Introduction to Tides

Sep 28, 2026 · @Ivan

Tides are the slow, regular rise and fall of the sea, driven mainly by the Moon's and Sun's gravity and shaped by the size and form of each ocean basin. This lesson turns the 11-slide deck "Intro to Tides" into a self-contained read, adds practical parts on GNSS tide measurement (IMCA S 027), the Admiralty tide publications, tidal calculations, tidal streams in navigation, 21 practice exercises, the tide symbols of Chart No. 1, a spreadsheet tide calculator, tidal currents in depth and reading an hourly tide table, with the physics explained step by step and a few errors in the slides corrected (listed at the end).

Who it is for: students of coastal geography, oceanography or seamanship, and anyone who uses tide tables. No maths beyond simple ratios is needed.

By the end you will be able to:

1. Explain why there are two high tides a day, not one.
2. Explain why high tide comes about 50 minutes later each day.
3. Tell spring tides from neap tides and say when each occurs.
4. Recognise semidiurnal, mixed and diurnal tides from a tidal curve.
5. Describe how an amphidromic system moves the tide around a sea.
6. Classify a coast as micro-, meso- or macrotidal and read the common tidal datums.
7. Explain how tidal asymmetry and wind change water levels and move sediment.
8. Read a tide table and estimate the height between high and low water.
9. Describe how a survey vessel measures the real tide with GNSS and reduces depths to chart datum.
10. Use the Admiralty Tide Tables to work out high and low water at a secondary port, and find tidal information in charts and Pilots.
11. Find the height of tide at a given time, or the time for a given height, and check under-keel clearance.
12. Use tidal stream data to find an estimated position and a course to steer.

How to use it: read the nineteen parts in order, since each builds on the last. Key terms are in bold where they first appear and collected in the glossary. Test yourself with the quiz at the end.

Part 1. What a tide is and why it happens

A **tide** is the regular rise and fall of sea level along the world's coasts, caused mainly by the gravitational pull of the Moon and, to about half that extent, the Sun. As the water rises and falls it also flows, producing **tidal currents** that carry nutrients and sediment landward on the flood and seaward on the ebb.

The starting point is Newton's law of gravitation. Any two bodies attract each other with a force that grows with their masses and falls with the square of the distance between them:

```
F = \frac{G \, m_1 m_2}{R^2}
```

Here m1 and m2 are the **masses** of the two bodies, R is the distance between their centres, and G is the gravitational constant (6.674×10^{-11} N·m²/kg²).

Why the Moon beats the Sun

The Sun is about 27 million times more massive than the Moon, so its overall pull on Earth is far stronger. Yet the Moon raises the bigger tide. The reason is that tides are not caused by the pull itself but by the **difference** in pull across Earth's width. That difference falls off with the **cube** of distance, not the square:

```
F_{tide} \approx \frac{2 \, G \, M \, r}{d^3}
```

M is the mass of the Moon or Sun, r is Earth's radius and d is the distance to the body. Because the Sun is about 390 times farther away than the Moon, cubing that distance cuts its tidal effect by roughly 59 million times, more than cancelling its 27-million-fold mass advantage.

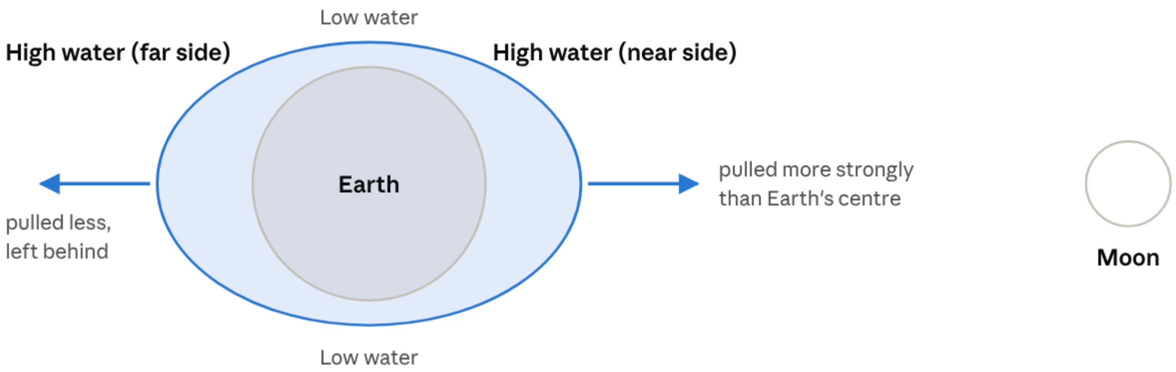
Body	Mass relative to the Moon	Mean distance from Earth	Tide-raising force relative to the Moon
Moon	1	about 384,400 km (239,000 mi)	1
Sun	about 27 million	about 149.6 million km (93 million mi)	about 0.46

The take-away: the Moon is the main tide-maker, and the Sun mostly strengthens or weakens the Moon's tide (Part 4).

