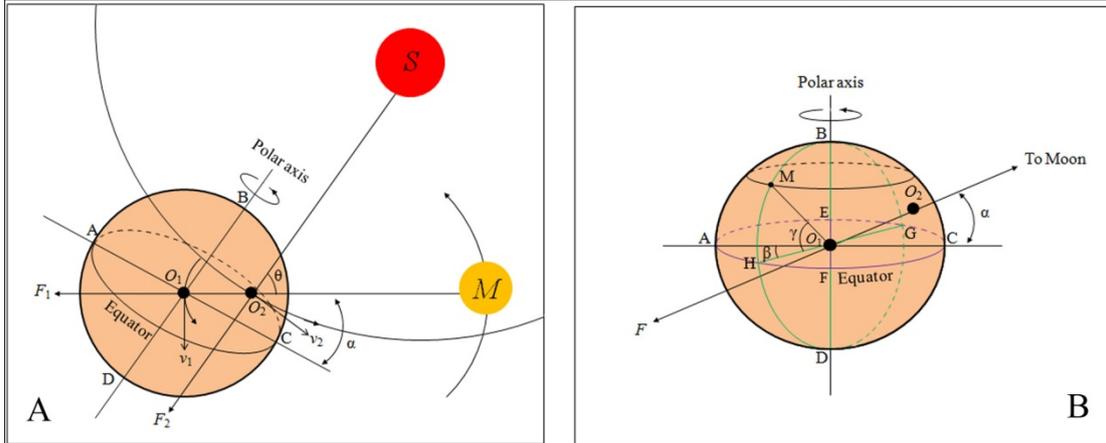


Figure 3: Combined centrifugal effects for solid Earth and the resulting extension. F_1 and F_2 are the centrifugal effects that solid Earth undergoes because of curved motions around the barycenter of the Earth-Moon system and around the Sun. O_1 , O_2 , M , and S are the Earth's centre, the barycenter of the Earth-Moon system, the Moon, and the Sun, respectively. θ is the angle between the Moon and the Sun relative to the barycenter of the Earth-Moon system. v_1 and v_2 are respectively the velocity of the Earth orbiting the barycenter of the Earth-Moon system and the velocity of the Earth-Moon system orbiting the Sun, which generate the centrifugal effects F_1 and F_2 .

To better run the following deduction, we suppose a global water covering of same depth and cut the oblate spheroid to form two sections $A_0E_0C_0F_0$ (including section AECF), which is the equatorial plane, and $H_0B_0G_0D_0$ (including section HBGD), the section HBGD passes through a site M that is at the surface of the oblate spheroid. We use the generated component $(F_1 + 4F_1 | \cos\theta |) \cos\alpha$ to stretch the oblate spheroid along the line $AC(A_0C_0)$. The two sections $A_0E_0C_0F_0$ and $H_0B_0G_0D_0$ then become sections $A_0'E_0'C_0'F_0'$ and $H_0'B_0'G_0'D_0$, the sections AECF and HBGD then become sections $A'EC'F$ and $H'BG'D$, site M also turn to the site M' (Figure 4).

