What Causes Tides?

Yongfeng Yang
Bureau of Water Resources of Shandong Province
No. 127 Lishan Road, Jinan, Shandong Province, 250014, CHINA
e-mail: roufengyang@gmail.com

Abstract

It has been known for thousands of years that the waters of coastal seas ebb and flow on a daily basis. The established idea ascribes this phenomenon to the Moon's gravitational attraction. Here, we propose that the Earth's curved motions around the barycenter of the Earth-Moon system and around the Sun may create two centrifugal forces to stretch the Earth's body respectively in the line of the Earth-Moon system and in the line of the Earth and the Sun, the resulting deformation, together with the Earth's daily rotation, makes each part of solid Earth regularly move up and down per day. The rise and fall of coastal site accordingly produce the ebb and flow of water at local, and also the fall and rise of water level.

1 Introduction

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 theory 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 Cavalleri, 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 tides was increasingly strengthened and became the cornerstone of modern tidal theory. A fuller review of the tidal history may be found in the books (Pugh 1987; Cartwright 1999). From then on, it is extensively believed that the attractive theory is the most competent paradigm to account for tide. However, a strict investigation does not support this conclusion.

1) The attractive theory cannot account for the distribution difference of tidal range. Larger tidal ranges occur generally on the coastal seas, while in the open oceans there are smaller tidal ranges. The highest water level at the Bay of Fundy (Canada) and Yangon (at the north end of the Andaman Sea) respectively reaches 15.0 m and 5.6 m, the tidal range around most of Australia is generally from 1.8 to 10.0 m. At Vardo (Norway) it reaches 3.2 m, Reykjavik (Iceland) has a tidal range of up to 5.0 m. Contrary to this, Port Louis (Mauritius) has a tidal range of no more than 0.5 m. Tahiti has a tidal range of about 0.3 m, and at Hilo (Hawaii) it is about 0.6 m. This distribution difference of tidal range also occurs in the Mediterranean. Trieste and Alexandria have a tidal range of respectively 0.7 m and 0.4 m, but in the open Mediterranean and around its islands, the tidal ranges are often very small. Galileo in his *Dialogue Concerning the Two Chief World Systems* completely 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.*"

To account for this distribution difference of tidal range, as described in the Pugh's work (1987), the attractive theory treats tide as long wave that is closely related to the Earth's rotation, the Coriolis, the natural oscillation of ocean and shelf basins, and the elastics of solid Earth. For the tide in the ocean, it was thought to be generated directly by external gravitational force, for the tide in the coastal sea, it was thought to be generated mainly by the resonance with ocean tide. In detail, the resonance describes such a behavior: ocean tide (treated as one wave) travels to coastal sea to resonate with the natural oscillation (treated as another wave) of coastal sea. Indeed, waves have the properties of amplitude and frequency, and waves may be reflected by barrier, and even interfere mutually, in particular, two waves may resonate to amplify amplitude when their frequencies are close to. However, for the occurrence of any resonance there has a strictly physical constraint. At least, at a fixed point the arrivals of two waves should not lag each other too much, otherwise, the resulting amplitude would be depressed. This may be demonstrated with the composition of two sinusoidal waves $\sin(2\omega t)$ (the natural) and $\sin(2\omega t+k45)$ (the forced), which resemble semidiurnal tides, where ω is angular speed of unit degree per hour, and $\omega=15^o$, t is time of unit hour, $k45$ is phase lag, and k=0,1,2,3,4,5,6,7, and 8. As shown in Figure 1 it is unnecessary to form larger amplitude anywhere. The composed amplitude is greatly decreased when phase lag of the two is between 135 ^{o}~225^{o}, in particular, the composed amplitude reduces to zero when phase lag reaches 180^{o}. The amplitude is enhanced when phase lag is respectively between 0^{o}~135^{o} and between 225 ^{o}~360^{o}.

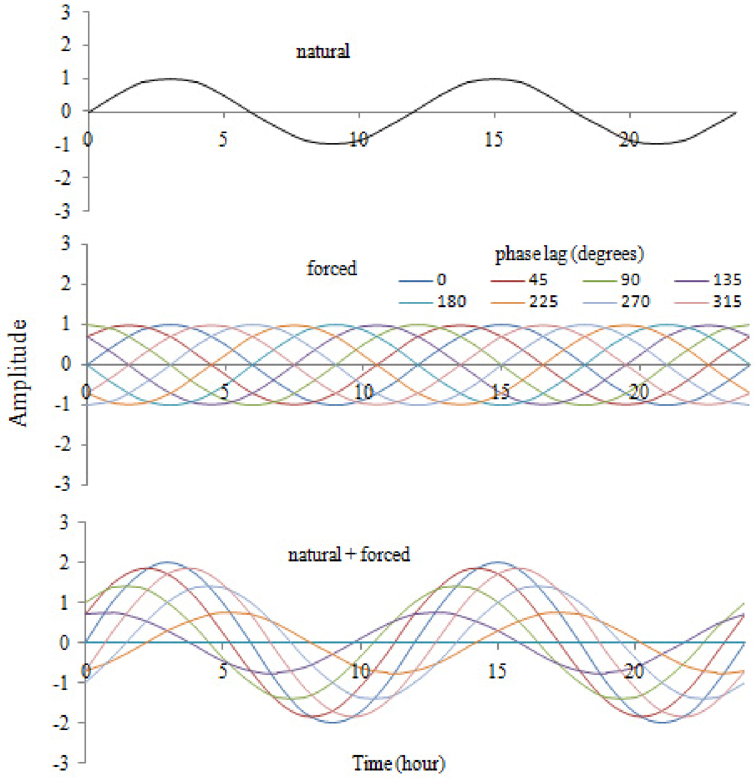

Figure 1: Modelling the resonance between natural and forced oscillation due to different phase lag.

One must be aware that, due to the Moon's advancement in the orbit of the Earth-Moon system, if the Moon's gravitational force were workable, the Moon's gravitational attraction on an Earthly site will have a time lag of about 52 minutes per day. As both the occurrence of ocean tide and the occurrence of coastal tide simultaneously hold time lag per day, to realize a resonance of coastal sea's natural oscillation with ocean tide (namely, a larger amplitude), the coastal sea's natural oscillation has to hold a time lag as ocean tide does, as required in Figure 1. A noticeable problem is thus left why the natural oscillation of coastal sea can lag day by day. One also must be aware that in everyday life we never see the natural (inherent) oscillation of a system can lag. In addition, the occurrences of resonance events (collapsing bridge, acoustic speaker, for instance) are extremely discrete, there has no eternal resonance for a special system. Attempting to link resonance to tide seems violate our intuition greatly. Furthermore, a coupling of coastal sea and ocean tide may lead to other problems. First of all, the waters in the oceans and the waters in the coastal seas are physically connected together, there is no a clear boundary between them, nobody can separate one from another, therefore, it is difficult to define a resonance between them. Secondly, resonance means the release of inherent energy of a system. The tides had existed since the oceans were created. Anyone that relates the tides to the natural oscillations of coastal seas needs to consider how the energy of maintaining these oscillations is formed and stored during a timescale of billions of years. Thirdly, as mentioned in the Pugh's work (1987), the process of transition of the oceanic tidal wave onto the coastal sea has not been observed, the resonance between ocean tide and coastal sea still is at a state of hypothesis.

