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Abstract

Tides on Earth are produced by differences in the Moon's gravitational attraction across the planet. This paper investigates how this behaviour would change if both the Earth and Moon were instead modelled as uniform, thin circular disks. The disks are assumed to be parallel, with the Moon centred above the Earth at the present Earth–Moon separation. The finite size of the flat Moon is first considered and is found to have very little effect on its gravitational field at the Earth because the Moon's radius is much smaller than the Earth–Moon separation. In contrast, flattening the Earth changes the direction in which the lunar gravitational field acts across its surface. The horizontal component of lunar gravity points towards the centre of the Earth disk, causing ocean water to accumulate beneath the Moon. Assuming an Earth-like downward gravitational acceleration, the equilibrium ocean surface is approximately 0.18 m higher at the centre of the disk than at its edge. The standard two-bulge tidal pattern would therefore be replaced by an approximately axisymmetric central high-water region.

Introduction

Tides are produced by differences in gravitational attraction across an extended body. In the real Earth–Moon system, the Moon's gravitational influence is not identical across the Earth, producing tidal forces that redistribute ocean water and contribute to two broad tidal bulges [1, 2].

This paper considers a hypothetical system in which both the Earth and Moon are modelled as uniform, thin circular disks. The Earth and Moon retain their present masses, radii and mean separation. The Earth disk has radius $R_E = 6.37 \times 10^6$ m, while the Moon disk has radius $R_M = 1.74 \times 10^6$ m and mass $M_M = 7.35 \times 10^{22}$ kg [1]. Their centres are separated by $D = 3.84 \times 10^8$ m [3].

The disks are assumed to be parallel and coaxial, with a shallow ocean covering the upper surface of the Earth disk. The aim is to determine how changing the geometry of both bodies alters the direction of the Moon's gravitational field across the Earth's surface and therefore changes the resulting tidal pattern.

Theory

The Moon is modelled as a uniform circular disk with surface mass density

$$\sigma_M = \frac{M_M}{\pi R_M^2}. \tag{1}$$

The gravitational acceleration along the symmetry axis of a uniform disk is [4]

$$g_{\text{disk}} = 2\pi G \sigma_M \left(1 - \frac{z}{\sqrt{z^2 + R_M^2}}\right), \tag{2}$$

where z is the perpendicular distance from the disk. Since the Earth–Moon separation is much greater than the Moon's radius, $D \gg R_M$, the lunar gravitational field at the Earth can be approximated using Newtonian gravity [1],

$$g_M \simeq \frac{GM_M}{D^2}. \tag{3}$$

For a point on the Earth disk at radial distance r, the component of the lunar gravitational acceleration parallel to the surface is

$$a_r = \frac{GM_M r}{(D^2 + r^2)^{3/2}}. \tag{4}$$

This component acts towards the centre of the disk, causing ocean water to move towards the point directly beneath the Moon.

For this simplified model, g is assumed to be constant across the Earth disk, with $g = 9.81\ \mathrm{m\,s^{-2}}$. For a shallow ocean in equilibrium, the surface gradient balances the horizontal lunar acceleration [5],

$$g\frac{dh}{dr} = -a_r. \tag{5}$$

Integrating from the centre of the Earth disk to its edge gives the difference in water height,

$$\Delta h = \frac{GM_M}{g}\left(\frac{1}{D} - \frac{1}{\sqrt{D^2 + R_E^2}}\right). \tag{6}$$

Results and Discussion

At the edge of the Earth disk, where $r = R_E$, Eq. (4) gives $a_r \approx 5.5 \times 10^{-7}\ \mathrm{m\,s^{-2}}$. Using the present Earth and Moon parameters in Eq. (6) gives $\Delta h \approx 0.18$ m.

The ocean surface would therefore be approximately 18 cm higher at the centre of the Earth disk than at its outer edge.

This differs from the tidal pattern of the real Earth. On a spherical Earth, the variation in lunar gravity across the planet contributes to two broad tidal bulges approximately aligned with the Earth–Moon direction [1, 2]. In the flat-disk model, the lunar acceleration parallel to the surface instead points towards the centre from all directions. The resulting tidal pattern is therefore approximately axisymmetric, with water accumulating beneath the Moon rather than forming two opposing bulges.

Flattening the Moon itself has comparatively little effect. Since $R_M/D \ll 1$, the Moon is sufficiently distant that its gravitational field at the Earth is almost identical to that produced by a point mass.

If the Moon remained centred above the Earth disk, the central high-water region would also remain approximately stationary. This is unlike the real Earth, where rotation carries locations through the tidal deformation and contributes to periodic changes in sea level.

This model assumes a constant downward gravitational acceleration across the Earth disk and does not calculate how the Earth's own gravity would change in a flat geometry. It neglects continents, ocean depth, rotation and detailed fluid motion.

Conclusion

Modelling the Earth and Moon as flat circular disks significantly changes the geometry of the tides. Flattening the Moon has little effect because its radius is much smaller than the Earth–Moon separation, so its gravitational field remains close to that of a point mass.

The main change results from flattening the Earth. The component of lunar gravity acting across the surface points towards the centre of the disk, causing ocean water to accumulate beneath the Moon. Under the simplified constant-g model, the ocean surface is approximately 0.18 m higher at the centre than at the edge. The standard two-bulge tidal pattern of spherical Earth would therefore be replaced by an approximately axisymmetric central tidal region.

References

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