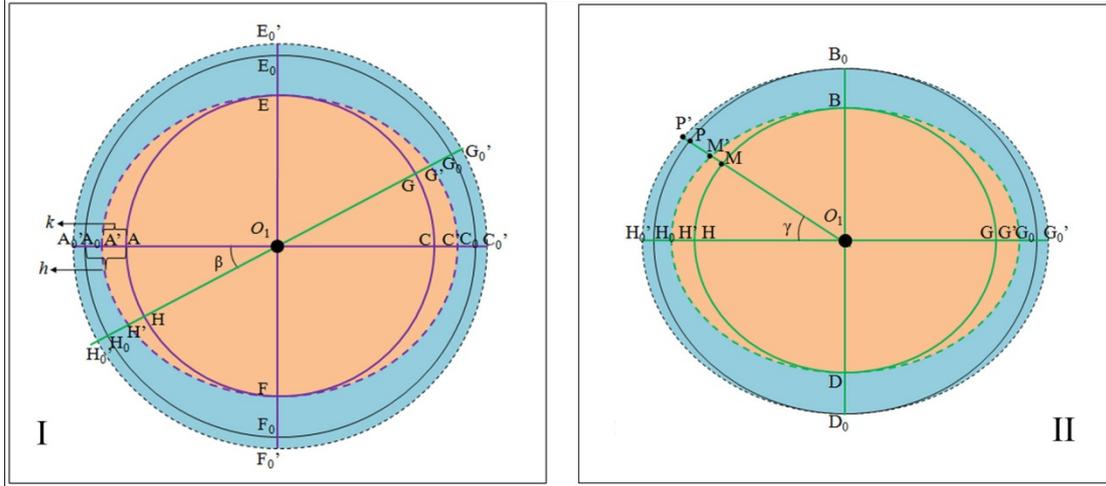


Figure 4: A global water covering the Earth. I: an equatorial section of the Earth and covering water. Black dashed line is the original water level while black real line is the water level after the Earth is extended in the line AC. Purple dashed line presents the Earth's deformation due to the centrifugal effect while purple real line presents the original shape. Ellipse A'EC'F represents the Earth's shape in the direction of equator. II: a longitudinal section of the Earth and covering water that passes through polar axis, which represents a perspective view of the oblate spheroid. O_1 is the Earth's centre.

These adjustments yield a globally water reallocation that occurs dominantly in the direction of line $E_0'F_0'$. This is because the Earth's extension in the direction of line AC makes water gravitationally flow towards the direction of line $E_0'F_0'$, in addition, the Earth's extension is rolled from east west due to the Earth's rotation, this makes water reallocation in the direction of line B_0D_0 become slight. With the Earth's rotation around its axis, site M (if not polar) will continuously pass through these regions of different water depth. We suppose that another site P of water surface turns to site P' when water reallocation takes place and that both sites P and M are with same latitude and longitude. According to the geometry of ellipse, the water depth of site M may be expressed as

$$Q = P'O_1 - M'O_1 \quad (1)$$

$$P'O_1 = [H_0'O_1^2 \cos^2 \gamma + B_0O_1^2 \sin^2 \gamma]^{1/2} \quad (2)$$

$$M'O_1 = [H'O_1^2 \cos^2 \gamma + BO_1^2 \sin^2 \gamma]^{1/2} \quad (3)$$

Where

$H_0'O_1$ and B_0O_1 are respectively the semi-minor axis and semi-major axis of ellipse $H_0'B_0G_0'D_0$, $H_0'O_1 = A_0'O_1 = F_1O_1$, $A_0'O_1$ may be further obtained by an area formula $\pi \times A_0O_1 \times F_0O_1 - \pi \times AO_1 \times FO_1 = \pi \times A_0'O_1 \times F_0'O_1 - \pi \times A'O_1 \times FO_1$, $A_0O_1 = F_0O_1$, $A_0O_1 = AO_1 + h$, $F_0O_1 = FO_1 + h$, $B_0O_1 = BO_1 + h$, $A'O_1 = AO_1 + k$, where h is the mean water depth of global water, and k is the extension of the oblate spheroid in the line AC that is due to the combined centrifugal effect, β is the angle of section ABCD and HBGD, which is equal to the difference in longitude between the Moon and site M.

$H'O_1$ and BO_1 are respectively the semi-major axis and semi-minor axis of ellipse $H'BG'D$, $H'O_1$ may be obtained by a formula $H'O_1 = [A'O_1^2 \cos^2 \beta + FO_1^2 \sin^2 \beta]^{1/2}$;

γ is the angle of line MO_1 and equatorial plane AECF, which is equal to the latitude of site M;

We further suppose an island that stands on the position of site M to protrude the water surface, then the water level variation of a site (site P, for instance) at the shore of this island may be used to rule the water depth variation of site M. The related parameters are considered as follows: the equatorial and polar radius of the Earth are respectively 6378.00 km and 6357.00 km, the difference between them is 21.00 km (Milbert and Smith 1996; Sandwell and Smith 2006). The ratio of centrifugal effect between the Earth's rotation around its axis and the Earth's rotation around the barycenter of the Earth-Moon system is about 500:1. A rough estimation based on this ratio is the Earth's rotation around the barycenter of the Earth-Moon