Part 2. The two tidal bulges

Most coasts get two high tides a day because the Moon stretches Earth's ocean into two bulges, one facing the Moon and one on the opposite side. Earth turns underneath both bulges each day, so a given coast passes through two highs and two lows.

Two bulges: the near side is pulled more than Earth, the far side less



tidal bulges · not to scale

The Moon's pull weakens with distance, so it is not the same everywhere on Earth:

1. **Near side.** The ocean facing the Moon is about 6,400 km closer to it than Earth's centre. It is pulled toward the Moon slightly more than the solid Earth, so it heaps up into a bulge.
2. **Centre.** Earth as a whole is pulled toward the Moon with an average force. Earth and Moon actually orbit their common centre of mass, which lies inside Earth about 4,700 km from its centre.
3. **Far side.** The ocean on the far side is pulled slightly less than Earth's centre. It is "left behind" as Earth is drawn toward the Moon, forming the second bulge.
4. **In between.** Water is drawn from the sides of Earth toward the two bulges, so those areas have low water.

Tractive forces. *The American Practical Navigator* (Bowditch, Chapter 9) makes this precise. Split the Moon's differential force at each point into a part at right angles to the surface and a part along it. Only the part along the surface, the **tractive force**, moves the water. It is zero directly under the Moon, at the opposite point and on the great circle halfway between them, and it is strongest 45° from those two points. It pushes water towards both points until the heaped-up water balances it. On a water-covered Earth this equilibrium tide would have a range of less than 1 m at the Equator. Real tides are larger in many places because of the basin effects in Part 6. (The Earth–Moon centre of mass lies 0.74 of the way from Earth's centre to its surface.)

Watch the wording. The slides say that "centrifugal force causes the water envelope of the Earth to bulge at the Equator". That describes a different effect: Earth's spin makes the whole planet slightly wider at the Equator, permanently. Tidal bulges come from the difference in the Moon's (and Sun's) pull across Earth, and they point toward and away from the Moon, wherever it is.

Why the two daily tides are often unequal

The Moon's orbit is tilted relative to Earth's Equator, so the Moon spends part of each month north of the Equator and part south of it. This angle is the Moon's **declination**. When the Moon is north or south of the Equator, the bulges are tilted too, and a coast away from the Equator passes through a thick part of one bulge and a thin part of the other. The result is two high tides of different heights, the **diurnal inequality**.

The tide as a very long wave

In this simple model the two bulges are the crests of one wave. Its wavelength is half of Earth's circumference, about 20,000 km, and its crests sweep westward around the planet as Earth turns. In the real ocean the continents block this wave, which is why each basin has its own pattern (Part 6).

Part 3. The tidal cycle

On most coasts high water arrives about 50 minutes later each day, because Earth must turn a little extra to catch up with the Moon. The time between successive high waters is about 12 hours 25 minutes.

The words for each stage

Term	Meaning
High water (high tide)	The highest level reached in one tidal cycle
Low water (low tide)	The lowest level reached in one tidal cycle
Flood	The rising tide, with the current usually running landward
Ebb	The falling tide, with the current usually running seaward
Slack water	The short period around the turn of the tide when the tidal current is weak or zero

Term	Meaning
Mean tide level	The level halfway between mean high water and mean low water
Tidal range	The height difference between a high water and the next low water

Why the lunar day is 24 hours 50 minutes

The Moon orbits Earth in the same direction that Earth spins. Measured against the stars it completes one orbit in about 27.3 days (27 days 7 hours 43 minutes; the slides round this to 27 days 8 hours). Relative to the Sun, new moon to new moon takes 29.5 days, so each day the Moon moves on by about one-thirtieth of a circle.

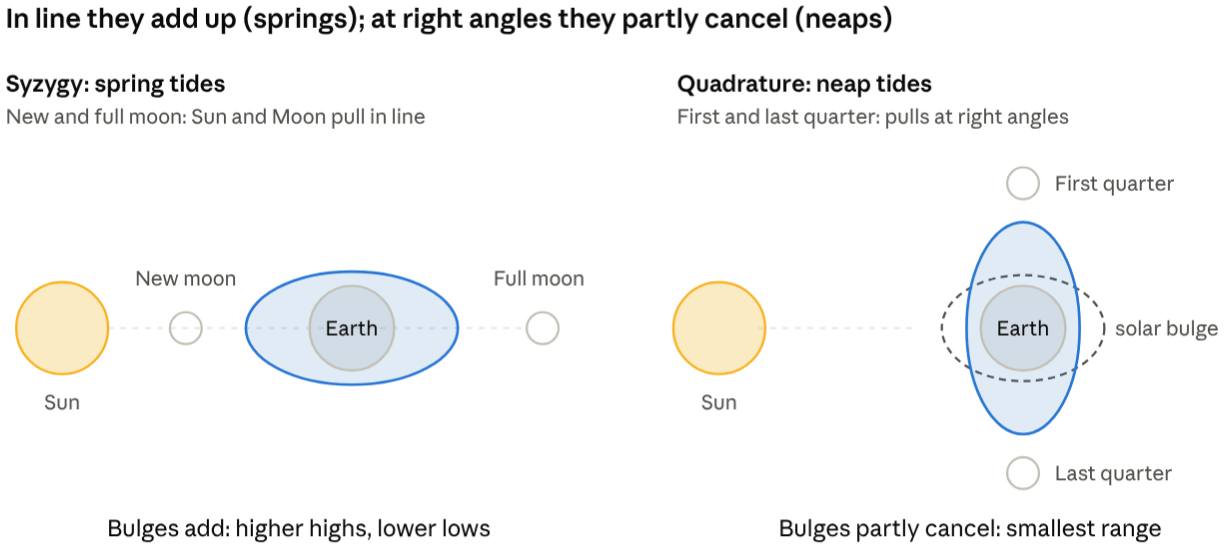
After one full 24-hour turn, a point on Earth is back where it started but the Moon has moved ahead. Earth needs roughly 50 more minutes to bring that point back under the Moon. This **lunar day** of 24 hours 50 minutes is the basic clock of the tide:

