The tidal-force theory of the Indian summer monsoon

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Abstract.

This article elaborates on the theory that both lunar and solar tractive tidal forces generate the wind flows responsible for the ISMR. Monsoon variability shows that the monsoon (ISMR) is not periodic simply on the tropical year or the Gregorian calendar. However, it was observed that the seemingly delayed monsoons of 2004 and 2026 came right on time for the rainy season on the traditional Indian calendar, and this article provides a physical and causal basis for that observation. Tidal forces act simultaneously at anti-podal points, so this may also lead to a better causal explanation for the ENSO-ISMR negative correlation between anti-podal phenomenon, better than the Walker circulation which is speculative and tenuous, as proved by debates over the last century. Version 2 of the article adds an appendix giving detailed calculations of the tidal forces. Unlike diurnal oceanic tides, the ISMR, or south-west monsoon, is due to long-acting north-directed tidal accelerations resulting in a slow northward drift from the equator, while the related Coriolis force generates the accompanying large eastern wind velocities.

Keywords: Monsoon variability, luni-solar tidal forces in atmosphere, tidal wind flows and ISMR, ENSO-ISMR correlation, Monsoon on traditional Indian calendar.

Contents

1. Introduction: the “delayed monsoon”

Monsoon variability results in the phenomenon of a “delayed monsoon”, as happened this year (2026). Because the Indian economy was and still is dependent on monsoon-driven agriculture, as are the lives and livelihoods of a large number of people, this supposed delay sparks widespread panic from fears of the failure of the monsoon, resulting in drought and crop failure. This has happened earlier, as in the “delayed monsoon” of 2004, fears of which were also similarly and widely articulated then in newspapers.[1]


HE TIMES OF INDIA

International
All set to break into movies, Naomi is

India
Court order on Bhandarkar's

Sport
Harbhajan plots

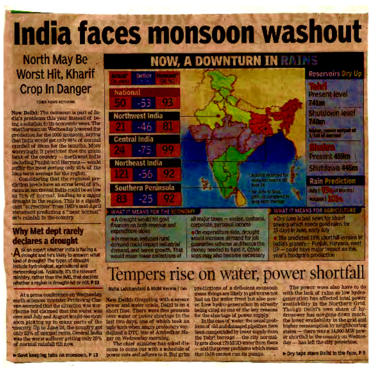

HE TIMES OF

M F HUSAIN GETS NOSTALGIC ABOUT AUG 15, 1947; RULES OUT RETURN TO INDIA 13

Govt scrambles to save kharif, prays for rabi

Deficient Rain In 31 Out Of 36 Met

Wages of DROUGHT


India faces monsoon washout

North May Be Worst Hit, Kharif Crop In Danger

NOW, A DOWNTURN IN RAINS

Why Met dept rarely declares a drought

Tempers rise on water, power shortfall


Drought almost certain now, admits IMD

GoM To Ready Contingency Plan

‘N India’s groundwater vanishing’

The fact is that this season of fears, in 2004 as in 2026, was followed by torrential rains. The 2004 monsoon resulted in massive flooding which drowned thousands of cars in Mumbai. In retrospect. India should have been preparing for flood relief rather than drought relief. 😊

The even more curious fact, first pointed out by this author in 2004, is that the rains came right on time on the rainy season on the traditional Indian calendar, in which the supposed delay was accounted for by an intercalary month (adhik Sawan in 2004 and an adhik Jyeshta in 2026). Therefore, since 2004, I have written and spoken[2] on the phenomenon of the “delayed monsoon”, specifically raising the question: *was the monsoon delayed or is the [Gregorian] calendar wrong?*

The Gregorian calendar uses the tropical year or the duration between one solstice and another of the same type (e. g., from one summer solstice to another). Talk of “delayed monsoon” involves the **assumption** that a statistical average start-date (1 June) fixed on the Gregorian calendar corresponds to the “true” date of onset of the monsoon. In other words, **the (wrong) assumption is that the tropical year decides the periodicity of the monsoon**. However, I know of no study which established such a periodicity. To the contrary, the very active subject of monsoon variability exists just because the monsoon does not have the simplistic periodicity of the tropical year. Indeed, the pre Gregorian Christian calendar had the very duration of the tropical year (or date of equinox) wrong for over a thousand years until the Gregorian reform corrected it in 1582, with inputs brought by secretive Jesuits from India[3] to help solve the European navigation problem. (Fixing latitude in daytime needs knowledge of the solar declination, which cannot be measured at sea but can be estimated by a correct calendar which gets the date of the equinox or solstice right.)

From the viewpoint of physics rather than sentiment, for or against, the key difference between the Gregorian calendar and the Indian calendar is this. The Gregorian calendar is purely a solar calendar, whereas the traditional Indian calendar is a more sophisticated lunisolar calendar. This is instantly clear from the haphazard duration of the months on the Gregorian calendar which are of 28, 29, 30, and 31 civil days none of which has a clear connection to any cycle of the moon, though the very word month derives from the moon In contrast, on the Indian calendar,[4] the cycle of the moon’s phases from one full moon to another say, is always a duration of exactly 30 tithis, where a tithi is defined in a luni-solar way as the time in which the celestial longitude of the moon increases by 12° over that of the sun. The traditional European calendar had no way to calculate the duration of the month of phases of the moon, which is hence called the synodic month, because it was determined by the authority of a synod or a religious gathering (as the date of Eid, the counterpart of Pascha, and Easter among Muslims, is still determined).

Anyway, in terms of physics, the issue of the “delayed monsoon” coming out right on the Indian calendar really amounts to this. Is there any way in which the moon (and its phases) can physically affect the timing of the monsoon in India?

The answer is yes, though from the perspective of Western-controlled academic knowledge, the idea that the moon affects the seasons is a radical new idea which has never been articulated earlier by anyone else.

Earlier, I critiqued Meghnad Saha, the chair of the post-independence Indian Calendar Reform Committee,[5] who asserted the validity of the European belief that the periodicity of the seasons was “obviously” decided by the tropical year. **Solar motion does decide the heat balance**, hence summer and winter seasons, and also the intermediate seasons of autumn and spring, the only seasons known to Europe. But Europe has no rainy season like the Indian summer monsoon. Therefore, Western and colonial biases in the matter, based on European experiences, cannot be trusted.

It is far from obvious that solar motion alone, or the tropical year, decides the rainy season or its periodicity in India. Thus, the rainy season depends on the **moisture balance** and related wind flows. It does not depend purely on the heat balance as Saha (famous for his text on heat and thermodynamics) wrongly thought. The wind flows related to the monsoon are obviously not mere convection currents as was once thought.

This article explains how the moon and its phases (used in the Indian calendar) **physically** affect the rainy season in India, through tidal forces, so that a luni-solar calendar can better explain the periodicity of the monsoon, which is variable on the tropical year. This explanation through tidal forces is a very simple explanation and therefore even just on grounds of simplicity, or Ockham's razor, it should be accepted over earlier explanations.

2. The ENSO-ISMR correlation: its causal basis

Among the more interesting points about the "delayed monsoon" of 2026 was the journalistic talk of El Niño or ENSO (El Niño-Southern Oscillation), suggesting that the monsoon or ISMR (Indian summer monsoon rainfall) may fail due to it.

Doubtless a negative correlation coefficient was found between the two (ENSO and ISMR). But the question here is of **a causal relation**, not **a mere correlation**. What is the causal way to understand how El Niño, a phenomenon in the Pacific Ocean in the antipodal region to the Indian subcontinent, can be causally related to the rains in India?