system may generate an extension of about 42.00 m. However, the Earth's bulge in the equator is likely to be resulted from an accumulating effect of Earth's rotation around its axis during a time scale of billions of years, thus, the centrifugal effect due to the Earth's rotation around its axis at instant will give rise to only a slight extension. Here we assumed the extension due to the centrifugal effect F_1 at instant to be 0.10 m when the Moon is at the equator, the resulting extension k in the line AC may be expressed by formula $k = (0.1 + 4 \times 0.1 |\cos\theta|) \cos\alpha$, where α is the Moon's declination. And therefore, within these ellipses (as shown in Figure 4) there will be $AO_1=FO_1=6378.00$ km, $BO_1=6357.00$ km. We assume h to be the reference water depth and value it as 3.60 km. In consideration of the fact that the oceans cover approximately 71% of Earth's surface, the total water volume is estimated to be 1.32×10^9 km³. This amount approaches the established threshold 1.34×10^9 km³ (Eakins and Sharman 2010). A site (30° N) is selected to run the simulation (Figure 5). In detail, the variation of water depth (also water level) is semidiurnal, and within a lunar month the variation experiences two cycles. The high water and the low water are symmetrically developed. The highest high water (the so-called spring tide) occurs shortly after the times of full Moon and new Moon, the lowest low water (the so called neap tide) occurs at first quarter and last quarter. This is because at times of spring tides the combined centrifugal effect ($F_1 + 4F_1 |\cos\theta|$) in the line of the Earth-Moon system becomes maximal, and thus in the direction of equator the resulting centrifugal effect ($F_1 + 4F_1 |\cos\theta|$) $\cos\alpha$ also becomes maximal, and further the deformation of the Earth is the most serious, but at times of neap tides the combined centrifugal effect in the line of the Earth-Moon system becomes minimal, and further the deformation is the slightest. As α , the Moon's declination, is usually between -18.3° and 18.3° , this makes the Moon's individual contribution in deforming the Earth not important.

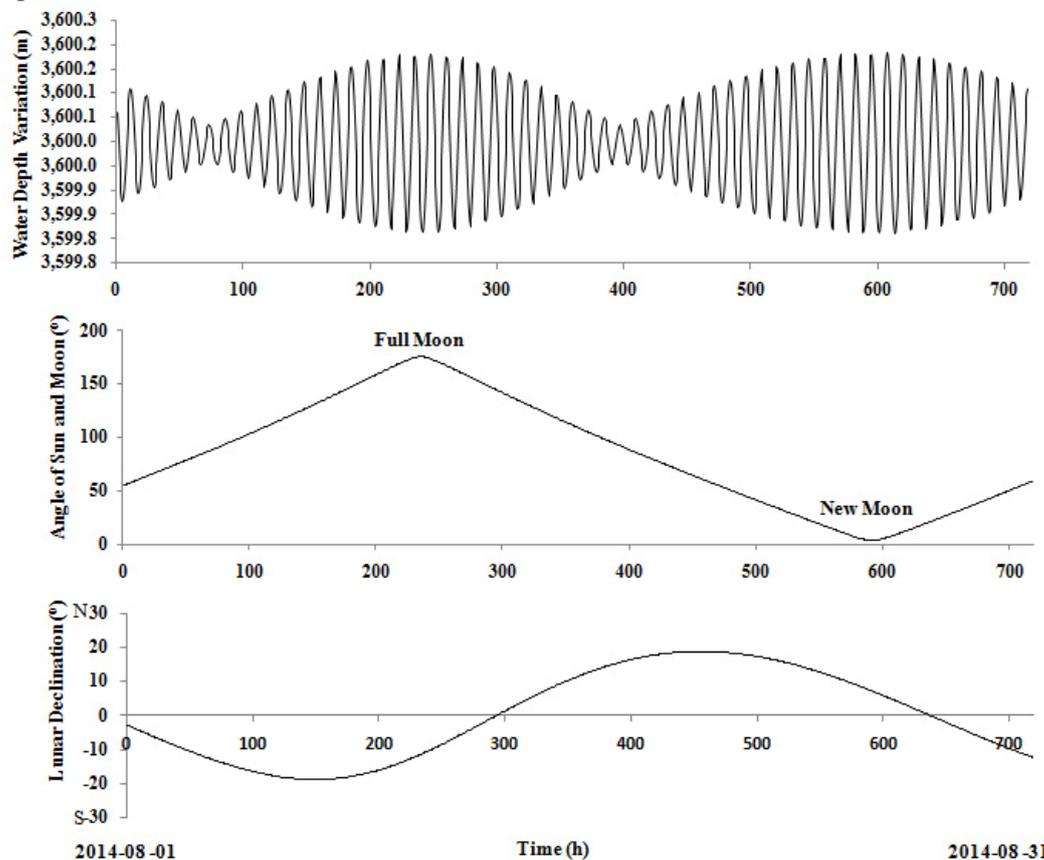


Figure 5: The expected tide out to the phase of the Moon and Sun. Time span is from 2014-08-01 00:00:00 to 2014-08-30 23:00:00.