- two high waters per lunar day, so one every 12 hours 25 minutes;
- about 6 hours 12 minutes from high water to low water;
- high water about 50 minutes later each day.

The astronomy sets this rhythm, but the local timing and height of the tide depend on the shape and depth of the coast and basin. Two ports a short distance apart can have high water hours apart.

Part 4. Spring and neap tides

The tidal range swells and shrinks on a roughly two-week cycle, because the Sun’s tide alternately adds to and subtracts from the Moon’s. Largest ranges come about every 14.8 days, near new and full moon.



spring and neap tides · not to scale

- **Syzygy** (Greek for "yoked together") is when Sun, Earth and Moon lie in a line, at new moon and full moon. The solar and lunar bulges line up, the tidal forces add, and the result is a **spring tide**: the highest high waters, the lowest low waters and the strongest currents. "Spring" has nothing to do with the season; it comes from the sense of the water "springing up".
- **Quadrature** is when the Moon is at right angles to the Sun as seen from Earth, at first quarter and last quarter. The solar bulge falls where the lunar low water is, so it partly cancels the Moon's tide. The result is a **neap tide**, with the smallest range and the weakest currents.

Because the Sun's effect is about 46% of the Moon's, spring ranges are roughly 1.46 units against neap ranges of about 0.54 units in the simple theory. In practice many ports see springs a day or two after new or full moon, because the ocean takes time to respond.

Distance matters too

The Moon's orbit is an ellipse. At **perigee**, its closest point, the tide-raising force is higher than average; at **apogee**, about two weeks later, it is lower. When a perigee falls near new or full moon, the result is a **perigean spring tide**, often called a king tide. These are among the highest tides of the year and can flood low-lying coasts, especially when combined with onshore wind or low pressure (Part 9). Earth's own orbit has the same effect on a smaller scale: ranges are slightly enhanced around perihelion in early January.

"King tide" is not a scientific term. In Australia it is popularly used for the very high tides of summer around Christmas; the Australian tide notes in the course point out that equally high tides happen in winter, but at night, so fewer people notice them.

More variations and the cycles behind them

- **Priming and lagging.** Between quadrature and new or full moon, the solar tide pulls the combined bulge slightly ahead of the Moon or behind it, so high water comes a little earlier or later than the Moon alone would give.
- **Tropic and equatorial tides.** When the Moon is at its greatest declination north or south, the diurnal inequality is largest (**tropic tides**). When it crosses the Equator, the inequality is smallest (**equatorial tides**).
- **Springs are not simply "more water".** High waters are higher, but low waters are lower too, so there is less water at spring low water than at neap low water.