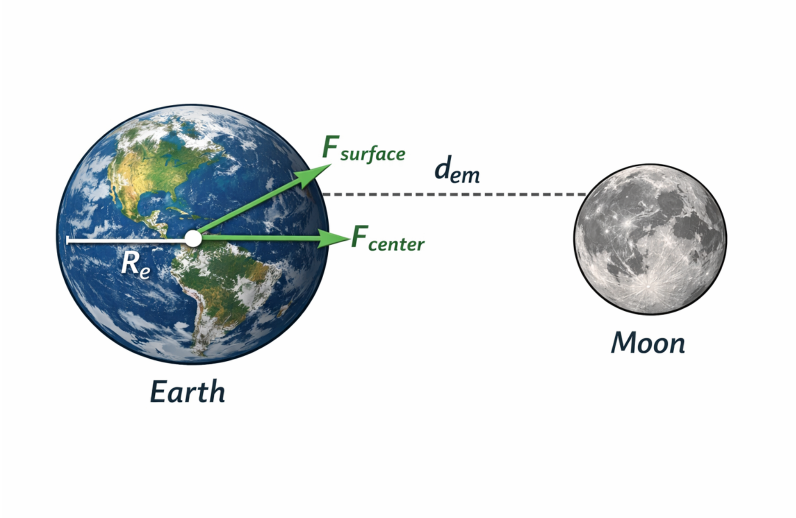
Long ago, the Walker circulation,[6] a convective cycle, in the Pacific Ocean was suggested as the causal basis of the ENSO-ISMR connection. But the huge debate over it across the last century[7,8] shows that this suggested causal basis is complex, speculative and uncertain.

A simple theory which easily explains this causal relation between anti-podal points is my tidal theory of the monsoon: tidal forces always act simultaneously at anti-podal points. There is no speculative element in this theory which cannot be so easily contested, since the only thing it involves is elementary Newtonian gravitation. Moreover, it brings in, in an essential way, lunar motion and the phases of the moon both of which are well-known to affect tidal forces (hence tides in the sea). Since both sea water and air are fluids which move according to the same equations of fluid dynamics, the effect on tides in the atmosphere is similar, though, according to conventional wisdom,[9] this effect is imperceptible.

According to my theory, the monsoon (ISMR) is due to **wind flows created by tidal forces** in the atmosphere, due to both the sun and the moon. Wind flows are perceptible! 😊 The correlation with anti-podal phenomenon is also, in principle, explicable because tidal forces always act simultaneously on the sub-lunar/sub-solar point **and** the anti-podal points. These tidal forces involve both moon and sun and can be accounted for better by a lunisolar calendar instead of merely a solar calendar.

For tidal forces, the moon is more important than the sun, as is well known for sea tides, for reasons recapitulated below.

3. Tidal force varies as the inverse cube of the distance



The tidal force theory of ISMR was first outlined in the appendix of my book: "Indian calendar scientific aspects",[10] used as a text to teach the traditional Indian calendar to students in both high-schools and at IIT Mandi.

The (gravitational) tidal force of one body (body 1) on another (body 2) is usually defined as the difference between the gravitational force due to body 1 at two points of body 2. On Newtonian physics, tidal forces, being the difference of two inverse-square law forces,[11] at distances large compared to the size of the object on which the tidal forces act, **vary as the inverse cube of the distance.**

Thus, consider a point X on earth. The **tidal force** at X, $F_1 = F_{surface}$ due to the moon is typically defined as the difference in the gravitational force of the moon at X and its gravitational force at the centre of the earth $F_2 = F_{center}$. Here, d_{en} is the distance between the centres of the moon and the earth, and R_e is the radius of the earth.

On Newtonian gravitation, if M_m is the mass of the moon, then the tidal force T is given by,

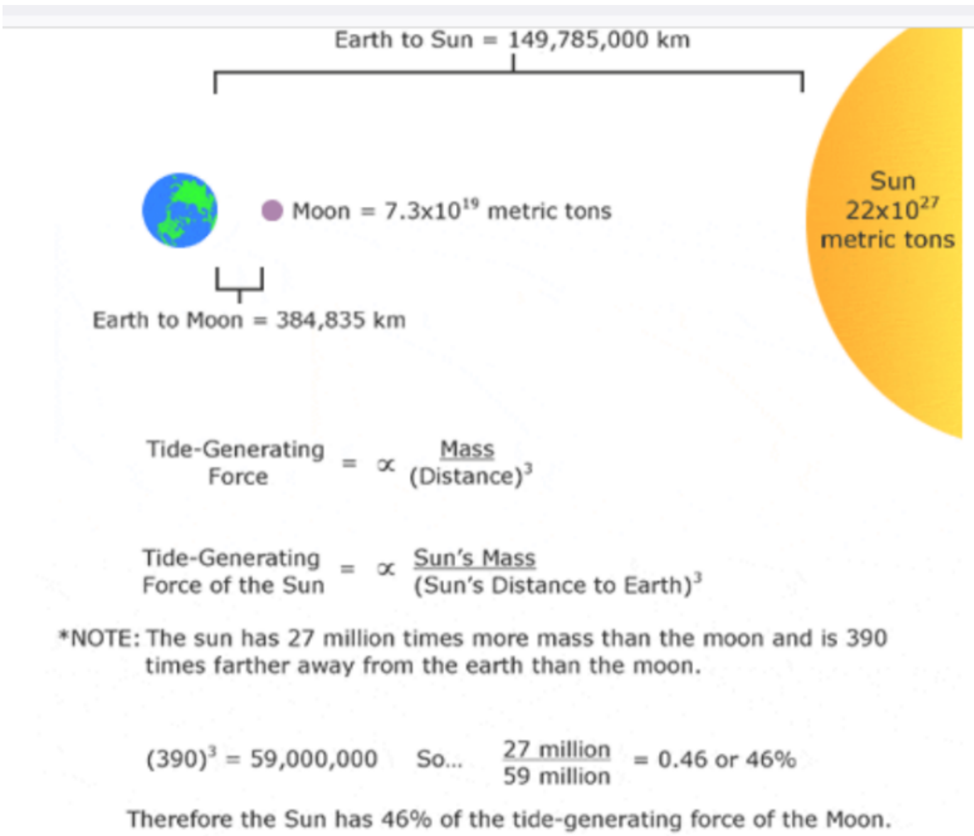
$$\|T\| = \|F_1 - F_2\| = \frac{GM_m}{(d_{em} - R_e)^2} - \frac{GM_m}{(d_{em})^2}$$
$$= GM_m \frac{(d_{em})^2 - (d_{em} - R_e)^2}{(d_{em} - R_e)^2 (d_{em})^2}$$
$$= GM_m \frac{2R_e d_{em} - R_e^2}{(d_{em} - R_e)^2 (d_{em})^2}$$

Since $d_{em} >> R_e$ this simplifies to

$$\|T\| = \frac{2GM_m R_e}{(d_{em})^3}$$

A similar calculation applies to solar tidal forces.

As a consequence of this inverse-cube dependence, the tidal force due to the moon may be over twice as large as the tidal force due to the far more massive sun, as shown in the graphic below. (Image credit: https://oceanservice.noaa.gov/education/tutorial_tides/tides02_cause.html.)



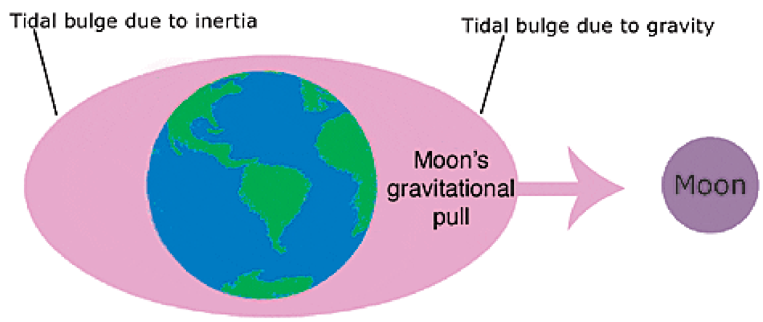
The immediately important point for us is that tidal forces are luni-solar in nature, more luni than solar! As shown below, this explain why the luni-solar Indian calendar is better able to predict the monsoon (the months of Sawan and Bhadon) than the solar calendar based on the tropical year, on which the monsoon is irregular.