Let's further consider the influences of these factors such as continent, topography, ocean

width, and so on. Practically, the continents and oceans are randomly distributed around the global. We cut the Earth along equator to form a section. This section ideally includes two continents and two oceans, and within one of the continents there is an enclosed sea/lake. Because of the effect of the centrifugal effect, the Earth is extended in the direction of line AC (refer to Figure 6 (left)). The elevation in the direction of line AC leads local water to gravitationally flow towards the direction of line EF. With the Earth's rotation about point O_1 , these sites (a, b, c, d, g , for instance) located at the shores of continents and islands will continuously pass through the deep water in the direction of line EF and the shallow water in the direction of line AC. Two high waters and two low waters are therefore experienced by them per day. It should be noted that, even if ocean one is short, latitudinally less than 90° , with the Earth's rotation, the oscillation of ocean bed $a'b'$ still makes water flow back and forth between site a and site b . The high and low waters are accordingly generated for these two sites. This mechanism also adapt to the matter of enclosed sea/lake. The amplitude of high (low) water at one end of the sea/lake is determined by the difference of the rise (fall) of another end and the fall (rise) of this end. If we select two sites respectively from the east end and from the west end of Black sea and use the formula (2) above to estimate, Black sea will hold a tide of about 6.0 cm. Similarly, a tube of water (20 m in length) horizontally located at equator will experience a tide of about 9.3×10^{-4} mm, an imperceptible amount. This means that, any vessel, such as swimming pool, water cup, water bowl, and so on, because its size is too short, will not experience an perceptible tide.

Most of continental shores are bent, they are either convex or concave. These features may largely boost the amplitudes of tides. We cut a little part from the equatorial section to form a plane area (Figure 6(right)). At the area the Earth's extension in the direction of line AC makes water flow towards continent one if site c (representing the shore of continent one) moves to the direction of line EF. Suppose the extension is h_1 , from the viewpoint of energy conservation, the expelled water will then hold a movement of $v_1 = (2gh_1)^{1/2}$. If there is no loss of energy and the shore is vertical to the movement of water, the water will accumulate at shore c with an amplitude of h_1 on the assumption that shore c is straightforward. As shore c is often concave, this creates an effect of narrow to enlarge the speed of water. This effect of narrow fits to a simple relation: $v_1 L_1 = v_2 L_2$, where L_1 and L_2 are respectively the width of section $c_1 c_2$ and section $c_1' c_2'$, namely, the flow velocity is inversely proportional to the width of passage. Thus, the water of velocity v_2 , if accumulated at section $c_1' c_2'$, may theoretically form a water of amplitude $h_2 = (L_1/L_2)^2 h_1$. In contract, the shores of those islands (represented by d) that are isolated in the deep oceans are too short and not vertical to the movement of water. The expelled water cannot be effectively accumulated and may bypass. This determines larger tides to occur at the shores of coastal seas and smaller tides to occur at the shores of the islands in the deep oceans.