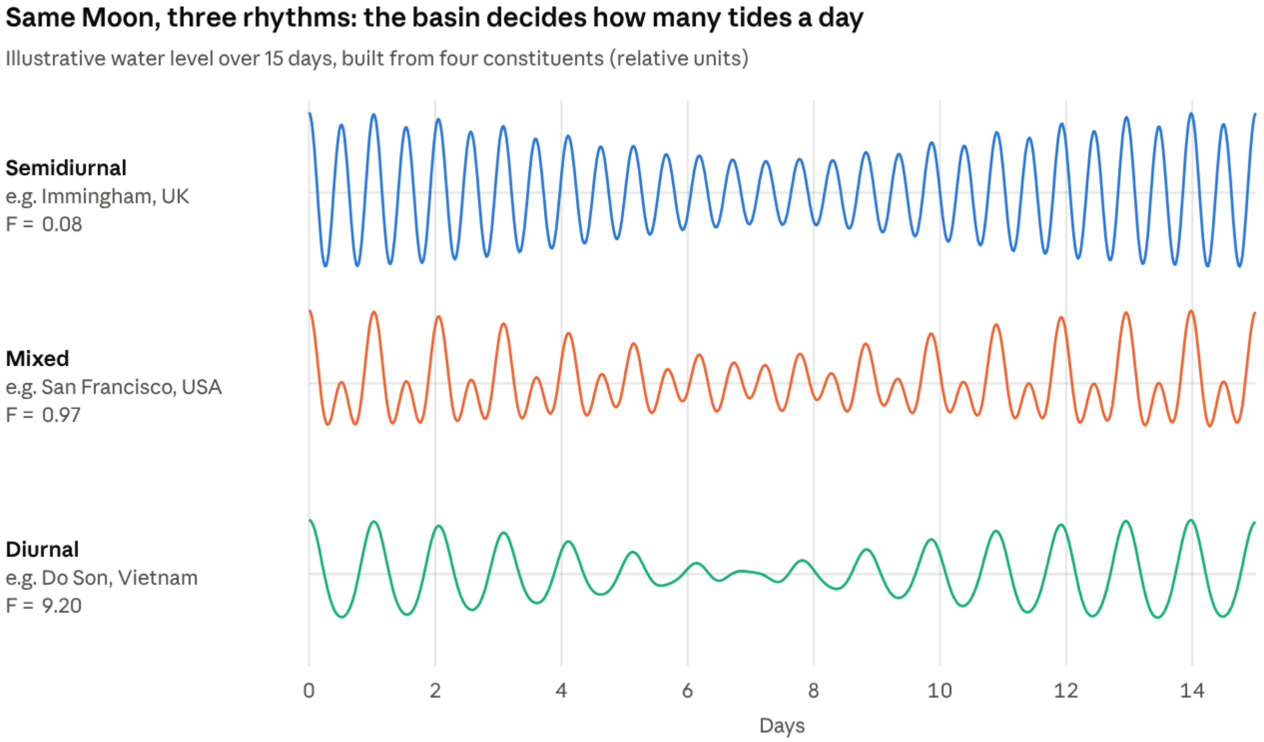
Cycle	Length	Effect on the tide
Tidal cycle	12 h 25 min	One high and one low of a semidiurnal tide
Lunar (tidal) day	24 h 50 min	Two highs and two lows
Synodic month (new moon to new moon)	29.5 days	Spring–neap cycle every half month
Tropical month (declination)	27.3 days	Tropic–equatorial cycle every half month
Anomalistic month (perigee to perigee)	27.5 days	Perigean and apogean tides
Sun's declination and distance	6 months and 1 year	Seasonal changes
Nodal period	18.6 years	Changes in the Moon's greatest declination; the reason datums are averaged over 19 years

The 18.6-year cycle

The Moon's orbit is tilted about 5° to the plane of Earth's orbit, and this tilted plane slowly swings round once every 18.6 years (the **lunar nodal cycle**). As it does, the Moon's greatest monthly declination varies between about 18.3° and 28.6° north and south of the Equator. Years of high declination bring larger diurnal inequalities; years of low declination bring more equal tides. This is why tidal datums are averaged over a full 19-year period, called the **National Tidal Datum Epoch** in the United States.

Part 5. Tidal curves and tide types

A **tidal curve** plots water level against time. Its shape shows which of three tide types a coast has, and that depends mostly on the basin, not on the sky above it.



synthetic curves from M2, S2, K1, O1 · amplitudes chosen for illustration · place names from the slide's figure (Briggs et al., 1997)

Type	Pattern per lunar day	Example from the slides	Other examples
Semidiurnal	Two highs and two lows of nearly equal height	Immingham, east England	Most of the North Atlantic coasts of Europe and North America
Mixed	Two highs and two lows of clearly different height	San Francisco (mainly semidiurnal); Manila (mainly diurnal)	Pacific coast of North America
Diurnal	One high and one low	Do Son, Vietnam	Parts of the Gulf of Mexico

Tide-generating components

The real tide is the sum of many regular waves called **harmonic constituents**, each tied to one motion of the Moon or Sun. Tide predictions are made by measuring each constituent's height and timing at a port, then adding them up for any future date. The slide lists the most important ones, with amplitudes relative to the largest, M2 = 100:

Group	Symbol	Period (solar hours)	Relative amplitude	What it represents
Semidiurnal	M2	12.42	100.0	Principal lunar semidiurnal
Semidiurnal	S2	12.00	46.6	Principal solar semidiurnal
Semidiurnal	N2	12.66	19.1	Larger lunar elliptic: the Moon's changing distance over the month
Semidiurnal	K2	11.97	12.7	Lunisolar semidiurnal: changing declination of Sun and Moon
Diurnal	K1	23.93	58.4	Lunisolar diurnal
Diurnal	O1	25.82	41.5	Principal lunar diurnal
Diurnal	P1	24.07	19.3	Principal solar diurnal
Long period	Mf	327.86 (13.66 days)	17.2	Lunar fortnightly

Two useful links between the tables: spring and neap tides are simply M2 and S2 drifting in and out of step (they come back into step every 14.77 days), and the diurnal inequality comes from the diurnal constituents K1 and O1.