4. Tidal bulges and barycentric motion

The tidal force results in two bulges on the earth whether in the sea or the atmosphere. The bulges in sea water are not very prominent and less than one meter high in the open sea. Though the same equations of fluid motion apply to both the sea and the atmosphere, the fact is that sea water is about

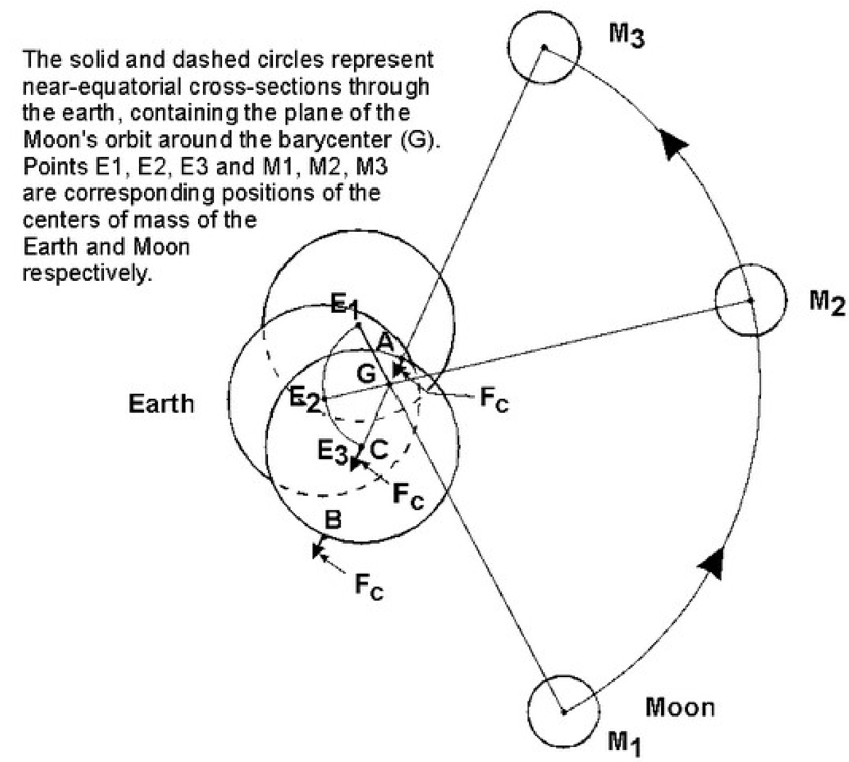
1000 times more dense than the atmosphere. Consequently, the tidal bulges in the atmosphere would be about 0.5 km tall, quite prominent, though invisible.

These bulges form at the sub-lunar and sub-solar points which are the points on earth directly under the moon or the sun. **They also form at the anti-podal points**. (Image credit: https://oceanservice.noaa.gov/education/tutorial_tides/tides03_gravity.html.)



However, merely saying that the bulge at the anti-podal point is due to inertia, while technically correct, is not very communicative. The inertial force in question is better known as the centrifugal force in common parlance, a fictitious or inertial force, which exists only in a non-inertial frame. The gravitational attraction of the moon and the centrifugal force are balanced at the centre of the earth. They are imbalanced at the sub-lunar and the anti-podal point. At the sub-lunar point, the gravitational force exceeds the centrifugal force. At the anti-podal point, the centrifugal force exceeds the gravitational pull. This causes the bulges to be formed at the two points.

Once we have stated matters in this way, in common parlance, it is possible to clarify a key confusing point. The centrifugal force in question is NOT the centrifugal force due to the rotation of the earth about its axis. To the contrary, **it is the centrifugal force due to the barycentric rotation** of the earth-moon system about their common barycentre. (Image credit: https://tidesandcurrents.noaa.gov/restles3.html.)



The Monthly Revolution of the Earth and Moon around the Barycenter of the Earth-Moon System
FIGURE 1

Similar remarks apply to the tidal forces due to the sun on earth.

As explained in my book on the Indian calendar, exact heliocentric motion of the earth, or exact geocentric motion of the moon are impossible on Newtonian physics, despite the huge tales that have been told about this. In Newtonian physics, the motion of two particles (gravitational 2 body problem) is always around the barycentre, which may lie approximately within the sun (but also outside) for the planetary system and which may lie within the earth (but not at its centre) for the earth-moon system.

The other point to clarify is why the phases of the moon are important. **The phases of the moon are important because they depend upon the relative positions of the sun, moon and earth, hence decide how the tidal forces of the sun and moon combine together**. Thus, it is well known that during no moon (or new moon) the forces will act together since both sun and moon are on the same side of the earth. This leads to spring tides or larger than usual tidal forces, and tides in the sea, and the same will happen in the atmosphere.

The tidal forces of the sun and the moon also act together even on the full moon, when the sun and moon are on diametrical opposite sides of the earth. In this case, the sub-solar point coincides with the anti-podal point of the sub-lunar point and vice versa, so the bulges due to the two again coincide.

5. The tractive tidal force and wind flow near summer solstice and related lunistices

It is true that the tidal force does create two bulges at anti-podal points. However, these bulges are a minor matter, whether in the atmosphere or in the sea, because the vertical component of the tidal force is quite tiny compared to the downward gravitational pull of the earth. Even in the sea, the observed rise of sea level due to tides is **not** due to these bulges.

Rather, it is due to the tractive force: **the horizontal component of the tidal force which is unopposed and results in a flow,** of sea water or air, towards the sub-lunar or sub-solar point to form the concerned bulges. In the case of the sea, it is well known that when this flow of sea water is blocked by a landmass, the water level rises near the shore in a way which also depends on the underlying topography.

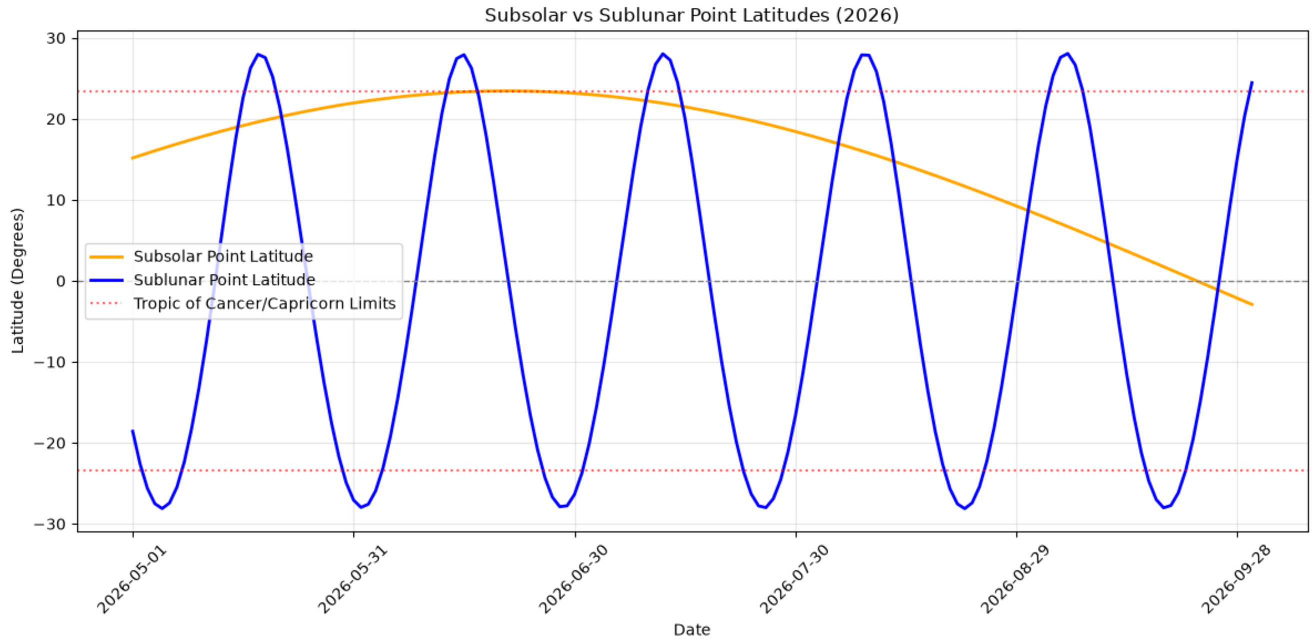
Our concern with atmospheric tides is not with these bulges but only with the related wind flows. In the case of sea tides, the height increase near the shore is not due to the vertical tidal forces, but due to the flow of water (due to horizontal component of tidal forces) which flow gets stopped by land. To reiterate, our concern always is with the horizontal component of the tidal forces which is unopposed, and results in a wind or flow of air in the atmosphere or a current of water in the sea.