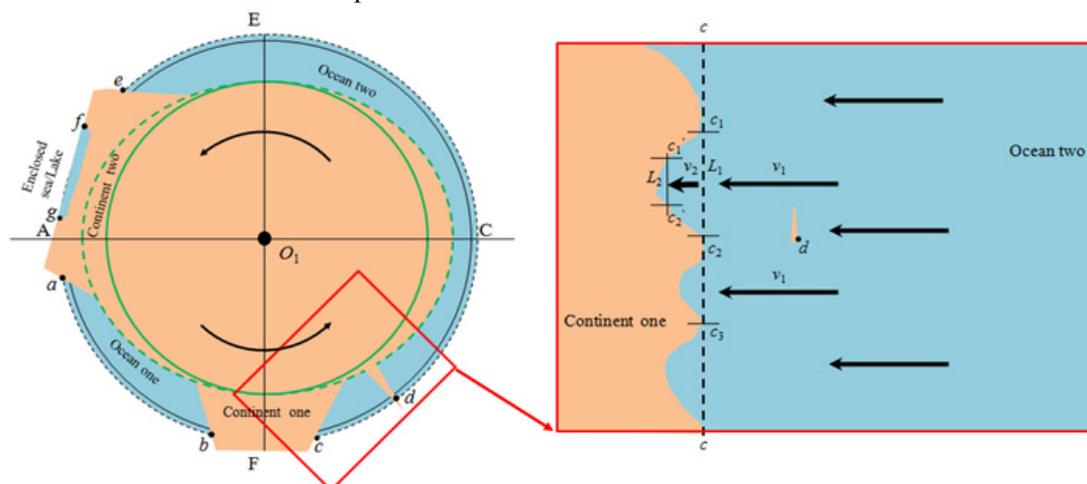


Figure 6: A realistic distribution of global water and solid Earth. Left: an equatorial section of the Earth. Black dashed line is the water level after the Earth is extended in the line AC while black real line the original water level. Green dashed line represents the deformation of the Earth

due to the centrifugal effect. Black arrows represent the Earth's rotation around O_1 (the Earth's centre); Right: an interaction of moving water and uneven shore.

There are some shores that are concave, nearly semi-enclosed, but with openings connecting to the oceans. These regions include the Mexico Gulf, the Persian Gulf, the Karumba Gulf, and so on. The east end and west end of these areas may oscillate as the Earth is continuously deformed from east to west, at the same time the north end and south end of these areas may also oscillate because the extension of the Earth is gradually decreased from equator to pole. These may give rise to respectively a latitudinally water movement and a longitudinally water movement. As these openings are connected to the oceans, the water within these areas will be greatly disturbed by the water that is from the oceans, the variation of water level therefore becomes irregular, this generates the so-called diurnal or mixed tide. Here we employ the Karumba Gulf to demonstrate such a process. As shown in Figure 7, during the period of $T=0\sim 6$ h, the Earth is continuously stretched from east to middle, the rising part of land makes the water (marked with red) at the shore of Papua flow southerly, at the same time the rising part makes the water (marked with purple) at Arafura Sea flow westerly. The water level of the Karumba Gulf begins to rise. During the period of $T=6\sim 12$ h, the Earth is continuously stretched from middle to west, the rising part makes the water of the Karumba Gulf flow northerly and makes the water of Indian Ocean and Java Sea flow easterly. Suppose that the easterly water is stronger than the northerly water in both size and speed, this provides a condition for the easterly water ahead of the northerly water to arrive at the north end of the Karumba Gulf, the easterly water thus blocks the northerly water. Part of the easterly water will deflect into the Karumba Gulf to give rise to a rise of water level. Suppose that at the time of $T=11$ h, a great deal of westerly water is deflected into the Karumba Gulf, water level reaches the highest at the moment. After that, water level begins to fall. During the period of $T=12\sim 18$ h, the Earth is again stretched from east to middle. Note that there are two symmetric elevations for the Earth because of the centrifugal effect. The rising part makes the water at the north end of the Karumba Gulf flow westerly, this removes the block for the northerly water. The water level of the Karumba Gulf continues to fall. At the time of $T=18$ h, the westerly water reaches Indian Ocean and Java Sea, the northerly water continues to flow towards the shore of Papua. The water level of the Karumba Gulf continues to fall. During the period of $T=18\sim 24$ h, the Earth is continuously stretched from middle to west, the rising part makes the northerly water continue to flow towards the shore of Papua and makes the water of Indian Ocean and Java Sea return. The water level of the Karumba Gulf still continues to fall. At the time of $T=24$ h, water level reaches its lowest point. On the whole, one high water and one low water are determined for the Karumba Gulf per day.