2) The attractive theory cannot account for some tidal behaviors. Qiantang River tide is extremely noticeable. Before the advent of tide the water surface is quiet, but suddenly a tidal bore protrudes from water and quickly moves forwards. If the Moon's gravitational attraction were the cause of tide, the Moon's gravitational attraction will pull all waters of Qiantang River to be dragged to move, but observation does not support this expectation. As shown in Figure 2, there is a clear boundary between the occurring tide region and non-occurring tide region, the water surface of the non-occurring tide region always keeps calm, no evidence of being perturbed can be found. The tide in Qiantang River appears to be the movement of one water within another water.

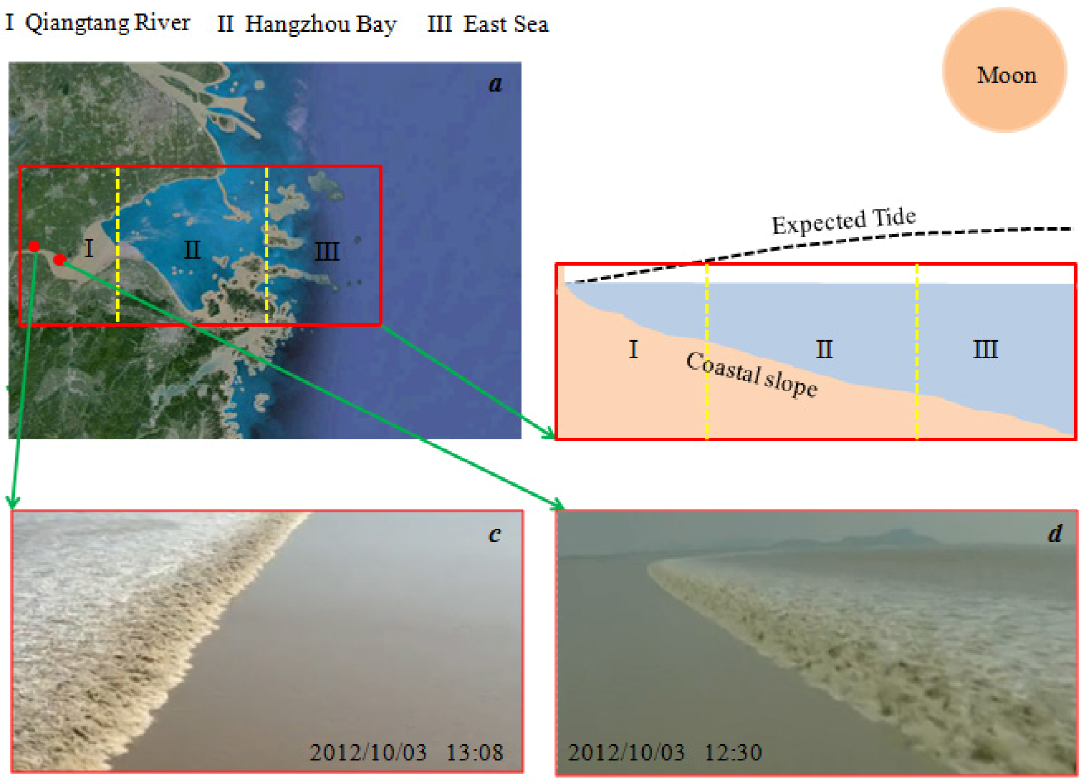

Figure 2: Comparison of observed and expected tides in Qiangtang River. *a*, the geographical location of Qiangtang River, Hangzhou Bay, and East China Sea from a clipping of Google Earth; *b*, the expected tide from the attractive theory; *c* and *d*, the observed tides respectively at Haining Yanguan site and at Haining Daquekou site.

2 Proposition

As demonstrated in the first section, the Moon (Sun)'s gravitational attraction cannot account for the distribution difference of tidal range and some tidal behaviors well, but observations really reveals there is a strong coupling between the variations of tidal ranges and the positions of the Moon, the Sun, and the Earth. Figure 3 shows larger tidal ranges always correspond to smaller lunar declination, while the Moon reaches the highest declination, tidal ranges become minimum. In most cases, when three of the Moon, the Sun, and the Earth keeps in one line (solar or lunar eclipse, for instance), tidal ranges usually reach maximum. So, what is the possible mechanism between them? It's already known that the Earth is not a standard sphere but an oblate spheroid (namely, its equatorial radius is slightly larger than its polar radius). It is widely accepted that the oblate is resulted from a centrifugal effect. In detail, the Earth's rotation around its axis creates a centrifugal force, by it the equator slowly bulges. And then, if this centrifugal force may deform the Earth's body, we have reason to infer, other centrifugal force may also deform the Earth's body.

The Earth and the Moon compose a two-body system, within it the Earth orbits around the barycenter of this system. This circular motion may create a centrifugal force to stretch the Earth's body in the line of the Earth-Moon system, a deformation is formed accordingly. The Earth consists of mainly solid Earth and liquid water. The density of solid is often larger than that of liquid, it may be treated that solid Earth is submerged in liquid water. The waters in the oceans and the waters in the coastal seas are physically connected and their water levels are globally constant. With the Earth's rotation on its axis, the deformation makes each part of solid Earth undergo two rises from and two falls into water per day. The rises and falls of each part accordingly create ebbs and flows of water at local, and further falls and rises of water level. These are the tides.

