SAMPLE

Earth's Dynamic Systems: Ocean Tides

The Moon's Pull on the Sea

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

Twice a day, on most coasts of the world, the sea walks up the beach and walks back down, and it keeps this appointment so reliably that harbours, sailors and shore creatures alike organise their lives around it. This book is about that rhythm: what ocean tides are, why they exist, how people came to understand them, and what that understanding is still used for.

The short physical answer is gravity's reach. The Moon's pull first, with the Sun's a weaker second, tugs on the ocean differently at different places, raising two bulges of water that the spinning Earth carries beneath them. The fuller answer is far richer. Because the two bodies wander in elliptical orbits, tilt at angles to one another and drag the ocean across a complicated seafloor, the actual tide at any harbour is a sum of dozens of overlapping rhythms, each with its own period, strength and character. Mathematicians call these rhythms tidal constituents, and learning to separate and predict them was one of the great practical triumphs of nineteenth-century science.

Tides matter far beyond the shoreline, as the rest of this book keeps showing. They stir nutrients into sunlit water, set the schedules of a whole zone of hardy shore life, shape navigation and trade, and are increasingly harvested for electricity. Their slow braking of the Earth's spin and gentle pushing of the Moon away from us are written into the length of the day itself, and into sediments laid down hundreds of millions of years before anyone thought to measure them.

A word on scale is worth keeping in mind throughout. The tide's raw force raises the open ocean by barely half a metre; the sixteen-metre ranges of a few famous bays are the ocean's answer to a particular shape of basin, not the sky pulling harder there. Understanding tides is largely understanding how water resonates in the containers the coastline gives it, which is why the same Moon makes such different seas.

The chapters that follow move from the first written puzzles about the sea's breathing, through the physics of forces and waves, to the modern machinery of gauges, satellites and numerical models, and finally to the places where tidal knowledge is heading next, from the flood-forecast desks of rising coasts to the turbines now spinning on the seafloor.

Chapter 1: The Discovery of Ocean Tides

Tides are commonly semi-diurnal (two high waters and two low waters each day), or diurnal (one tidal cycle per day). The two high waters on a given day are typically not the same height (the daily inequality); these are the higher high water and the lower high water in tide tables. Similarly, the two low waters each day are the higher low water and the lower low water.

The daily inequality is not consistent and is generally small when the Moon is over the Equator.

The following reference tide levels can be defined, from the highest level to the lowest: Highest astronomical tide (HAT) - The highest tide that can be predicted to occur. Note that meteorological conditions may add extra height to the HAT. Mean high water springs (MHWS) - The average of the two high tides on the days of spring tides. Mean high water neaps (MHWN) - the matching figure for the two daily high waters at neap.

Mean sea level (MSL) - This is the average sea level. The MSL is constant for any location over a long period. Mean low water neaps (MLWN) - the matching figure for the two daily low waters at neap. Mean low water springs (MLWS) - The average of the two low tides on the days of spring tides. Lowest astronomical tide (LAT) - The lowest tide which can be predicted to occur.

The semi-diurnal range (the difference in height between high and low waters over about half a day) varies in a two-week cycle. Approximately twice a month, around new moon and full moon when the Sun, Moon, and Earth form a line (a configuration known as a syzygy), the tidal force due to the Sun reinforces that due to the Moon. The tide's range is then at its maximum; this is called the spring tide.

It is not named after the season, but, like that word, derives from the meaning "jump, burst forth, rise", as in a natural spring. Spring tides are sometimes referred to as syzygy tides. When the Moon is at first quarter or third quarter, the Sun and Moon are separated by 90° when viewed from the Earth (in quadrature), and the solar tidal force partially cancels the Moon's tidal force.

At these points in the lunar cycle, the tide's range is at its minimum; this is called the neap tide, or neaps. Neap tides are sometimes referred to as quadrature tides. Spring tides result in high waters that are higher than average, low waters that are lower than average, "slack water" time that is shorter than average, and stronger tidal currents than average. Neaps result in milder tidal conditions.