In the case of both the sun and the moon, the unopposed horizontal component of the tidal force always points towards the sub-lunar or the sub-solar point, i. e., the points just below the sun and the moon (where the bulges form), or the anti-podal points. **This results in wind flow towards the sub-lunar and sub-solar points**.

In this article we will consider only the ISMR or the Southwest monsoon or the common rainy season across much of India. This rainy season always comes during the summer, after the equinox, during or after May, when the sea has been heated enough, despite its large specific heat, and a large amount of water vapour has been created by the heat of the sun, and has accumulated over the sea, on the equator.

The question is what forces drive this water vapour towards the Indian subcontinent?

To answer this, let us examine the tidal wind flows from just before and after the time of the summer solstice (typically in June). That is, we examine the tidal wind flows from May to September As stated above, the wind flows resulting from tidal forces are always directed towards the sub-solar and sub-lunar points. Therefore, to understand the resulting wind flow we first plot the latitudes of the sub-solar and sub- lunar points as done below for the year 2026. The plot was calculated and drawn using a Python program with the skyfield module, the DE 421 lunar and planetary ephemeris, and the Python utility matplotlib. The short program is available on request.



As clear from the above graph, during this entire period, from before solstice to equinox, or from May to September, the sun has a northern declination. Consequently, the sub-solar point always has northern latitude in this period. Hence, also, the resulting tractive force at the equator and the corresponding tidal flow of air due to solar tidal forces are northward.

The other key point to note in the above graph is that starting from around mid-May, **both the sub-solar and sub-lunar points have northern latitude at many points of time, and the latitude of the sub-lunar point is even more northward than that of the sub-solar point.** This means that (a) both solar and lunar tidal forces will act in unison, and there will be a general northward drift of the water-vapour-laden air from the equator, and (b) this will affect most of India, including the regions such as Delhi beyond the Tropic of Cancer.

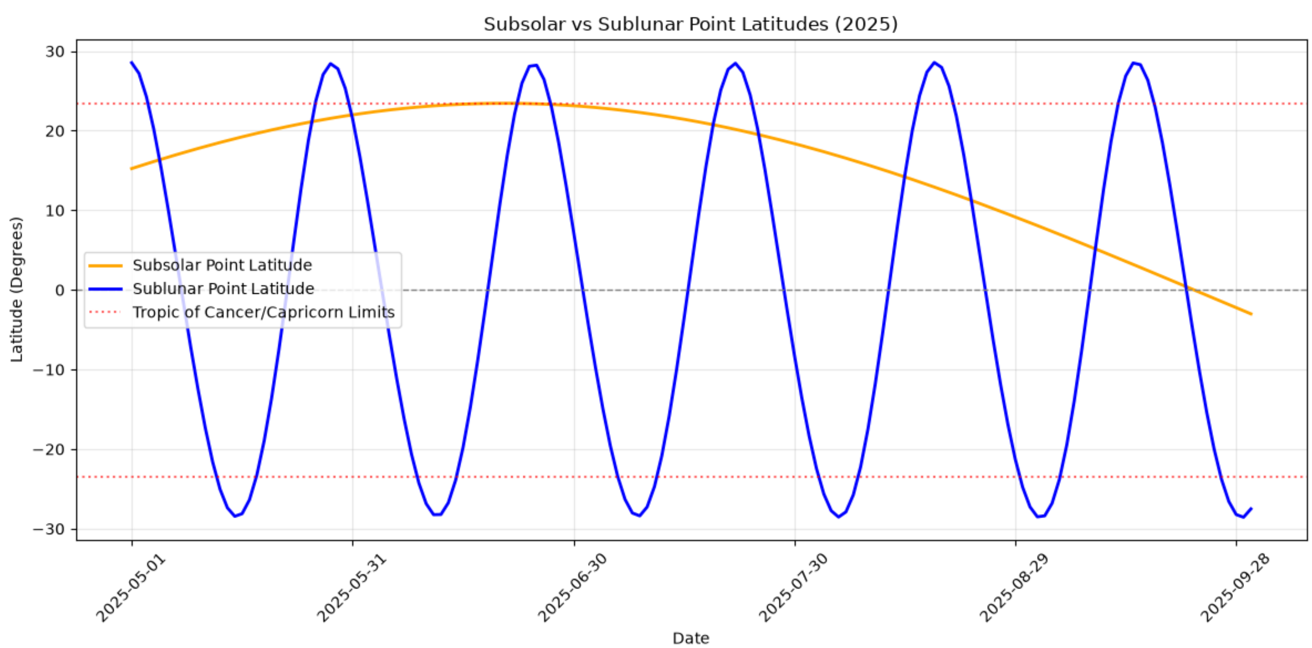
The Coriolis force

As this water vapour laden air moves towards the north from the equator, it will be deflected towards the east because of the Coriolis force. The Coriolis force is another fictitious force or an inertial force, which acts only in a non-inertial frame such as the rotating earth. At the equator, the earth (hence the air above it) is moving at the fastest possible velocity eastward due to the rotation of the earth from the west to the east. This rotation velocity is fastest at the equator because the angular velocity of the earth rotation is constant, and among all latitude circles, the equator is the biggest. Since the angular velocity of rotation is constant, hence the air above the equator has the maximum rotational velocity towards the east, whereas the eastward rotation velocity at higher latitudes is lower.

As the air moves towards north towards a higher latitude, the rotation speed of the earth at that latitude immediately below it reduces. But the air coming from the equator retains its original eastwards velocity because of inertia. Therefore, it seems to be deflected eastward **as if** an invisible force (the Coriolis force) is acting on it to deflect it.

That is, starting from the equator, a current of water vapour drifts towards the north and the east. As seen from India, this appears to be a current of water vapour coming from the south and the west, i.e., the south-west monsoon.

This starts happening from before the solstice, but how much before depends upon the particular year in question. Thus in 2025 the monsoon came “early” (based on a statistical average date on the Gregorian calendar) because both the sub-solar and sub-lunar points had moved northwards by mid May, as seen from the figure below. In Mumbai, the monsoon came by 23 May compared to its average date of 1 June for the onset of the monsoon in Kerala, so that it typically reaches Mumbai by mid June.



6. Effect of phases of the moon

A potentially confusing point in the above diagram is the following. During almost the entire period in question, the sun has northern declination, therefore, the subsolar point is at a northern latitude. Therefore, tidal wind flows due to the sun’s tidal forces will always be northward.

But the moon has both northern and southern declination. When the sublunar point has a northern latitude, the moon's tidal force will also be northward. But what happens when the sub-lunar point has a southern latitude? How do we evaluate the net force in this case? This is where the phases of the moon come in.

It is well known that high tide in the sea corresponds to phases of the moon. This happens because the tidal forces due to the sun and the moon are aligned on the occasions of the full moon (purnima) and the new moon or no moon (amavasya). Thus, on a new moon (amavasya) day the sun and the moon are aligned and on the same side of the earth. Therefore, the sub-lunar and sub-solar points overlap, and the tidal forces of the sun and the moon act in unison.

On a full moon day (purnima), the sun and moon are on diametrically opposite sides of the earth. Therefore, the anti-podal point to the sub-lunar point overlaps with the sub-solar point, and vice versa. Since tidal forces act simultaneously on anti-podal points, therefore, again, the tidal forces of the sun and the moon act in unison during the full moon.