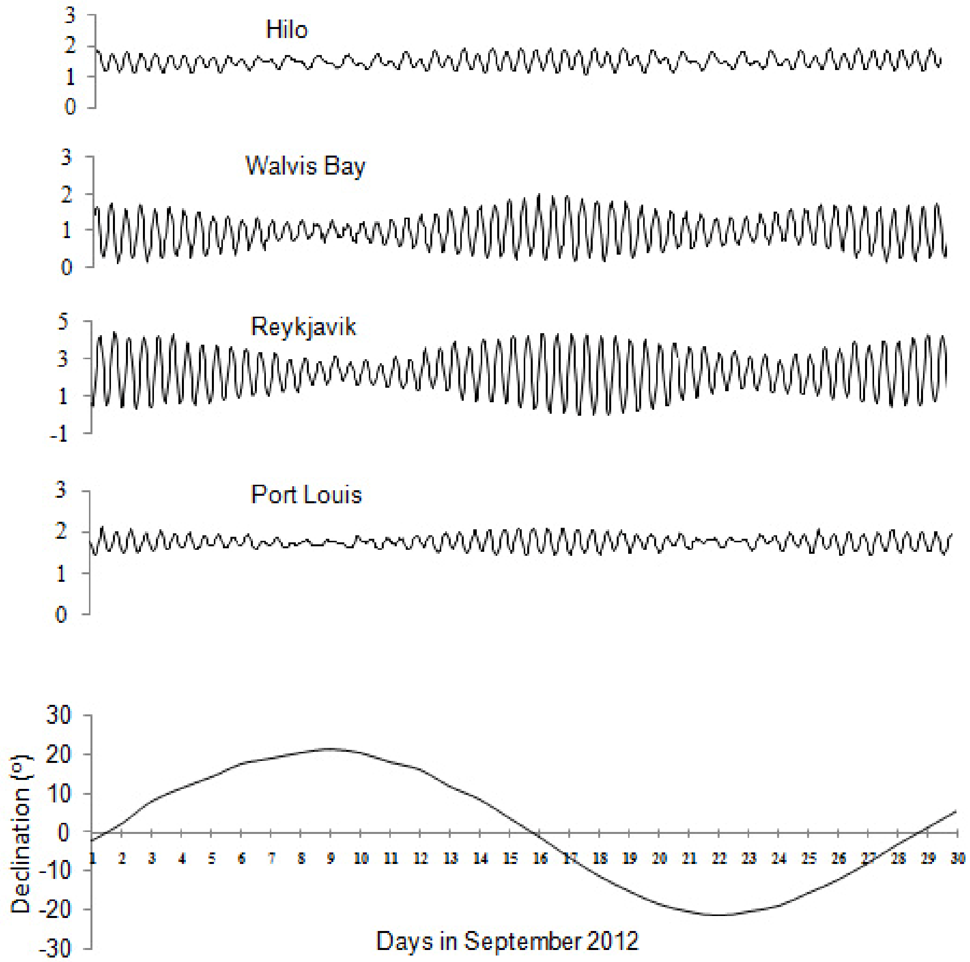

Figure 3: Tidal range variations in different regions. The vertical represents tidal range of order m and the horizontal does the time of order h during September 2012. The lunar declination performs a strong correlation with tidal patterns. The tidal data is from both GLOSS database - University of Hawaii Sea Level Center, and the lunar ephemeris is from JPL HORIZONS system.

At the same time, the Earth orbits around the Sun, this circular motion may create a force to stretch the Earth's body in the direction of the Sun and the Earth, a deformation is formed accordingly. In consideration of the Earth's rotation around its axis, the Earth's rotation around the barycenter of the Earth-Moon system, and the Earth's rotation around the Sun, and of the inclinations between these rotations, the combination of two deformations together makes the rise and fall of water level vary periodically.

3 An analytic treatment of the Earth's deformation and the resulting tide

As shown in Figure 4, within the Earth-Moon system the Earth orbits around the barycenter of the Earth-Moon system, this circular motion creates a centrifugal force $F=MV^2/r$, where M is the Earth's mass, V is the orbital speed, and r is the orbital radius. The net effect of the centrifugal force is to stretch the Earth's body in the line of the Earth-Moon system. This results in a prolate spheroid for solid Earth which is slightly elongated along the axis between the Earth and the Moon. Now we assume solid Earth to be fully covered with liquid water and treat Figure 4 as an equatorial section of the Earth, and taking into account the Earth's rotation on its axis (O_1), each point on the circumference (the surface of solid Earth) will experiencing two maximum and two minimum water levels for each daily rotation. This result in two tides a day, the semidiurnal tides. The inequality of semidiurnal tides is generated because the maxima and minima of the rise and fall of water level in each daily rotation are different in amplitude, except for a special case when the Moon lies in the equatorial plane.

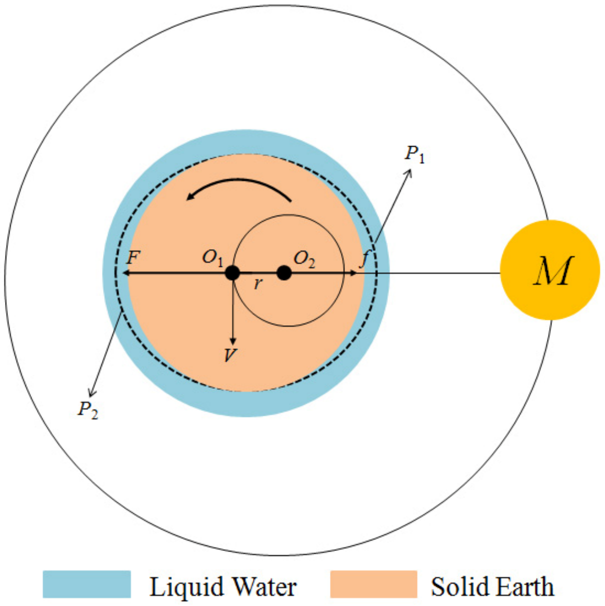

Figure 4: Dynamical frame for the Earth's deformation. *F* is the centrifugal force that the Earth undergoes due to its circular motion around the barycenter of the Earth-Moon system, which is balanced by the Moon's gravitational attraction *f* anytime. O_1, O_2, and *M* are the Earth's centre, the barycenter of the Earth-Moon system, and the Moon, respectively. Large circle and small circle are respectively the Earth's orbit and the Moon's orbit within the Earth-Moon system. Two bulges P_1 and P_2 (marked with dashed lines) represent the resulting deformations. Curved arrow represents the Earth's rotation around its axis. Note the bodies of the Earth and Moon are extremely exaggerated with respect to the distance between the two.

We relate a centrifugal force to a deformation, and further relate a deformation to an extension, namely, $F \sim K$, where *K* is the resulting extension due to centrifugal force *F*. We temporarily set aside the extension that is due to the Earth's rotation around the Sun, and consider the effect of the extension that is due to the Earth's rotation around the barycenter of the Earth-Moon system. Based on the geometry of a prolate spheroid, the rise and fall of water level of a site at the surface of solid Earth may be written as

$$H = a-(a^2\cos^2\varphi+b^2\sin^2\varphi)^{1/2}$$

Where

a is long axis of prolate spheroid, equal to $R+K$, and *R* is the Earth's radius, *K* is the extension that is due to the Earth's rotation around the barycenter of the Earth-Moon system;

b is short axis of prolate spheroid, equal to *R*;

φ is the angle between the site (*N*) and the Moon relative to the Earth's centre;

O_1, O_2, and *M* are the Earth's centre, the barycenter of the Earth-Moon system, and the

Moon, respectively.