Telling the type from the numbers

Oceanographers classify a coast with the **form factor**, the ratio of the main diurnal to the main semidiurnal amplitudes at that place:

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F = \frac{K_1 + O_1}{M_2 + S_2}
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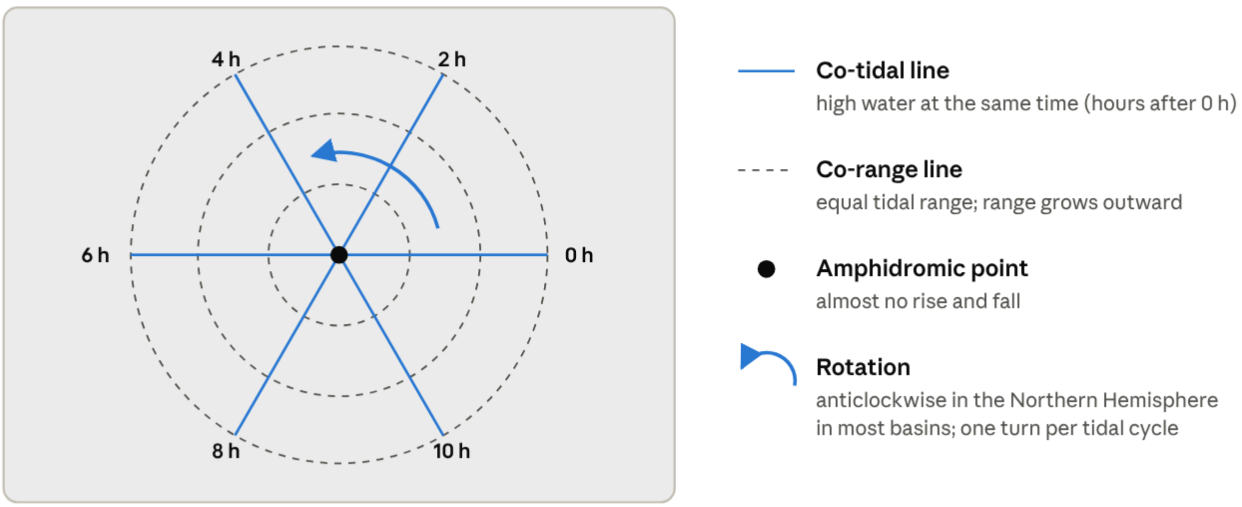
Form factor F	Tide type
below 0.25	Semidiurnal
0.25 to 1.5	Mixed, mainly semidiurnal
1.5 to 3.0	Mixed, mainly diurnal
above 3.0	Diurnal

The F value beside each curve above is worked out from the amplitudes used to draw it.

Part 6. Amphidromic systems

In a real sea the tide does not simply sweep past as two bulges. It circles round points of almost zero tide, called **amphidromic points**, taking one tidal cycle (about 12 hours 25 minutes for a semidiurnal tide) to go all the way round.

The tide wheels round a point of no tide



idealised amphidromic system in a Northern Hemisphere basin · not to scale

How the system forms

1. **The tide enters a basin as a long wave.** Continents stop the bulges travelling freely round the globe, so each ocean or sea responds as a basin of its own.
2. **The wave reflects off the far coast.** The reflected wave travels back and meets the incoming one.
3. **The two waves combine into a standing wave.** Water sloshes from one end of the basin to the other, like water in a bath. The line where the level hardly changes is a **node**; the ends, where it rises and falls most, are **antinodes**.
4. **Earth's rotation turns the node into a point.** The **Coriolis effect** deflects moving water to the right in the Northern Hemisphere. Water flowing one way piles up against one side of the basin, and water flowing back piles up against the other. The high water therefore travels round the basin instead of rocking back and forth, and the nodal line shrinks to a single amphidromic point. A tide wave that travels along a coast in this way, highest against the coast and fading offshore, is a **Kelvin wave**.

Why basin size matters: resonance

A standing wave in a closed basin has a natural period that depends only on its length and depth (Merian's formula):

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T_n = \frac{2L}{\sqrt{g h}}
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L is the basin length, h its mean depth and g the acceleration due to gravity (9.81 m/s^2). For example, a basin 500 km long and 50 m deep has a natural period of about 12.6 hours, very close to the 12.42-hour M2 tide. When a basin's natural period matches the tide, the tide resonates and the range becomes very large. The Bay of Fundy, which is open at one end and so resonates at a quarter wavelength ($T = 4L/\sqrt{gh}$), is tuned close to 13 hours; that is the main reason it has the largest tides in the world.

Real examples

- The North Sea has three amphidromic points, and the tide circles each of them anticlockwise.
- The English Channel is more complex. Its amphidromic point is "degenerate", lying close to or on land in southern England, so the central south coast has a small range and unusual double high waters.
- In the open oceans, amphidromic systems are ocean-wide, and their co-range lines explain why ranges are small at mid-ocean islands but much larger at some continental coasts.