There is about a seven-day interval between springs and neaps. Tidal constituents are the net result of multiple influences impacting tidal changes over certain periods of time. Primary constituents include the Earth's rotation, where the Moon and Sun stand relative to Earth, the Moon's altitude (elevation) above the Earth's Equator, and bathymetry. Variations with periods of less than half a day are called harmonic constituents. Conversely, cycles of days, months, or years are referred to as long period constituents.

Tidal forces act on the entire Earth system. In Earth's crust, these forces produce periodic vertical displacements of centimeters, a phenomenon known as Earth tide. In the atmosphere, gravitational forcing by the Moon and Sun, together with solar heating, generates global-scale oscillations in pressure, density, and wind known as Atmospheric tide. Whereas Earth tides involve elastic deformation, atmospheric tides are observed primarily as oscillations in pressure gradients and wind patterns.

In most locations, the largest constituent is the principal lunar semi-diurnal, also known as the M2 tidal constituent or M2 tidal constituent. Its period is about 12 hours and 25.2 minutes, exactly half a tidal lunar day, which is the average time separating one lunar zenith from the next, and thus is the time required for the Earth to rotate once relative to the Moon. Simple tide clocks track this constituent.

The lunar day is longer than the solar day because the Moon orbits in the same direction as the Earth spins. The Moon orbits the Earth in the same direction as the Earth rotates on its axis, so it takes slightly more than a day—about 24 hours and 50 minutes—for the Moon to return to the same location in the sky.

During this time, it has passed overhead (culmination) once and underfoot once (at an hour angle of 00:00 and 12:00 respectively), so, in many places, the period of strongest tidal forcing is the above-mentioned, about 12 hours and 25 minutes. The moment of highest tide is not necessarily when the Moon is nearest to the zenith or nadir, but the period of the forcing still determines the time between high tides.

Because the gravitational field created by the Moon weakens with distance from the Moon, it exerts a slightly stronger than average force on the side of the Earth facing the Moon, and a slightly weaker force on the opposite side. The Moon thus tends to "stretch" the Earth slightly along the line connecting the two bodies.

The solid Earth deforms a bit, but ocean water, being fluid, is free to move much more in response to the tidal force, particularly horizontally (see

equilibrium tide).

For the civilisations of the Mediterranean, the ocean's breathing was nearly invisible: enclosed basins of that sea answer the Moon with barely a hand's-width of rise and fall, so Greek natural philosophers could debate the sea's motions for centuries without ever watching a true tide come in. The shock of the Atlantic was recorded early. Pytheas of Massalia, sailing north around 325 BC, brought back accounts of a coast where the sea rose and fell by many feet twice each day, and where the flood ran far up the rivers. Julius Caesar's fleet, anchored on a British shore in 55 BC, was caught by a tide the Mediterranean had never taught his captains to expect; the storm-damaged ships of that first landing are among history's more expensive lessons in tidal ignorance.

From such encounters, patient observation accumulated wherever the water truly moved. The earliest surviving European tide tables are monastic works: a thirteenth-century abbot of St Albans, John of Wallingford, left a reckoning of the flood at London Bridge, computed for the benefit of travellers crossing the river, and by the late fourteenth century Catalan pilots could consult printed tables for the approaches of their own ports. In the North Sea and Baltic, Hanseatic skippers built working rules of the tide into the routine of trade, while Arab pilots of the Indian Ocean worked the monsoon's wind together with the flood in a single body of craft knowledge.

What all these traditions lacked was a cause. Some attributed the water's motion to the breath of the sea or the winds the Sun stirred up; a few, remarkably, guessed the Moon. The true turning point waited for a mathematics of invisible force, and that story, from Newton's insight to the harmonic machines of the Victorian era, belongs to the next chapters.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.