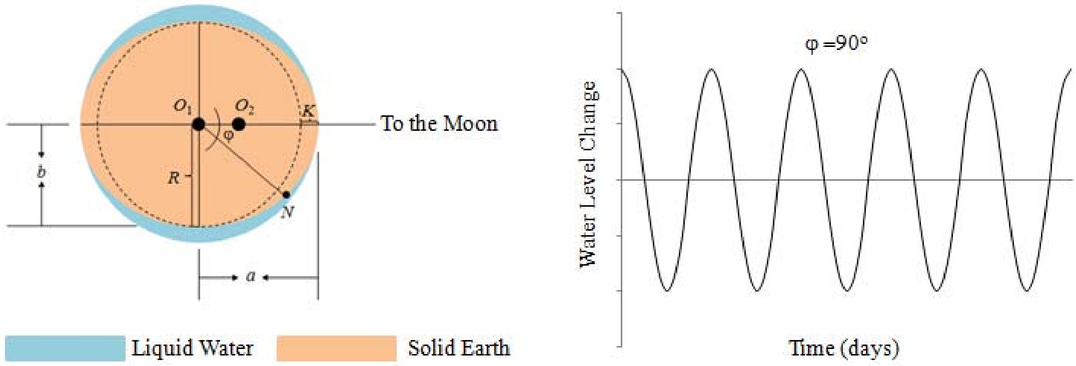

Figure 5: Simulating the rise and fall of a site (left) and its resulting water level change (right). Dashed circle reflects an unperturbed solid Earth.

It may be seen from Figure 5, the site experiences two rises and two falls (response to two falls and two rises of water level) for each Earth's rotation on its axis. Because of the Earth's rotation around its axis and the Earth's rotation around the barycenter of the Earth-Moon system, and also because of the inclination between these two rotations, the daily rise and fall of water level hold a monthly oscillation. Now we add the extension that is due to the Earth's rotation around the Sun. As shown in Figure 6, the so-called Earth's rotation around the Sun is actually the Earth-Moon system's rotation around the Sun. This circular motion of the Earth-Moon system about the Sun creates a centrifugal force F_2 for the Earth. Similarly, a centrifugal force relates to a deformation, and a deformation further relates to an extension, therefore, $F_2 \sim K_2$, compared to $F_1 \sim K_1$, where F_1 and F_2 are the centrifugal forces that the Earth undergoes at the same time, K_1 and K_2 are the resulting extensions. In consideration of the unusual position of O_2 (which is the barycenter of the Earth-Moon system), it is difficult to determine which deformation is the dominant. This is because, although the centrifugal force F_2 is practically larger than the centrifugal force F_1 (F_2/F_1 is about 780 based on established parameters), the working point of F_2 is not at the Earth's centre, compared to the working point of F_1 which is at the Earth's centre. Let us consider a special case, if O_2 were beyond the Earth's body, the centrifugal force F_2, no matter how strong it is, cannot stretch the Earth to deform. Regardless of the position of the working point of F_2, the deformation due to F_2 is assumed to be equal to a net effect that F_2 is working on O_1 (the Earth's centre) to stretch the Earth's body. Nevertheless, the close response of tidal time to the Moon at various site appear to confirm that K_1 is the dominant. From Boston (West Atlantic), Kiribati (Middle Pacific Ocean), Brisbane (South Pacific Ocean), to Venice (Mediterranean Sea), the occurrence of high tide (or low tide) generally holds a time lag of 60 minutes more or less per day. The Moon in its orbit advances 13.18^{o} per day, for an earthly site, in order to catch up with the position (longitudinally relative to the Moon) in the previous day it takes about 24 hours plus 53 minutes. If K_1 is treated as the dominant, and then, in the line of the Earth-Moon system the extension may be expressed as $K_1+K_2|\cos\alpha|$, while in the direction that is perpendicular to the line of the Earth-Moon system the extension may be expressed as $K_2|\sin\alpha|$, where α is the angle between the Moon and the Sun relative to the barycenter of the Earth-Moon system. Combined with Figure 6, *a* (long axis of prolate spheroid) should be equal to R+K_1+K_2 ∣ cosα ∣ , b (short axis of prolate spheroid) should be R+K_2 ∣ sinα ∣ . Taking into account the inclination between the Earth's rotation around the barycenter of the Earth-Moon system and the Earth-Moon system's rotation around the Sun, we conclude, the daily rise and fall of water level of a site hold an annually oscillation. In particular, when $\alpha = 0^{o}$ (namely, three of the Earth, the Moon, and the Sun is in one line), the daily rise and fall of water level reach maximum, while $\alpha = 90^{o}$ (namely, the Moon is at the first or last quarter relative to the Sun), the daily rise and fall of water level reaches minimum.

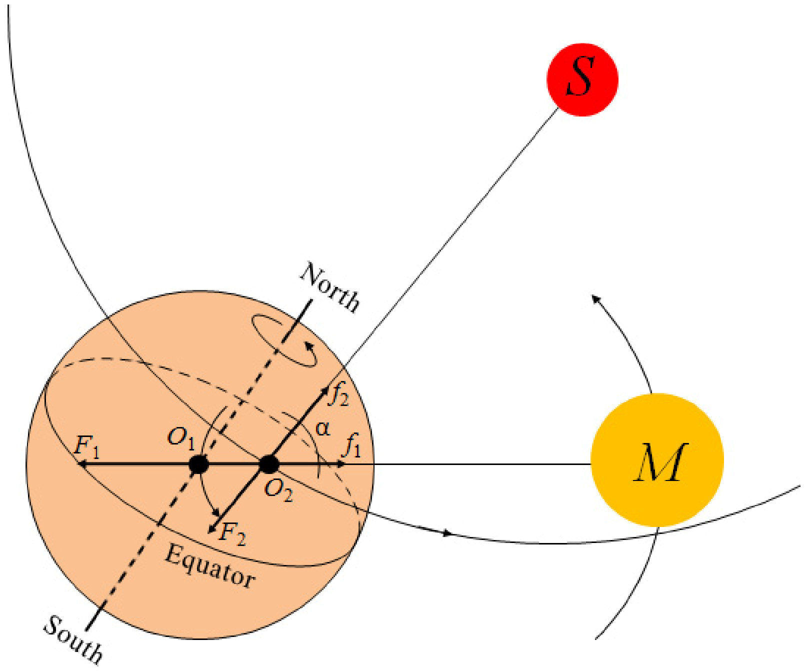

Figure 6: Combined forces for solid Earth. F_1 and F_2 are the centrifugal forces that solid Earth undergoes because of circular motions, which are balanced by the attraction f_1 from the Moon and f_2 from the direction of the Sun. O_1, O_2, M, and S are the Earth's centre, the barycenter of the Earth-Moon system, the Moon, and the Sun, respectively. Curved arrows represent the Earth's rotation around its axis, the Earth's rotation around the barycenter of the Earth-Moon system, the Moon's rotation around the barycenter of the Earth-Moon system, and the Earth-Moon system's rotation around the Sun. α is the angle between the Moon and the Sun relative to the barycenter of the Earth-Moon system.

The rise and fall of each part of solid Earth result in the fall and rise of water level at local, but their response to the Moon's position is not fully consistent. This is because, for the continental shores, on the one hand, the falling of themselves will lead to an inflow of ocean water since global sea level is constant. After these shores reach the lowest they begin to rise up, the coming water due to inertia will continue to enter. On the other hand, the rising of their adjacent regions (those are under the oceans) also will press some water to flow towards these shores. The combination of the two coming waters together determines the variation of water level at these shores. We assumed that lunar phase (first or last quarter) timely corresponds to the fall of a shore (as a part of solid Earth), but anyway, the two coming waters are unlikely to reach these shores at the same time. In addition to these, various factors such as coastline orientation, Coriolis effect, ocean bed's friction also may greatly disturb the response.