Other local effects (Bowditch)

- **Tidal bores.** In shallow water the trough slows more than the crest, so the front of the rising tide steepens. In a few estuaries it overtakes the low water and runs upstream as a breaking wave: examples are the Petitcodiac River (Bay of Fundy) and the Qiantang River near Haining, China. Bores are strongest at spring tides.
- **Double high and low waters.** Southampton has a double high water and Hoek van Holland a double low water. Both lengthen the stand at high or low tide.
- **Solar tides.** In parts of the South Pacific and Indonesia the solar tide dominates, so high and low water come at about the same clock time every day. At Port Adelaide, Australia, the solar and lunar semidiurnal tides are equal and cancel each other at neaps.
- **Progressive and standing waves.** In the open sea the tide can be a progressive wave, a standing wave or a mix. Be careful when estimating the time of tide at one place from a nearby one. In a river the tide usually travels upstream, so high water comes progressively later further up.

Part 7. Tidal range and tidal datums

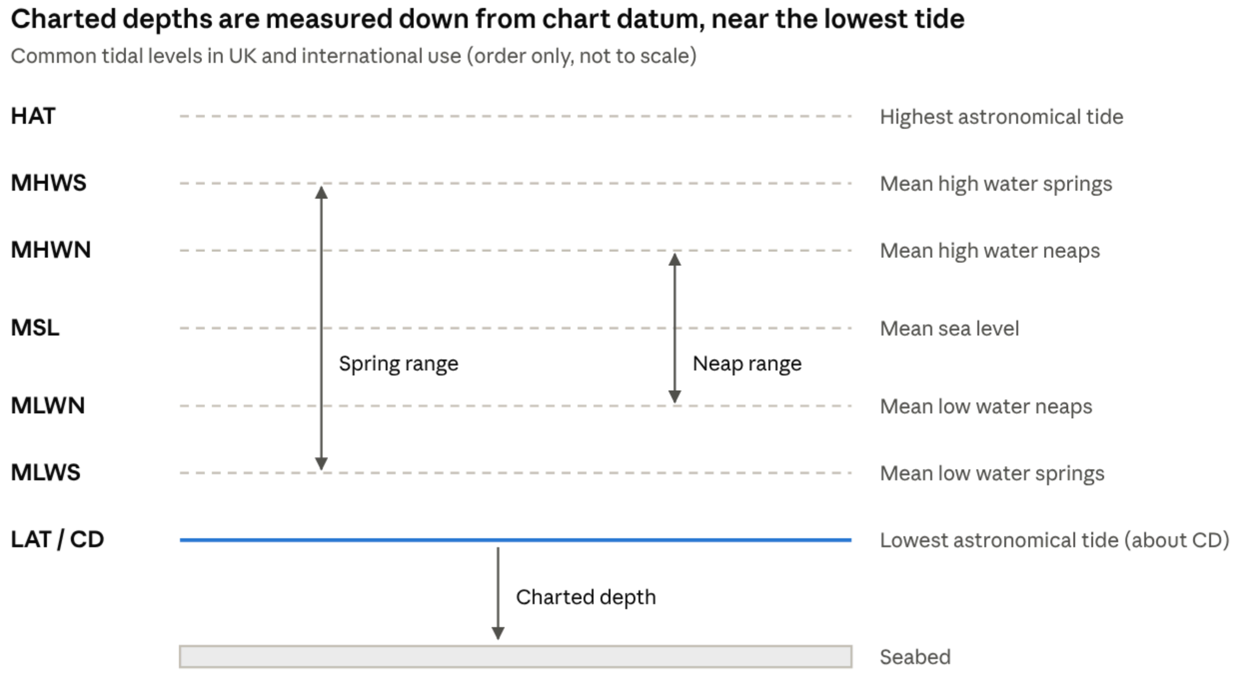
Coasts are grouped by their typical spring tidal range, because range controls how waves, currents and sediment shape the shore. The scheme below comes from Davies (1964).

Class	Spring tidal range	Example from the slides	What the coast tends to look like
Microtidal	less than 2 m	Chesapeake Bay, USA	Waves dominate: long barrier islands, few tidal inlets
Mesotidal	2 to 4 m	Georgia coast, USA	Mixed wave and tide: short "drumstick" barrier islands, many inlets, tidal deltas
Macrotidal	more than 4 m	Bay of Fundy, Canada (up to about 16 m)	Tides dominate: wide tidal flats, salt marshes, funnel-shaped estuaries

Some later schemes split off **hypertidal** coasts (above 6 m), such as the Bay of Fundy and the Severn Estuary in the UK.

Tidal datums

A **tidal datum** is a reference level worked out by averaging the tide at a place over a long period, ideally a full 18.6-year nodal cycle (Part 4). Charts, tide tables and surveys all quote heights and depths against one of these levels.



tidal datums · order only, not to scale

Datum	Meaning
HAT / LAT	Highest / lowest astronomical tide: the highest and lowest levels that can be predicted under average weather. Weather can push the real level beyond both.
MHWS / MLWS	Mean high / low water springs: the average of the high and low waters at spring tides
MHWN / MLWN	Mean high / low water neaps: the same at neap tides
MHW / MLW	Mean high / low water: the average of all high waters and of all low waters
MHHW / MLLW	Mean higher high / lower low water: the average of the higher of the two daily highs, and the lower of the two daily lows. Used where tides are mixed (for example, all US coasts), so that the diurnal inequality is not averaged away.
MSL	Mean sea level: the average of the still-water level over a long period, with the tide averaged out

Datum	Meaning
Chart datum (CD)	The level from which depths on a nautical chart are measured: set so low that the tide rarely falls below it. In the UK and many other countries CD is at or close to LAT; in the US it is MLLW.