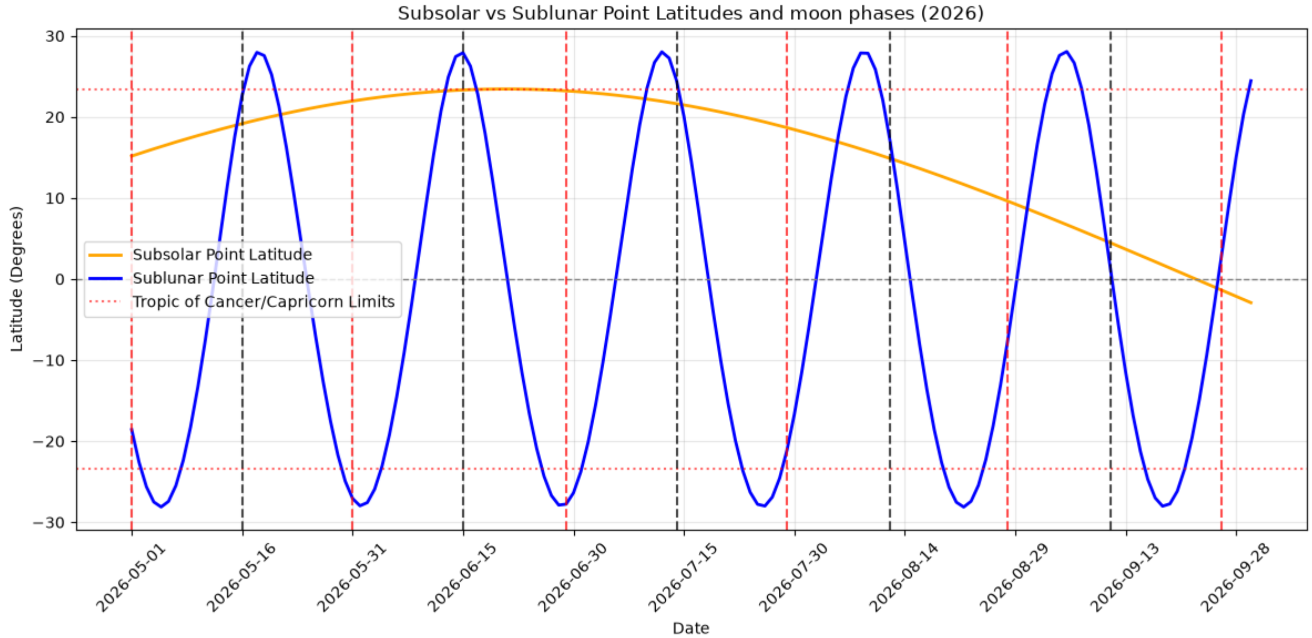
On the Indian lunisolar calendar, it is trivial to calculate the dates of the full moon and the new moon. Thus, on the amanta system each month ends and a new month begins with the new moon. On the purnimant system, each month ends and a new month begins with the full moon. On the Gregorian calendar, these dates were difficult to calculate earlier but may today be easily calculated using a small Python program (also available on request) and the pyephem module. The new moon and full moon dates for the period from May 2026 to September 2026 are listed below.

--- Moon Phases from 2026-05-01 to 2026-09-30 ---

🌑 NEW MOONS (No Moon):
• 2026-05-16 20:00 UTC
• 2026-06-15 02:54 UTC
• 2026-07-14 09:43 UTC
• 2026-08-12 17:36 UTC
• 2026-09-11 03:26 UTC

🌕 FULL MOONS:
• 2026-05-01 17:23 UTC
• 2026-05-31 08:45 UTC
• 2026-06-29 23:56 UTC
• 2026-07-29 14:35 UTC
• 2026-08-28 04:18 UTC
• 2026-09-26 16:48 UTC

Using this, we can modify the above graph as follows.



The vertical dotted black lines denote the dates of the new moon, while the vertical dotted red lines denote the dates of the full moon. **We see that in 4 cases, the peak northern latitudes of the sub-lunar points (the lunistices) correspond closely to successive new moons during this period of 4 months.** So, the latitude peaks of the sub-lunar points also represent the peaks of the combined northern luni-solar tractive tidal forces.

As for the troughs of the sub lunar points, these correspond to the full moon in 3 cases. At these times, the latitude of the anti-podal points to the sub-lunar points are aligned with the sub-solar point. Thus in this case too the lunar and solar tidal forces act in unison.

That is during the monsoon period we have the phenomenon of northern lunistices corresponding with the new moon and the southern lunistice corresponding with the full moon so that the lunar tractive tidal force then is northward, and synchronised with the solar tidal force. Consequently, the luni-solar tractive tidal force is strongly directed northward in this season.

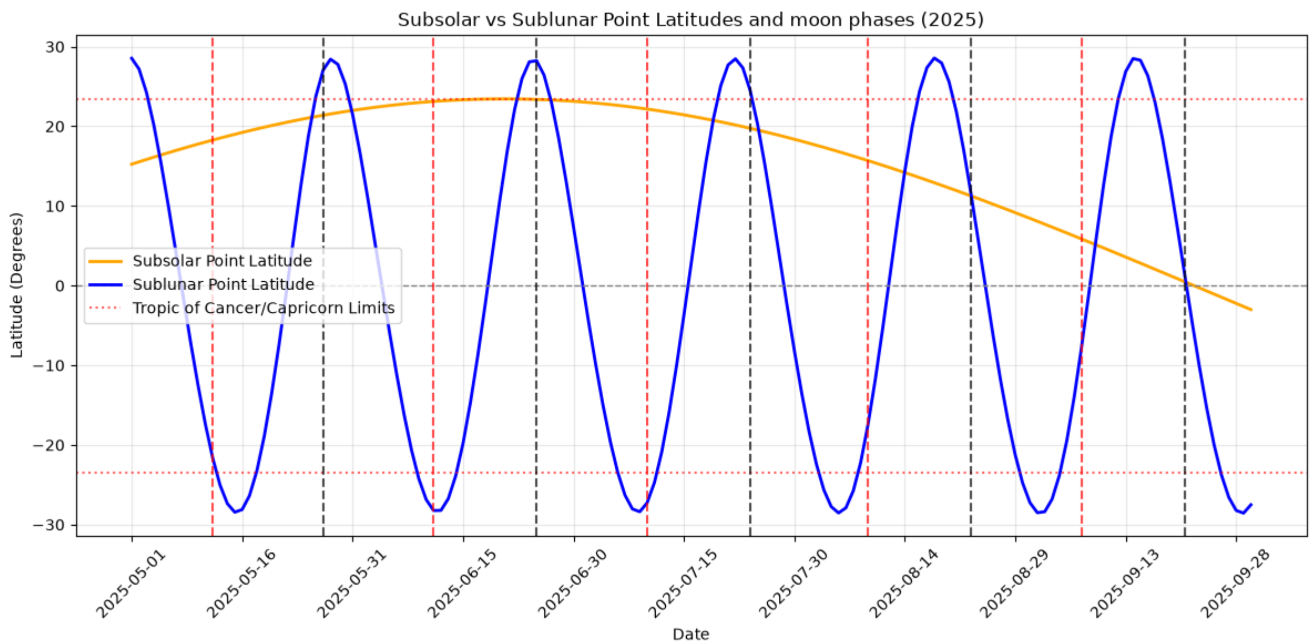
We further see from the right part of the graph graph that this coherent action of moon and sun breaks up by October. Indeed, as clear from the above graph, the northern declination of the sun itself ends at equinox around 23 September. The northern tidal pull of the moon may continue for some more days, after the equinox, but the net northward drift will soon end as the sun acquires greater southern declination. This is as predicted by the traditional Indian calendar, where Dussehra, which traditionally marks the end of the rainy season, will be about a month later on 20 October in 2026. This end time of the monsoon, a little after equinox, may be regarded as a prediction of the theory.