Several features of the observed tides may be explained further. Comparing the tidal changes plotted in Figure 3 with the lunar declination changes, we see that the maximum diurnal tidal ranges occur when the lunar declination is greatest, and that the ranges reach smallest when the declination is zero. This is because the effect of 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 tidal bulges. As shown in Figure 7, a site at *N* is experiencing a much higher water level than it will experience about 12 hours later when the Earth's rotation brought it to N'. The two high water levels would be equal if *N* lies on the equator. The fortnightly modulation of water levels is due to the combination of two deformations of solid Earth. The maximum ranges of water levels occur usually around the times of new Moon and of full Moon, while the minimum occur at first quarter and last quarter. The reason is at times of spring tides in the line of the Earth-Moon system the final deformation of solid Earth is a plus of two deformations (that is due to the Earth's rotation about the barycenter of the Earth-Moon system and that is due to the Earth-Moon system's rotation about the Sun), the resulting water level changes are the maximal, but at times of neap tides in the line of the Earth-Moon system the final deformation is a deformation (that is due to the Earth's rotation about the barycenter of the Earth-Moon system) only, the resulting water level changes are the minimal. Figure 8 outlines the mechanism of spring-neap tide.

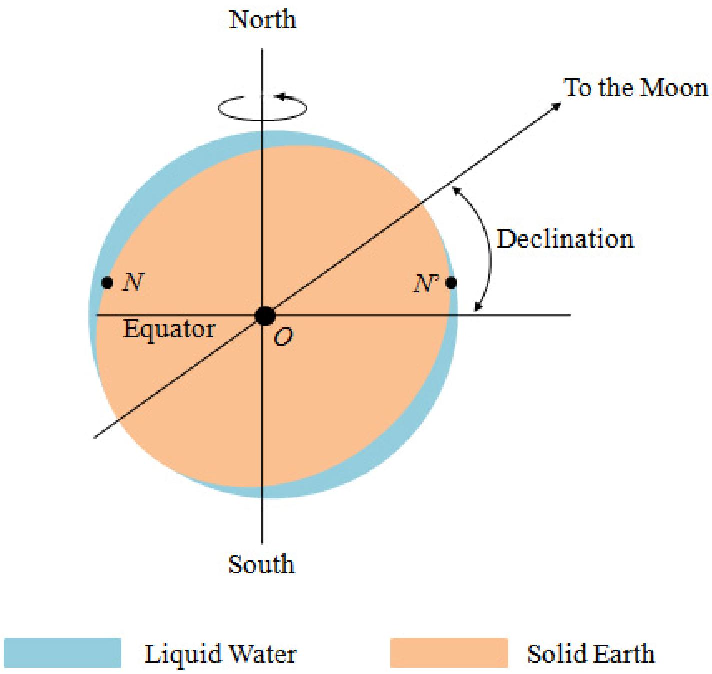

Figure 7: Showing how the unequal semidiurnal tides are determined as the Moon is at the north of the equator. *O* is the Earth's centre. Note the Earth's deformation is exaggerated

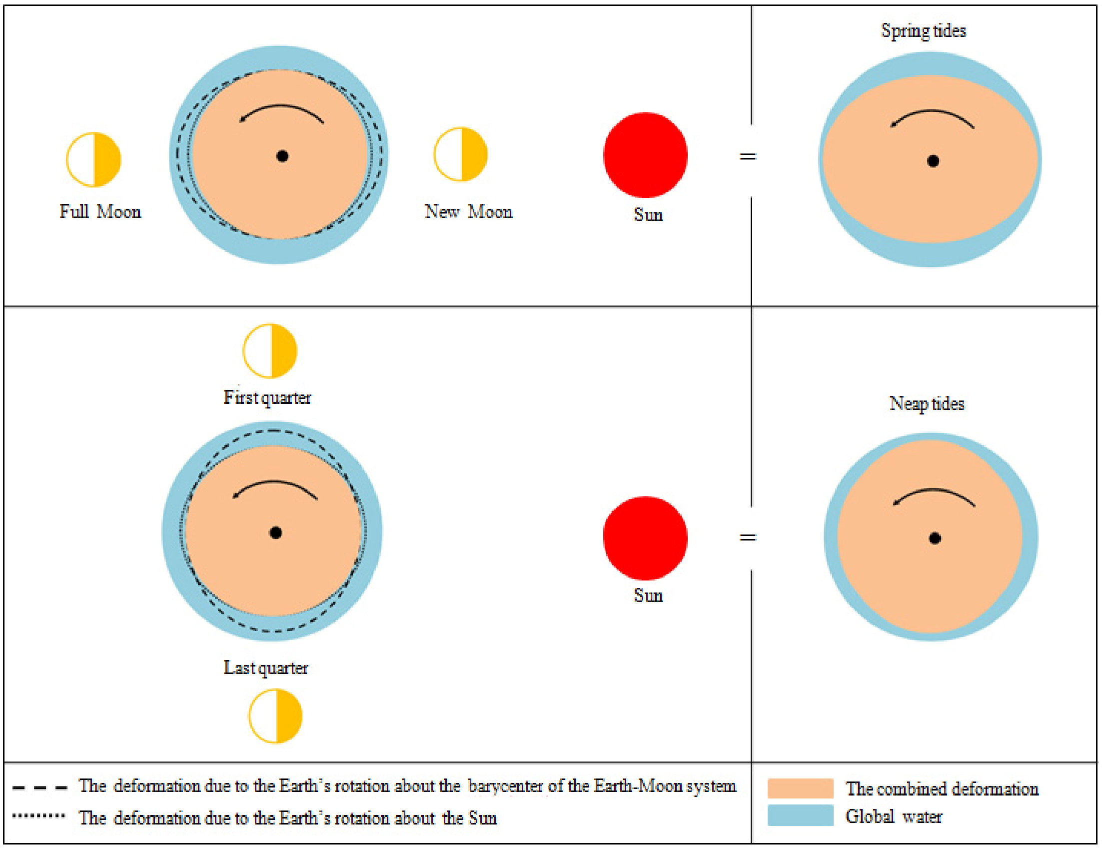

Figure 8: Spring-neap tidal cycles are produced by the motions of the Earth about the barycenter of the Earth-Moon system and about the Sun. The resulting deformation produce spring tides at new and full Moon and neap tides at the Moon's first and last quarter.