More low-water datums (Bowditch). Charts around the world have used other low-water levels as chart datum:

Datum	Meaning
Mean lower low water springs (MLLWS)	Average of the lower of the two low waters on spring-tide days
Tropic lower low water (TcLLW)	Average lower low water when the Moon is near greatest declination; rarely used
Indian spring low water (ISLW)	About the lower low water of a mixed tide when the Moon's greatest declination coincides with new or full moon. Common in the Indian Ocean, where predicted levels are then almost always above datum.
Lowest normal low water	Close to the average of each month's lowest low water, ignoring storm-disturbed tides
Lowest low water	An extremely low datum, near the lowest tide ever observed
Mean sea level	Used where there is little or no tide, such as the Baltic

High-water datums for heights and clearances work the same way. MHW is used on US charts; MHWS, MHHW and tropic higher high water (TcHHW) are all higher. A datum such as "Columbia River Lower Low Water Datum" is a local level kept for engineering. US datums are averaged over a fixed 19-year **National Tidal Datum Epoch**. The chapter quotes 1960–1978; that epoch has since been replaced by 1983–2001.

The practical rule for a navigator: **the actual depth of water = charted depth + height of tide**, where the height of tide comes from the tide table (Part 10).

Part 8. Tidal asymmetry and sediment transport

In shallow estuaries and inlets the rising and falling tides are rarely mirror images, and that lopsidedness decides which way sediment moves. The rule from the slides is short: **sediment moves in the direction of the strongest currents.**

Why the tide becomes lopsided

A tide wave travels faster in deep water than in shallow water. As it enters a shallow estuary, the crest (high water, deeper) moves faster than the trough (low water, shallower). The crest gradually catches up with the trough in front of it, so the rise becomes shorter and steeper than the fall. Friction and the shape of the channels and flats add to the distortion.

If the same volume of water must flow in during a shorter time, the current must run faster. This gives two kinds of system:

Type	What happens	Net effect on sediment
Flood-dominated	The flood lasts less time than the ebb, so flood currents are stronger	Sand is carried landward; the estuary tends to fill in
Ebb-dominated	The ebb lasts less time, or is concentrated in deep channels, so ebb currents are stronger	Sand is flushed seaward; channels stay open

As a rule of thumb (Friedrichs and Aubrey, 1988), estuaries with shallow channels and little tidal-flat area tend to be flood-dominated. Estuaries with deep channels and large intertidal flats tend to be ebb-dominated: the flats fill slowly near high water, then drain late and fast through the channels on the ebb.

The Postma model: how mud climbs the shore

Postma (1961), building on work by van Straaten and Kuenen, explained why fine mud builds up on the landward edges of tidal flats even where currents are symmetrical. Two delays are at work:

1. **Settling lag.** When the flood current slows near high water, a suspended grain does not drop at once. It keeps drifting landward while it sinks, so it lands further inland than the point where the current became too weak to carry it.
2. **Scour lag.** Once settled, a grain needs a faster current to pick it up again than the current that let it settle. On the ebb, the water over that spot never flows quite fast enough, or does so only briefly.

Each tidal cycle therefore moves fine sediment a small step landward. Over many cycles this builds mudflats and salt marshes at the back of estuaries and bays.

Part 9. Wind-driven (meteorological) tides and storm surge

Tide predictions assume average weather. When the weather is not average, the real water level can differ from the predicted one by tens of centimetres, and in storms by metres. These weather-driven changes are called **meteorological tides**, even though they are not caused by the Moon or Sun.

The two weather effects

1. **Air pressure (the inverse barometer effect).** The sea surface behaves like a very slow barometer. Each 1 hPa (1 millibar) drop in pressure below average raises the sea by about 1 cm, and each 1 hPa rise lowers it by about 1 cm. The response follows the average pressure over a wide area, not a local reading. In everyday weather this shifts levels by up to about 0.3 m.
2. **Wind stress (wind set-up).** Wind blowing steadily across the sea drags the surface water with it and piles it up against a downwind coast. Offshore winds do the opposite and lower the level. When the wind drops or changes direction, the piled-up water flows back.