The simple observation that the monsoon begins a little before solstice and ends a little after equinox is “obviously” enough to rule out any explanation of the monsoon season based purely on the sun, as Saha imagined.

Thus, the monsoon is a combined luni-solar phenomenon which begins from before the summer solstices and is dependent on the accompanying lunistices and the synchronised phases of the moon. It lasts until a little after the equinox when the northern declination of the sun ends.

The combined tidal forces generate a northward drift of vapor lade-air which is deflected eastward because of the Coriolis force, resulting in the southwest monsoon over India.

Using the existing Python program, this analysis can be repeated for any desired year, for example for 2025 when the rainy season not only started "early" but also ended "early" by mid September, as depicted in the graph below. This again corresponded to the traditional end date of the rainy season



with Dussehra, the festival traditionally marking the end of the rainy season, having arrived very early (on the Gregorian calendar) on 2 October 2025.

7. Calculation of the tidal forces

The magnitude of the tidal forces is calculated in Appendix 1. The key conclusion is this, though the tidal forces are tiny (combined luni-solar maximum value of 1.6×10^{-6} N/kg), compared to say the acceleration due to Earth's gravity (9.81 N/kg), the horizontal tractive component of the combined luni -solar tidal force (1.2043×10^{-6} N/kg) is unopposed. This is obviously substantial enough to give rise to the observed regular ocean tides, since unopposed.

However, unlike ocean tides, which have a periodicity of a day or twice a day, the tidal forces responsible for the northward drift of water vapour act in a consistent northward direction from before before solstice to after the equinox. The above constant northern acceleration over a long period of time, such as 15 days, results in the displacement of air over 1011.38 km (a little over the 900 km distance from Kanyakumari to the equator). Under the above acceleration this displaced air arrives

with a northward drift velocity of 5.62 km/h, which is a little over the observed northward drift velocity of the monsoon of 4.58 km/h observed as the monsoon migrates from Kanyakumari to Mumbai.
This slow northward crawl of the monsoon is not responsible for the high wind speeds often associated with the monsoon. The Coriolis force is. By the time the monsoon reaches Mumbai, because of the Coriolis force it would have acquired an eastward velocity of over 163.476 km/h.

This marked disparity between northern movement and eastern wind speed has not been explained on any other theory till now.
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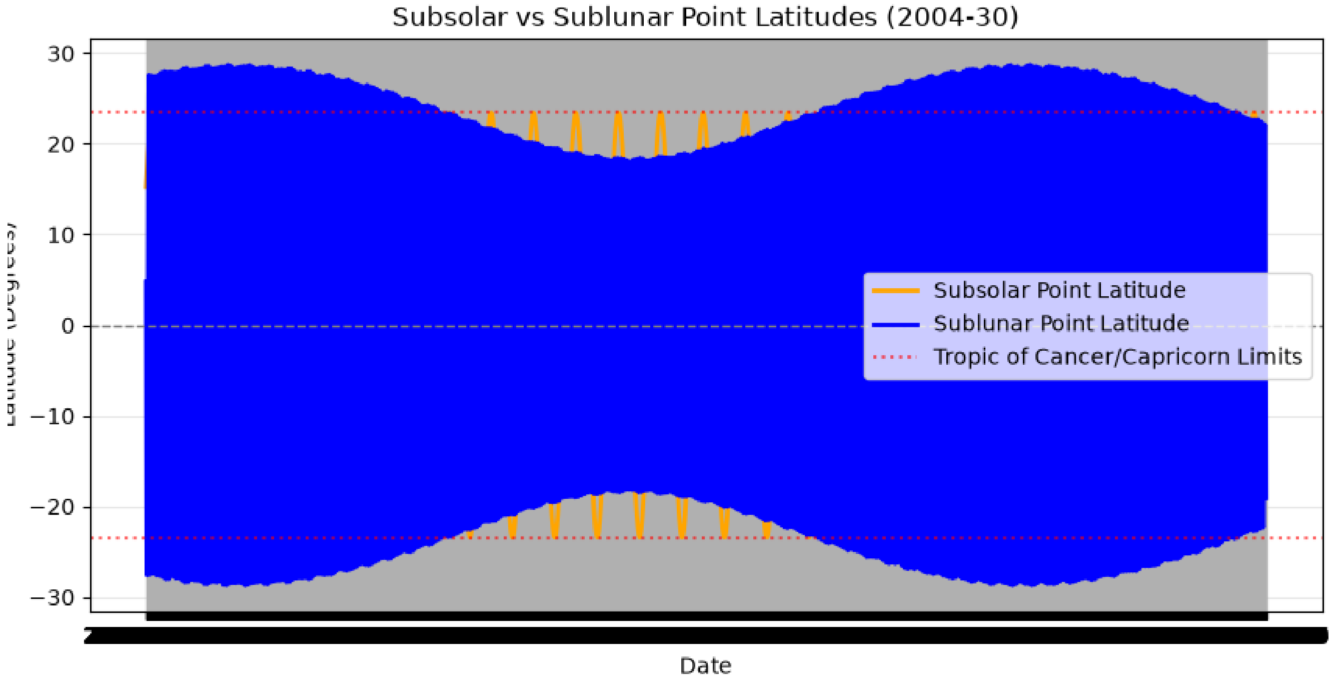
8. Discussion

This tidal-force theory of the south-west monsoon, or model of tidal drift northward deflected eastward by the Coriolis force, easily explains the observed fact that the monsoon first arrives at the southern tip of India before gradually drifting upward. Because tidal forces affect both atmosphere and ocean we can expect related ocean currents, with both having a common causal basis, instead of one driving the other.

The maximum and minimum latitude of the sub-lunar point is not always the same as shown in the above graphs. It is at a peak for the years 2024-26. Given that the earth axis of rotation is tilted to the ecliptic by 23.44°, and given that moon's orbit is inclined to the ecliptic by 5.145°, the maximum latitude of the sublunar point varies from 23.44±5.145°, or 28.585° and 18.295° and the minimum from the corresponding negative values. **Note that the maximum latitude above corresponds to the beginning of the Himalayas, where the vapour-laden winds are blocked, and rise higher to cool and condense causing intense precipitation.**

The maximum and minimum latitudes of the moon are periodic over an approximately 18.6 years cycle of the lunar nodes. The latitude of the sub-solar point, of course, always stays between ± 23.44°. This variation of lunistices is shown in the diagram below (the oscillations of the latitude of the sub-lunar point are plotted very dense over this 26 year period) and what is visible is only an envelope which makes the variation in the peak latitude of the sublunar point across 18.6 years easily visible.)



The theory that the ISMR (southwest monsoon) or the bulk of the rainfall in India during the summer rainy season is due to tidal wind flows coming from the equator should not be interpreted to mean that every case of rainfall in this season is due to this reason. It is commonly observed that during the summer, extreme heating results in thunderstorms or dust storms due to convective wind flows which balance the temperature and cool the atmosphere and sometimes also bring rain.

9. Conclusions

The tidal theory of the monsoon (ISMR) shows that the south west monsoon is a luni-solar phenomenon, due to luni-solar tidal forces. It is naturally best captured by a traditional luni-solar calendar, such as the Indian calendar, which was a key reason for pre-colonial Indian prosperity, due to successful rain-fed agriculture. The involvement of the moon in determining rainfall clearly explains why the monsoon dates are variable on the unscientific Gregorian calendar spread by colonial education.