4 Physical ideas for the tides in the oceans and in the coastal seas

The regular deformation of solid Earth results in mainly an oscillation of ocean water. For the shores of coastal seas, their long coastlines can effectively block the coming water to form large accumulation as the direction of coast is perpendicular to the direction of the coming water. For the shores of those islands that are fully isolated in the deep oceans, the coming water cannot be effectively blocked by their short coastlines and may bypass. The large water accumulation forms large tides on the shores of coastal seas, compared to the small tides on the shores of isolated islands that are mainly resulted from the rise and fall of the islands themselves. The coming water in travel, if constrained by the narrowness of strait, may form swift current, like that in the Cook Strait. Geographically, New Zealand is more latitudinal than longitudinal. As the deformation of solid Earth is in a manner of from east to west, this leads to that East New Zealand rise up or fall into water earlier than West New Zealand. In other words, during the deformation of solid Earth the whole New Zealand is tilt in the water. The greatest alternation of water level thus occurs at the two sides of New Zealand, the smallest alternation occurs in the middle. As a result, when the Pacific Ocean side is at high (low) tide, the Tasman Sea side must be at low (high) tide, the middle (the center of Cook Strait) is nearly without tide. The swift current in the Cook Strait represents an exchange of water between the Tasman Sea and the Pacific Ocean as the bottom of the Pacific Ocean (the

Tasman Sea) rise or fall because of the deformation of solid Earth.

For the regions that exhibit diurnal tides, their peculiar inlets as shown in Figure 9 would be inundated when their related parts of solid Earth fall into water, but with the Earth's daily rotation the rising related parts gradually close these inlets, so that the captured water cannot be expelled in a timely manner. This causes only an ebb and flow of water for the regions such as Gulf of Mexico, the Persian Gulf, Bering Sea, Karumba, and so on. This unusual geographic constraint also may account for the various tidal patterns (mixing tides, for instance) in other regions.

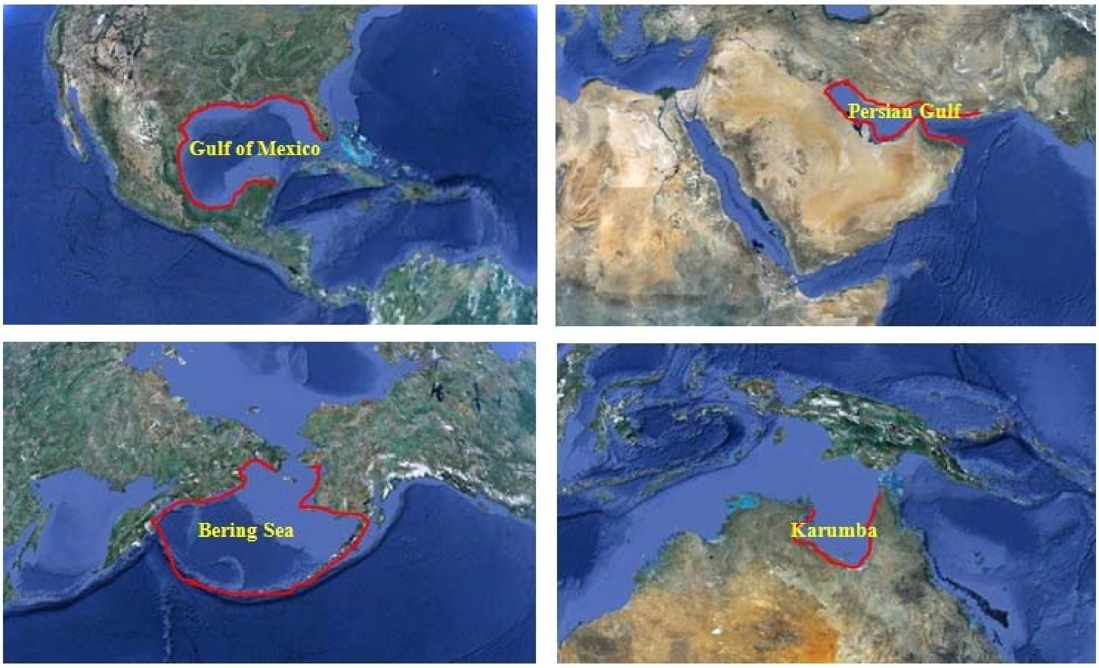

Figure 9: Shape of the regions that yield diurnal tides. The background is produced from Google Earth. Clearly, a curved obstacle between the Bering Sea and North Pacific Ocean favors a bay-shaped feature for the water area.

For the various features of the tides in the Atlantic and in the North West Europe shelf seas, they may be illustrated with Figure 10. One should be aware that, according to Figure 4, the deformation makes each part of solid Earth progressively rise up in a manner of from east to west. The rising part around West Africa firstly presses the water of East Atlantic to flow towards north, west, and south. With the passage of time, the elevation moves to middle Atlantic and continues to press water to flow towards east, north, west, and south. Finally, the elevation moves to West Atlantic and further presses water to flow towards north, east, and south. It can be seen that in this following process a large body of water is pressed to flow respectively towards north, east, south, and west. 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 is formed and may further 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 thus formed. On the other hand, the southerly water may be depressed by the import of the water from the southern ocean and becomes less observable. The water of the southern ocean has a westerly movement since the rising part of solid Earth progressively presses water to flow from east to west. This thus yields a general westward propagation of the tides. In the southern hemisphere the longer South America (55° S) and the shorter South Africa (35° S) together create an opening to trap the westerly water of the southern ocean to enter the Atlantic.

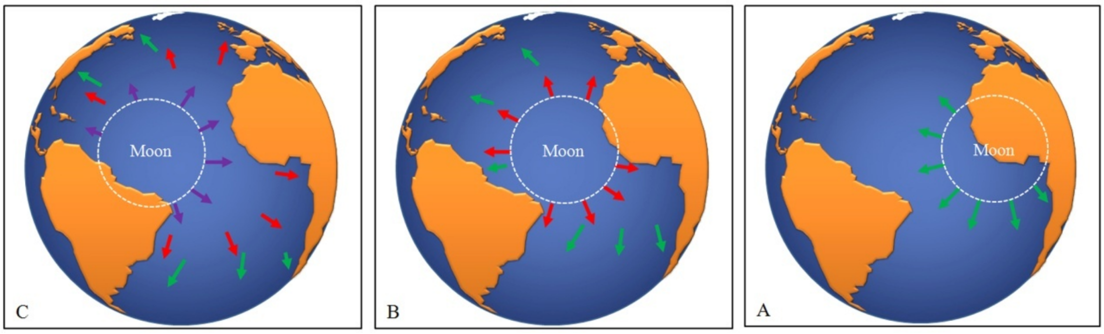

Figure 10: Modelling the currents due to the interaction of solid Earth and liquid water. From A to B to C, with the Earth's daily rotation, each part of solid Earth progressively raises up from liquid water in a manner of from east to west. A large body of water in the Atlantic is pressed to flow out (marked with green, red, and brown arrows). Dashed circle indicates the Moon's position (or its opposite) on the Earth.