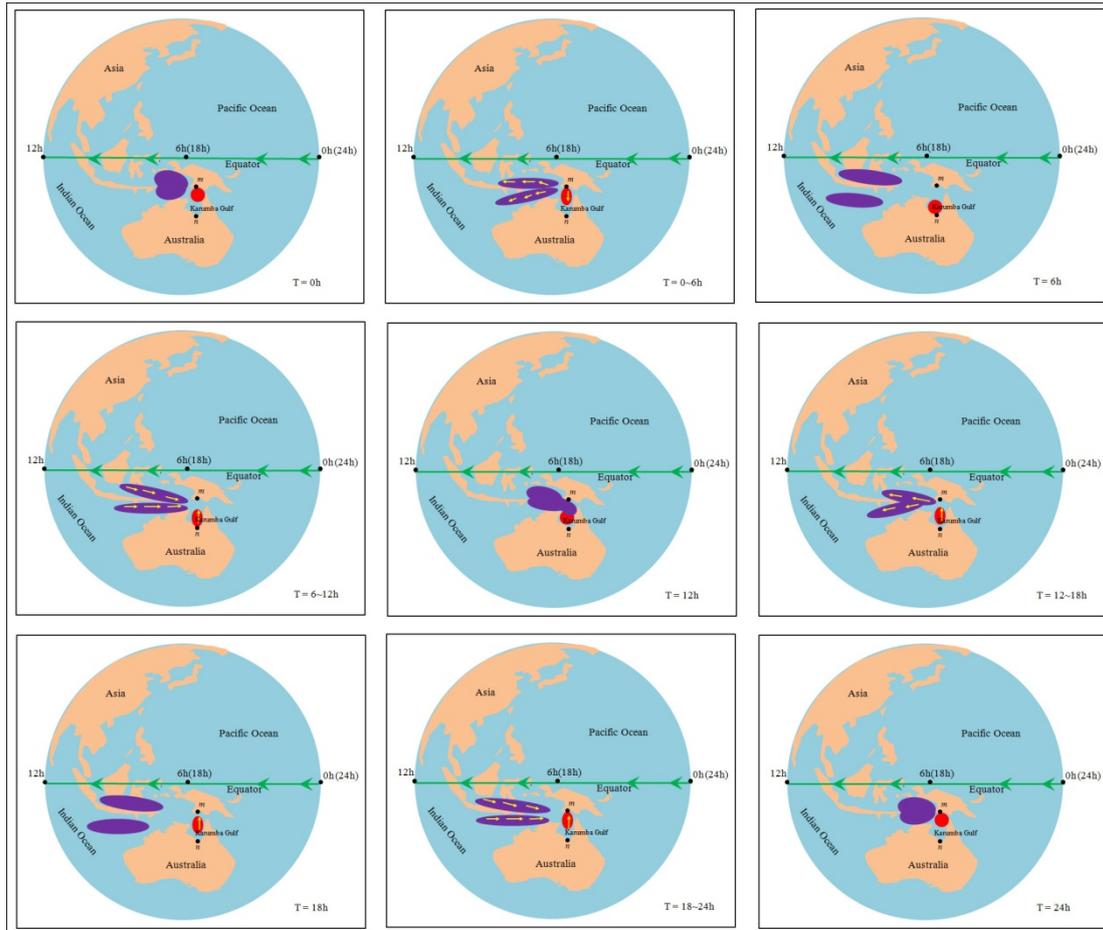


Figure 7: Modelling the formation of diurnal tide at the Karumba Gulf. Yellow arrows represent the moving direction of water, green arrows represent the Earth's rotation from east to west. The Earth is longitudinally divided by 0h, 6h, 12h, and 24h.

4 Discussion

The Earth's deformation results in mainly an oscillation of ocean water. The expelled water in travel, if constrained by the narrowness of strait, may form swift current, like that in the Cook Strait. For the various features of the tides in the Atlantic and in the North West Europe shelf seas, as the Earth is progressively stretched in a manner of from east to west, the Earth's rising part around West Africa firstly forces the water of East Atlantic to flow towards north, west, and south. With the passage of time, the Earth's extension moves to middle Atlantic and continues to force water to flow towards east, north, west, and south. Finally, the extension moves to West Atlantic and further forces water to flow towards north, east, and south. The westerly water may reach the eastern coastline of America nearly at the same time and leaves no difference of tidal phase. The tides from Florida to Nova Scotia are the case. The northerly water may form a progression of tidal phases in the North Atlantic. In particular, a large body of northeasterly water may enter the strait of Gibraltar and cross the Celtic Sea, from where it continues to run into the English Channel (until the southern North Sea) and into the Irish Sea and the Bristol Channel. A series of progressive tides along the shores of these regions are determined. On the other hand, the southerly water may be depressed by the import of the water from the southern ocean and becomes less observable. This is because the water of the southern ocean has a westerly movement since the extended Earth progressively rolls water to flow from east to west. This generates a generally westward propagation of the tides.