1 *Times of India* 30 July 2004, front page, archived at https://ckraju.net/papers/presentations/images/Monsoon-pages-from-calendar.pdf.
2 C. K. Raju, *Cultural Foundations of Mathematics: The Nature of Mathematical Proof and the Transmission of the Calculus from India to Europe in the 16th c. CE* (Pearson Longman, 2007). C. K. Raju, "A Tale of Two Calendars"," AIU Conference on Traditional Sciences for Sustainability, ed. Claude Alvares, Penang, 2012, http://www.ckraju.net/hps-aiu/ckr-calendar.html in: *A Tale of Two Calendars - Dr C K Raju - India Inspires Talks*, 2015, 1:02:13, https://www.youtube.com/watch?v=MvpuC7Dg4e0&feature=youtu.be.
3 Matteo Ricci, "Letter to Petri Maffei," in *Documenta Indica*, XII (1581). Goa, ff. 129r-130v, In the original handwritten source, Ricci states, "Com tudo no me parece que sera impossivel saberse, mas has de ser por via d'algum mouro honorado ou brahmane muito intelligente que saiba as cronicas dos tiempos, dos quais eu procurarei saber tudo." (He was looking for an "intelligent Brahmin or an "honest Moor" to learn the Indian calendar.
4 C. K. Raju, *Indian Calendar: Scientific Aspects* (Kant Academic Publishers, 2025).
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6 G. T. Walker and E. Bliss, "World Weather V," *Mem. Roy. Met. Soc* 4 (1932): 53–84; G. T. Walker, "Seasonal Weather and Its Prediction," *Nature* 132 (1933): 805–8.
7 Kumar, K. K. · Rajagopalan, B. · Cane, M. A. "On the weakening relationship between the Indian monsoon and ENSO" *Science.* 1999; 284:2156-2159. Kumar, K. K. · Rajagopalan, B. · Hoerling, M. ..."Unraveling the mystery of Indian monsoon failure during El Niño, Science. 2006; 314:115-119.
8 Xianke Yang and Ping Huang, "Restored Relationship between ENSO and Indian Summer Monsoon Rainfall around 1999/2000," *The Innovation*, ahead of print, February 2021, https://doi.org/10.1016/j.xinn.2021.100102.
9 Harold V Thurman, 1997. *Introductory Oceanography.* Eighth ed. Upper Saddle River, NJ: Prentice Hall.
10 Raju, *Indian Calendar: Scientific Aspects*.
11 Note, incidentally, that, even after general relativity, one may conceptually continue to speak of "forces", using my Lorentz covariant retarded gravitation theory, though, in our case, this would not differ much from the calculation done using Newtonian physics. C. K. Raju, "Retarded Gravitation Theory," in Sixth International School on Field Theory and Gravitation, ed. Rodrigues, Waldyr Jr et al. (American Institute of Physics, 2012); C. K. Raju, "Functional Differential Equations. 4: Retarded Gravitation"," Physics Education (India) 31, no. 2 (2015), https://doi.org/https://www.physedu.in/pub/Apr-Jun-2015/PE15-06-309.

A Appendix: Calculation of tidal forces

- Gravitational Constant (G): 6.6743×10^{-11} m^{3}kg^{-1}s^{-2}
- Earth's Equatorial Radius (r): 6.3781×10^6 m
- Mass of the Moon (M_{moon}): 7.342×10^{22} kg
- Earth-Moon Distance (d_{moon}): 3.844×10^8 m
- Mass of the Sun (M_{sun}): 1.989×10^{30} kg
- Earth-Sun Distance (d_{sun}): 1.496×10^{11} m.

A.1 Computation of lunar tidal force (per kg)/acceleration

Substituting the above lunar values into the tidal force formula:

$$F_{\text{lunar}} = \frac{2GM_{\text{moon}}m \cdot r}{d_{\text{moon}}^3} \tag{1}$$

$$\begin{aligned} F_{\text{lunar}} &= \frac{2(6.6743 \times 10^{-11})(7.342 \times 10^{22})(1.0)(6.3781 \times 10^6)}{(3.844 \times 10^8)^3} && (2) \\ &\approx 1.1005 \times 10^{-6} \text{ N/kg.} && (3) \end{aligned}$$

A.2 Computation of solar tidal acceleration

Substituting the solar values into the same tidal force formula:

$$\begin{aligned} F_{\text{solar}} &= \frac{2GM_{\text{sun}}m \cdot r}{d_{\text{sun}}^3} && (4) \\ &= \frac{2(6.6743 \times 10^{-11})(1.989 \times 10^{30})(1.0)(6.3781 \times 10^6)}{(1.496 \times 10^{11})^3} && (5) \\ &\approx 5.0579 \times 10^{-7} \text{ N/kg.} && (6) \end{aligned}$$

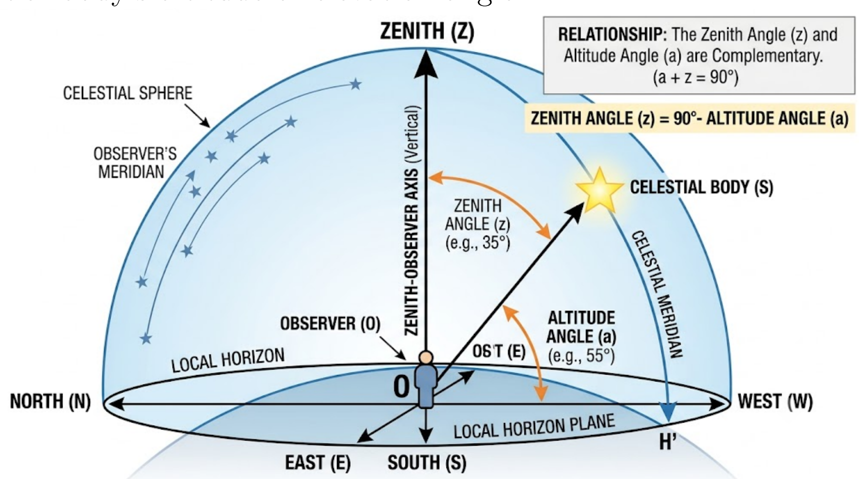
A.3 The ratio

$$\text{Ratio} = \frac{1.1005 \times 10^{-6}\ \text{N/kg}}{5.0579 \times 10^{-7}\ \text{N/kg}} \approx 2.18. \tag{7}$$

Though the Sun is some 27 million times more massive than the Moon, but because of the inverse-cube dependence of the tidal force, the moon's tidal force is 2.18 time stronger.

A.4 The horizontal and vertical components of the tidal force

The zenith angle (θ) of a celestial body X (S in figure), at the position of an observer O on the surface of the earth, is the angle (arc) from the celestial body to the observer's zenith Z. This angle XOZ is the complement of the celestial body's altitude or elevation angle.



Let d be the distance from the Earth's center to that of the Moon, and r be the Earth's radius. The distance R from the observer's position O to the Moon is given by

$$R^2 = d^2 + r^2 - 2dr\cos\theta. \tag{8}$$

The local gravitational potential (V_{local}) at the surface is proportional to $1/R$:

$$\frac{1}{R} = \frac{1}{d}\left(1 - 2\frac{r}{d}\cos\theta + \frac{r^2}{d^2}\right)^{-1/2} \tag{9}$$

A.5 The Legendre Polynomial Expansion

Because the Moon is very far away, the ratio of the Earth's radius to the Moon's distance ($\frac{r}{d}$) is very small (about 1/60). This allows us to use a binomial expansion (or Legendre polynomials) to break the expression into a series of simpler terms:

$$\frac{1}{R} = \frac{1}{d}\left[1 + \left(\frac{r}{d}\right)\cos\theta + \left(\frac{r}{d}\right)^2 \frac{1}{2}(3\cos^2\theta - 1) + \dots\right] \tag{10}$$

Multiplying this expansion by the Moon's mass and gravitational constant we find the the 1st term represents the gravitational field at the center of the Earth. The second (dipole) term vanishes in a barycentric frame, so what survives is the quadrupole term (the 3rd term),

$$\left(\frac{r}{d}\right)^2 \frac{1}{2}(3\cos^2\theta - 1) \tag{11}$$

The horizontal component of the tidal force is the derivative of this potential term w.r.t. θ (turning it into $\left(\frac{r}{d}\right)^2 3\sin 2\theta$). The vertical component measures the radial force pointing straight up or down. The vertical force is the derivative of the tidal potential w.r.t. the radius (r) this keeps the angular part ($3\cos^2\theta - 1$) intact.