If one end of a vessel filled with water is slightly raised because of some kind of reason, part of the water will be expelled from the rising end. The following experiment exhibits a real motion of the water in an oscillating vessel. As shown in Figure 11, we make the left side of the vessel rise slowly, buoy ③ and ② take a significant shift towards the right (buoy ③ is the most), while buoy ① and ④ take a slight motion towards the right. The buoy's motion basically reflects the motion of the water around it. That's to say, the deep water moves quicker than the shallow water does. On the whole, the greatest alternation of water level occurs at the two ends of this vessel, the smallest alternation occurs in the middle. We further consider, several islands are put in the middle of this vessel and stretch out to form straits at where buoy ④ lies in. Because of the narrowness of these straits, the moving water in travel will be constrained to form swift current, while the regions around these straits still keep tranquil. The mechanism of this oscillating vessel is suitable for explaining the matter in the Mediterranean. Although the interaction between the deformation of solid Earth and ocean water can hardly exert influence to the Mediterranean since the latter connects to the Atlantic by means of a narrow Gibraltar Strait, the deformation of solid Earth still will give rise to an oscillation for the Mediterranean since the deformation of solid Earth is in a manner of from east to west. The rising of the eastern end of the Mediterranean leads to the fall of water level at local, at the same time the rising of the eastern end presses water to flow towards the western end since the eastern end is elevated earlier than the western end. The greatest alternation of water level is between the two ends of the Mediterranean, while the smallest is in the open Mediterranean. The moving water, when being constrained by the straits between islands or islands and continent, forms swift current.

With reference to Figure 11, due to the regular deformation of solid Earth, the rising part of ocean bed will press the water around it to flow out, the expelled water moves mainly along ocean bottom. In travel, if the water meets with a steep topography such as midocean or submarine ridge, or continental slope, the interaction between them will make the water become spectacular, easily to be found. These are the “internal tides” cases around the ridges of Hawaii, Tahiti, and Luzon Strait, and around the Australian north west shelf (Munk, Snodgrass, Wimbush 1970; Gould and Mckee 1973(a); Magaard and Mckee 1973(b); Hendry 1977).

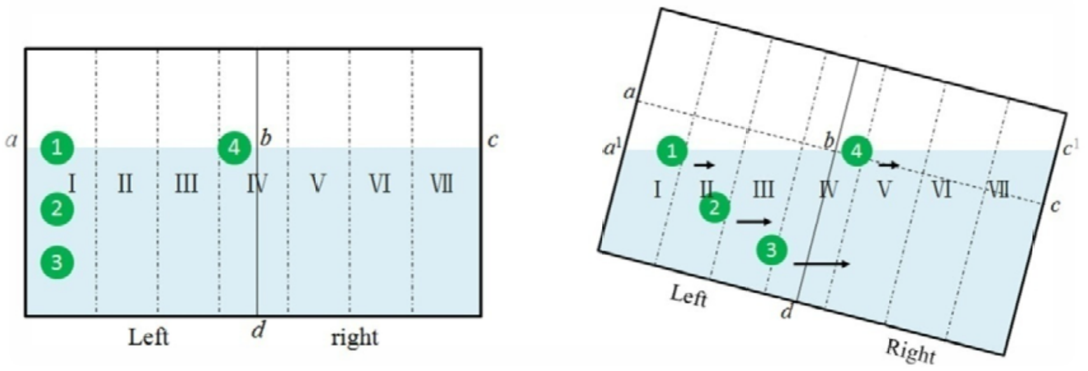

Figure 11: Modelling the motion of water in an oscillating vessel. Green circles with numbers represent buoys. Black arrows represent the motion of currents, and their lengths indicate the speeds of the current. Points *a*, *b*, and *c* represent the original water level position, while points a^1, *b*, and c^1 show the final water level position when the vessel is tipped. Line *bd* lies in the middle of the vessel. Please pay attention to one point, when the left side is raised, the water within Ⅰ area is firstly pressed by the rising side to flow towards Ⅱ area, subsequently, the water within Ⅱ area is pressed by the coming water to flow towards Ⅲ area, by order, the water within Ⅵ area is pressed by the coming water to flow towards Ⅶ area.

5 Discussion

The deformation of solid Earth is mainly related with a physically connected water of the oceans and coastal seas, these water bodies such as inland sea, lake, lagoon, reservoir, pond, river, bowl, cask, cup, and so on that are full isolated in the land would accompany related part of solid Earth moving up and down together. Nevertheless, as the deformation of solid Earth is in a manner of from east to west, this inevitably gives rise to oscillations for these water bodies. Compared to the Mediterranean, the longitudinally length of these bodies is too short, the two ends of each body fall or rise nearly at the same time, this yields a slight water alternation between the two ends, as a result, the change of water level is less noticeable.

For the tide in Qiantang River, the falling of the eastern coastline of continent leads to an inflow of ocean water. The coming water firstly enters East China Sea and further enters Hangzhou Bay, at where the coming water is constrained by a trumpet-shaped topography and becomes swift. The interaction between the coming swift current and local water in Qiantang River gives birth to a prominent boundary.

Any theory of tide needs to explain not only the cause of the pattern (diurnal, semi-diurnal, and mixed, for instance) and regular alternation, but also the cause of the distribution difference of tidal range and the cause of special tidal behaviors around the globe. The attractive theory evidently fails to reach many of these points. In appearance, the attractive theory gives a plausible explanation for the tide, but leaves much suspicion to the public. If the Moon’s gravitational force would pull water to move, according to Newton’s universal gravitation, it also would pull other things such as oil, salt, animal, bird, car, and so on to move in a manner of tide. Life experience tells us these actions do not happen.

The proposition presented here provides a general understanding of the Earth’s deformation and its resulting tide, a rigorous development is still needed. Undoubtedly, when a full process for tide is treated, other factors such as topography of ocean and sea, inertia and viscosity of water, Coriolis force, bottom friction, and so on must be included. Figure 11 offers some suggestions for tide. As the rising of each part of solid Earth is in a manner of from east to west, the continuously westerly rising of ocean bottom would press more water to flow towards west, north, and south than towards east. As a result, the tides around the western coastlines of continents could be generally smaller than that around the eastern, northern, and southern coastlines. The northerly and southerly water on the whole would cause a progression of tidal phases respectively in the northern hemisphere and in the southern hemisphere.

Four methods are provided to examine the proposed theory:

A) measure the alternation of water level at two ends of a tube that is half-filled water. Put two straight long tubes that are half-filed water horizontally on the Earth's surface, one keeps parallel to latitude and another keeps perpendicular to longitude. According to the proposed theory, the rise or fall of each part of solid Earth is in a manner of from east to west. This means, the rise or fall of the eastern end of the tube (parallel to latitude) is earlier than that of the western end as the rise or fall of the eastern land that supports the tube is earlier than that of the western land. As a result, the water at high end will gravitationally flow towards low end, the alternation of water level between the two ends should be in a manner of daily tide. Compared to this, the alternation of water level between the two ends of the tube (parallel to longitude) should be invisible as the whole tube rises or falls together with the land that supports it.

B) measure the oscillation of a weight. As shown in Figure 12, fix a weight on a long rope that is hanged at a pole. According to the proposed theory, the rise or fall of each part of solid Earth is in a manner of from east to west. This means, the uneven rising or falling of the land that supports the pole will give rise to a tilt for the pole. As a result, the weight will periodically oscillate in a manner of daily tide.