Galileo in his *Dialogue Concerning the Two Chief World Systems* described the tides in the Mediterranean (translated by Stillman Drake): “three varieties of these hourly changes are observed: in some places the waters rise a fall without making any forward motions; in others,

without rising or falling they move now toward the east and again run back toward the west; and in still others, the height and the course both vary. This occurs here in Venice, where the waters rise in entering and fall in departing., elsewhere the water runs to and fro in its central parts without changing height, as happens notably in the Straits of Messina between Scylla and Charybdis, where the currents are very swift because of the narrowness of the channel. But in the open Mediterranean and around its islands, such as the Balearics, Corsica, Sardinia, Elba, Sicily (on the African side), Malta, Crete, etc., the alterations of height are very small but the currents are quite noticeable, especially where the sea is restrained between islands, or between these and the continent.” We at first consider the water movement of an oscillating vessel. As shown in Figure 8, let the right side of water box rise, the water of the right side flows towards the left side. If line MN is a reference level, the water level of site M rises while the water level of site N falls. And then we restore the right side to its former level and let the left side rise, the water of the left side flows towards the right side, the water level of site M falls while the water level of site N rises. Repeat the rise and fall of these two ends continuously, the water level of sites M and N accordingly vary. Compared to sites M and N, another site S, which is in the middle of the vessel, holds the minimal variation of water level. Here we conclude that, although the oscillating ocean water can hardly exert influence to the Mediterranean since the latter connects to the Atlantic by means of a narrow Gibraltar Strait, the regularly Earth’s deformation still may give rise to an oscillation for the sea bed of the Mediterranean, which looks like a big vessel. As a result, the greatest alternation of water level is between the two ends, while the smallest is in the open area. The oscillating water, when being constrained by the straits, forms swift current, like that in the open Mediterranean and around its islands.

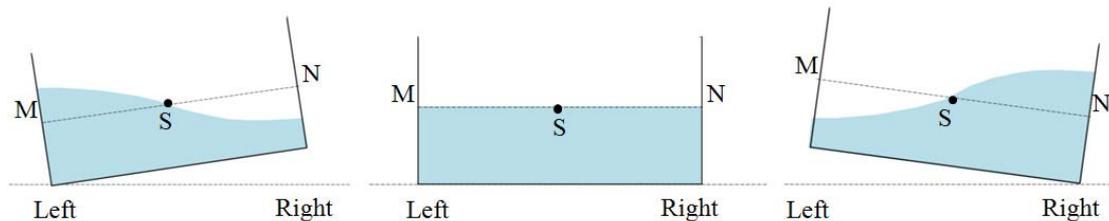


Figure 8: Modelling the water movement of an oscillating vessel. Line MN represents the reference level.

Most people must be confused because the attractive mechanism is thought to be competent for the tidal prediction. Refer to Pugh’s work (1987), one may see that the attractive mechanism is different from the tidal prediction. The former provides a reason why the Earth undergoes daily water movements of rise and fall, while the latter is based on a tidal analysis method that is fully experienced. The prevailing tidal analysis method is the harmonic method, considering tide as the sum of a finite number of harmonic constituents, $H_n \cos(\sigma_n t - g_n)$, a symmetrically cosine function. The attractive mechanism (the equilibrium mode, for instance), however, as we demonstrated in section 2, generates an asymmetric result that is against the observed tide. But by means of a trick (a series of mathematical transformations, the so-called expansion), this discrepancy is deeply hidden. The problem of the attractive mechanism lies at it develops a set of mathematics that are complicated enough to prevent the public making further investigation but don’t tell the truth that its expectation is inconsistent with the observed tide. One should note that, if we don’t examine the evolution of high and low water within a lunar month, it is difficult to find the problem of the attractive mechanism. Pugh (1987) clearly points out, “*The Equilibrium Tide bears no spatial resemblance to the real observed ocean tide*”. Only a few know this, but most of the people are likely to be unclear. This could be the reason why the attractive mechanism cannot be further questioned in the past hundreds of years. In appearance, tide looks like a movement of land and water. The proposed theory here provides a simple resolution: the Earth is deformed due to the centrifugal effect, together with the Earth’s daily rotation and the globally water covering, land regularly rises from and falls into water, this leads water to recede and advance, and also the fall and rise of water level.

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