Thus,

Vertical (Lift) Component (F_v): Acts perpendicular to the Earth's surface, lifting or depressing the fluid (air/water).

$$F_v = \frac{2GMm \cdot r}{d^3}\left(\frac{3\cos^2\theta - 1}{2}\right) = F_{\max}\left(\frac{3\cos^2\theta - 1}{2}\right). \tag{12}$$

Horizontal (Tractive) Component (F_h): Acts parallel to the Earth's surface, pushing the fluid (air/water) horizontally.

$$F_h = \frac{2GMm \cdot r}{d^3}\left(\frac{3\sin(2\theta)}{4}\right) = F_{\max}\left(\frac{3\sin(2\theta)}{4}\right). \tag{13}$$

A.6 Values of the components

For the calculations below, we use the lunar maximum acceleration ($F_{\max} = 1.10 \times 10^{-6}$ N/kg) as already calculated.

* Maximum upward lift ($\theta = 0°, 180°$):

$$F_v = 1.10 \times 10^{-6} \left(\frac{3(1)^2 - 1}{2} \right) = 1.10 \times 10^{-6} \text{ N/kg.} \tag{14}$$

This is negligible compared to the earth acceleration due to gravity $g =$ 9.81 N/kg.

* Maximum downward depression ($\theta = 90°$):

$$F_v = 1.10 \times 10^{-6} \left(\frac{3(0)^2 - 1}{2} \right) = -0.55 \times 10^{-6} \text{ N/kg.} \tag{15}$$

The horizontal acceleration is zero directly under the moon, peaks diagonally at 45°, and drops back to zero at the horizon.

* Maximum horizontal acceleration ($\theta = 45°, 135°$):

$$F_h = 1.10\times10^{-6} \left(\frac{3 \sin(90°)}{4} \right) = 1.10\times10^{-6}\times0.75 = 8.25\times10^{-7} \text{ N/kg.} \tag{16}$$

Similar considerations apply to the sun, except that in the solar case, as calculated earlier,

$$F_{\text{max}} = F_{\text{solar}} \approx 5.0579 \times 10^{-7} \text{ N/kg.} \tag{17}$$

Likewise, for the sun the maximum horizontal tractive component would be

$$5.0579 \times 10^{-7} \times 0.75 = 3.793 \times 10^{-7} \text{ N/kg.} \tag{18}$$

Therefore, the combined maximum tidal acceleration due to both the sun and the moon would be

$$F_{\text{max}} = F_{\text{comb}} \approx (1.10 + 0.50579 = 1.6) \times 10^{-6} \text{ N/kg.} \tag{19}$$

And the maximum combined horizontal tractive acceleration due to both sun and moon would be

$$(8.25 + 3.793) \times 10^{-7} = 1.2043 \times 10^{-6} \text{ N/kg.} \tag{20}$$

A.7 The northern pull

What can such a tiny acceleration achieve? Plenty, becuase it is unopposed. We observe its effect in the case of sea tides.

However, ocean tides vary on a daily or twice-daily basis. In contrast, as the above analysis shows, the combined northward tidal pull of both the sun and moon persists over longer periods of time.

The other distinguishing feature from sea tides or sea currents is that, in case of the atmosphere and wind flows, there are no obstructions to block the tidal wind flow, except for mountains (overland) like the Western Ghats, the Vindhyachal, and the Himalayas, in India.

Thus, using the elementary formula $d = ut + at^2$, for zero initial velocity and a constant acceleration a acting continuously for time t, we can easily determine the distance d, and the arrival velocity u.

The above long-term acceleration of 1.2043×10^{-6} N/kg, acting continuously for time t of 15 days, will displace air from the equator northward by 1011.38 km, or somewhat more than the distance of some 900 km from the equator to Kanyakumari, with an arrival velocity u of 5.62 km/h.

Like the above distance, this velocity too is a slight overestimate, since the monsoon is observed to travel from Kerala (Kanyakumari) to Mumbai, a distance of about 1321 km, in about 12 days, corresponding to an average northward velocity of 4.58 kmph. Of course, various refinements can be made, but the above calculation already establishes that the tidal forces are not too small to account for the Indian monsoon but are remarkably close to the right value needed.

To reiterate, various refinements can be applied. For example, in terms of the combined northward horizontal tractive force, we see that the sun has a nearly constant northern declination, while the northern declination of the moon fluctuates from zero to a maximum and back.

A.8 The Coriolis force

Another possible simplistic objection to the tidal-force theory of the Indian monsoon is that the monsoon's arrival corresponds to high velocity winds, whereas the above northern drift is at a mere crawl of a few kilometers per hour, about the speed of a walk. This objection too is easily overcome by taking into account the effect of the Coriolis force. Thus, let us calculate the wind speed, due to the Coriolis force, acquired by a mass of air moved northward from the equator.

Thus consider a mass of air move northward from the equator to Mumbai at a latitude of 19.076°. Given about 111 km per degree this gives us: $19.076 \times 111?2,115$ km, which let us round off for simplicity in calculation to 2000 km.

Using the Earth's mean radius $R \approx 6371$ km $= 6.371 \times 10^6$ m, the angular latitude ϕ in radians corresponding to displacement northward of $y = 2000$ km $= 2 \times 10^6$ m can be converted to radians, as: $\phi = \frac{y}{R} = \frac{2.000\times10^6 \text{ m}}{6.371\times10^6 \text{ m}} \approx 0.3139 \text{ rad} \approx 17.99°$.

At the equator ($\phi = 0$), the distance to the axis of rotation is R and the velocity due to Earth's rotation, with constant angular velocity Ω, is (ΩR) so that that angular momentum

$$L = m(\Omega R)R = m\Omega R^2. \tag{21}$$

At latitude ϕ, the distance to the rotation axis shrinks to $r_\phi = R\cos\phi$. Let u be the relative eastward velocity then:

$$L = m(\Omega R\cos\phi + u)R\cos\phi. \tag{22}$$

Since angular momentum is conserved equating both expressions gives:

$$\Omega R^2 = (\Omega R\cos\phi + u)R\cos\phi \quad \text{or} \tag{23}$$

$$u = \Omega R\frac{\sin^2\phi}{\cos\phi}. \tag{24}$$

Using Earth's angular velocity $\Omega \approx 7.292 \times 10^{-5}$ rad/s: so

$$u = (7.292 \times 10^{-5} \text{ s}^{-1}) \cdot (6.371 \times 10^6 \text{ m}) \cdot \frac{\sin^2(17.99°)}{\cos(17.99°)} \tag{25}$$

$$\approx 46.57 \text{ m/s} \tag{26}$$

We can do this in another way, considering only the horizontal component of the Coriolis acceleration, as traditional in meteorology

$$\frac{du}{dt} = 2\Omega v\sin\phi, \tag{27}$$

while omitting curvature terms:

$$\frac{du}{dt} = 2\Omega \sin\phi \frac{dy}{dt} \implies \tag{28}$$

$$du = 2\Omega \sin\left(\frac{y}{R}\right) dy. \tag{29}$$

Integrating from the equator ($y = 0$) to y:

$$u = \int_0^y 2\Omega \sin\left(\frac{y}{R}\right) dy \tag{30}$$

$$= 2\Omega R \left(1 - \cos\left(\frac{y}{R}\right)\right) \tag{31}$$

$$= 2\Omega R(1 - \cos\phi). \tag{32}$$

Hence,

$$u = 2 \cdot (7.292 \times 10^{-5}\ \mathrm{s}^{-1}) \cdot (6.371 \times 10^{6}\ \mathrm{m}) \cdot (1 - \cos(17.99^\circ)) \tag{33}$$

$$\approx 45.41\ \mathrm{m/s}. \tag{34}$$

We will neglect possible refinements.

This corresponds to a wind speed of $45.41 \times 3.6 = 163.476$ km/h.

Thus, the high wind speeds associated with the monsoon are due to the Coriolis force and not the tidal force which results only in the slow northward drift. No other theory, to my knowledge, accounts for this huge discrepancy between slow northward and high eastward wind speeds.