C) measure the deviation of a laser beam. As shown in Figure 13, put a laser emitter and a mirror respectively at two distant points of the Earth’s surface, and aim the laser emitter at the mirror. According to the proposed theory, the rise or fall of each part of solid Earth is in a manner of from east to west. This means, the rise or fall of the land that supports the laser emitter is earlier than that of the land that supports the mirror. As a result, the laser beam receipted in the mirror will periodically oscillate in a manner of daily tide.

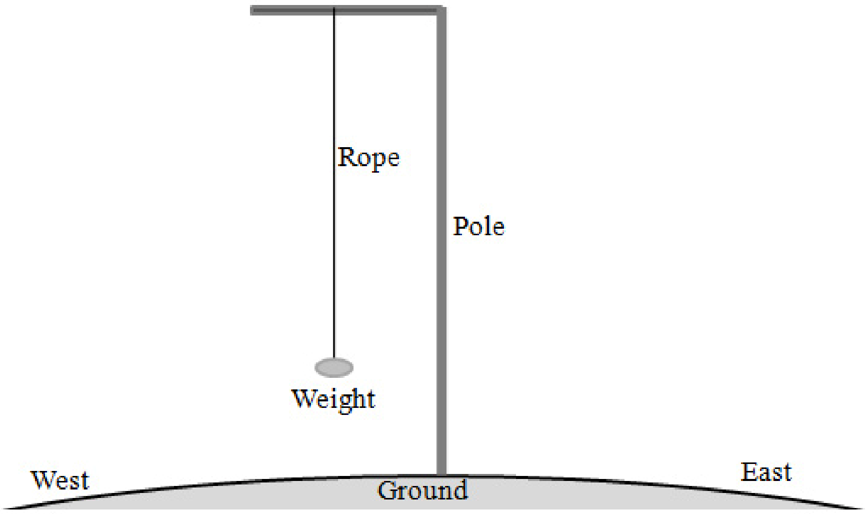

Figure 12: Experimental frame on measuring the oscillation of weight. The longer the rope, the more easily observable the oscillation of the weight.

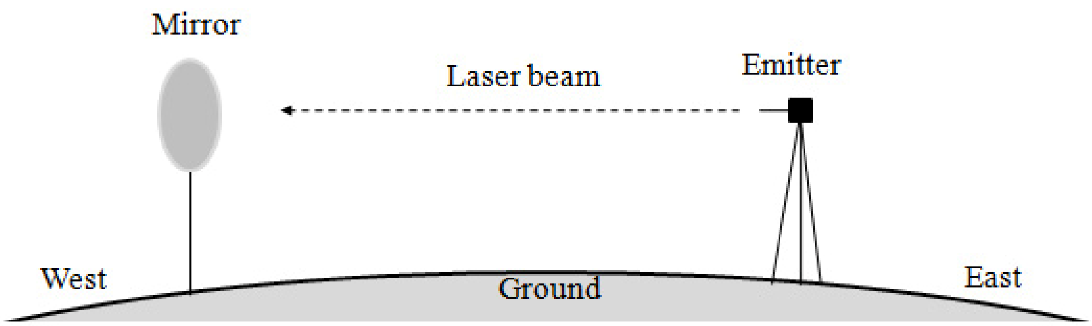

Figure 13: Experimental frame on measuring the oscillation of laser beam. The more distant between the two sites, the more easily observable the oscillation of the laser beam in the mirror.

4) Measure the acceleration of a freely falling object. As shown in Figure 14, the proposed theory requires solid Earth to deform, the deformation corresponds to the rise or fall of the Earth's surface relative to the Earth's centre, the acceleration of a freely falling object will accordingly change as the Earth's surface rises or falls, therefore, with the Earth's daily rotation the acceleration relation of a freely falling object between these four positions *a*, *b*, *c*, and *d* should be $g_a = g_c > g_b = g_d$ when the Earth's gravitational potential field is considered and the four positions and the Moon are given to be coplanar.

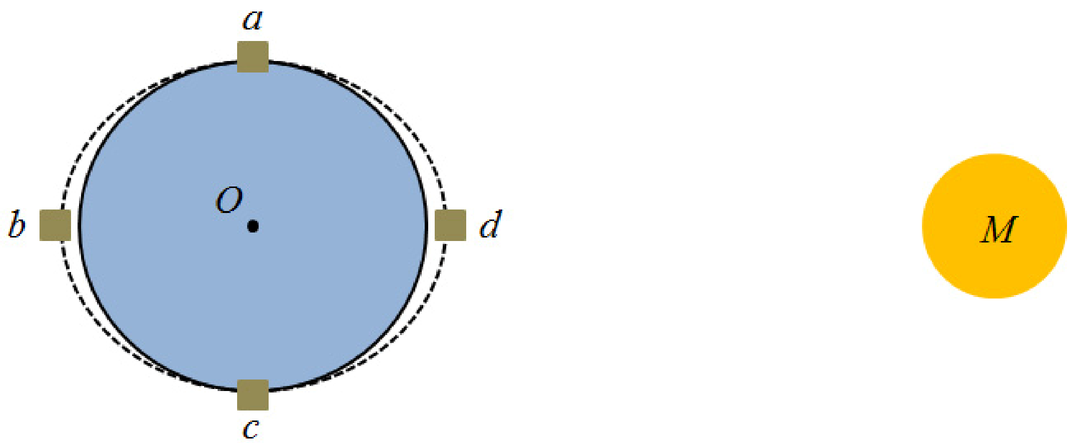

Figure 14: Modelling object's position at the deformed Earth. *O* and *M* represents the Earth's centre and the Moon, respectively. Dashed curved lines represent the resulting deformations. Given the object's positions and the Moon are co-planar.

Acknowledgement I am honestly pleased to thank University of Hawaii Sea Level Center and NASA's JPL, and express great thank to Mr. Walter Babin and Mr. Thierry De Mees for suggestive discussion.

Reference:

Pugh, D. T., Tides, Surges and Mean Sea-Level; a handbook for engineers and scientists, John Wiley, Chichester (UK), 1987.

Cartwright, D. E., Tides: A Scientific History, Cambridge University Press, 1999.

Robert, H. S., Introduction To Physical Oceanography, Texas A& M University, 2008.

Munk, W., Snodgrass, F., and Wimbush, M., Tides offshore: transition from Californian coastal to deep-sea waters, Geophys. Fl. Dyn., 1, 161-235, 1970.

Gould, W. J., Mckee,W. D., Vertical structure of semidiurnal tidal currents in the Bay of Biscay, Nature, 244, 88-91,1973.

Magaard, L and Mckee, W. D., Semidiurnal currents at Site D, Deep-Sea Res., 20, 977-1009, 1973.

Hendry, R., Observations of the semidiurnal internal tides in the western North Atlantic Ocean, Phil. Trans. R. Soc. London, A, 286, 1-24, 1977.