The barometer formula. For a stationary low, Bowditch gives the rise in metres as:

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R_0 = 0.01\,(1010 - P)
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where P is the pressure in millibars (hPa). A low of 980 hPa therefore raises the sea by about 0.30 m. A moving low raises it further:

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R = \frac{R_0}{1 - \dfrac{C^2}{g h}}
```

C is the speed of the low, g is 9.81 m/s^2 and h is the water depth. The rise R comes out in the same unit as R0. The chapter labels R in feet, but the formula only works with consistent units. For example, a 980 hPa low moving at 20 knots (10.3 m/s) over water 30 m deep gives R = 0.30 / (1 − 106/294) ≈ 0.47 m. As the speed of the low approaches $\sqrt{(gh)}$, the speed of a shallow-water wave (17 m/s, or 33 knots, at 30 m), the surge grows very large. This resonance is one reason surges are so dangerous in shallow seas.

When weather overwhelms the tide

On coasts with a weak astronomical tide, such as microtidal Chesapeake Bay, the wind effect can be as large as the tide itself or larger. A steady wind can hold the water high or low for several tidal cycles, so that there is no recognisable high or low water for days.

Storm surges

A **storm surge** is the combination of very low pressure and strong onshore wind during a storm. A **positive surge** raises the sea far above the predicted level; a **negative surge** lowers it, which matters to deep-draught ships. Surges are worst in shallow, funnel-shaped seas, where the water has nowhere to go. The southern North Sea is a classic example: the 1953 North Sea flood, a surge on top of a spring tide, drowned more than 2,000 people in the Netherlands and England.

The practical lessons are that predicted tides are a baseline, not a guarantee, and that the most dangerous combination is a storm surge arriving at a spring or perigean high water.

Part 10. Reading a tide table

A tide table gives the predicted time and height of each high and low water at a port, with heights measured above chart datum. Between those times you estimate the height yourself; the quickest method is the rule of twelfths. (The last slide of the deck, "Tide Tables", is blank, so this part is new.)

A sample day

The port and figures below are invented for practice.

Event	Time (local)	Height above chart datum
High water	04:12	5.8 m
Low water	10:31	1.2 m
High water	16:38	5.6 m
Low water	22:55	1.4 m

Check first: the highs are about 12 h 26 min apart and the range is about 4.5 m, so this is a semidiurnal, mesotidal port near spring tides.

The rule of twelfths

The tide does not rise at a steady rate. It starts slowly, is fastest around mid-tide and slows again near high water. For a roughly six-hour rise or fall, the water moves by 1, 2, 3, 3, 2 and 1 twelfths of the range in successive hours. The table applies this to the afternoon flood (low water 1.2 m at 10:31, high water 5.6 m at 16:38, range 4.4 m, so one twelfth is about 0.37 m):

Hour after low water	Share of range in that hour	Rise in that hour	Height at end of hour
1 (to 11:31)	1/12	0.37 m	1.57 m
2 (to 12:31)	2/12	0.73 m	2.30 m
3 (to 13:31)	3/12	1.10 m	3.40 m
4 (to 14:31)	3/12	1.10 m	4.50 m
5 (to 15:31)	2/12	0.73 m	5.23 m
6 (to about 16:38)	1/12	0.37 m	5.60 m

Half the range comes in the middle two hours. That is also when tidal currents are strongest.

Worked question

A boat drawing 4.5 m wants at least 0.5 m of water under its keel to cross a bar charted at 2.0 m. When can it cross on the afternoon flood?

1. **Water needed:** 4.5 m draught + 0.5 m clearance = 5.0 m.
2. **Height of tide needed:** actual depth = charted depth + height of tide, so height of tide = 5.0 − 2.0 = 3.0 m.
3. **Find it on the table:** the tide passes 2.30 m at 12:31 and 3.40 m at 13:31. It needs 0.70 m of that hour's 1.10 m, about 38 minutes.
4. **Answer:** from about 13:09 until the falling tide drops back below 3.0 m in the evening. Allow a safety margin, because the weather can make the real level lower than predicted (Part 9).

Things to watch

- **Time zone.** Tables are printed in standard time or UTC; add an hour for summer time where it applies.
- **Secondary ports.** Small harbours are predicted from a nearby standard port, with published time and height differences.
- **The rule's limits.** It assumes a smooth six-hour semidiurnal tide. It does not work well on mixed or diurnal coasts, in estuaries with lopsided tides (Part 8) or at places with double high waters (Part 6); use the port's tidal curve or prediction software there.

Part 11. Measuring tides in real time with GNSS

Offshore survey vessels can measure the actual tide as they work, using satellite positioning instead of tide tables. This part summarises the industry guideline **IMCA S 027, *Guidelines on the use of GNSS for tide calculations*** (International Marine Contractors Association, June 2021).

Why measure instead of predict

On land, heights are measured from a fixed surface. At sea, depths are measured from a moving one: the same spot gives different soundings at different times of day. Every surveyed depth must therefore be **reduced**: corrected for the tide and referred to a fixed vertical datum such as chart datum, LAT or MSL. The guideline lists four ways to get the tide correction:

1. Predicted, modelled tides (for example, the Polpred software from the UK National Oceanography Centre).
2. Standard ports, tidal harmonics and co-tidal charts (Parts 5, 6 and 10).
3. Tide gauges on the shore, offshore or on the seabed.
4. **GNSS** (Global Navigation Satellite Systems, such as GPS) on the vessel itself.

Predictions assume average weather, so they miss the pressure and wind effects in Part 9. GNSS measures the real water level, weather included.

The vertical chain

GNSS tide calculation · simplified, not to scale · after IMCA S 027 (2021), Fig…

A high-accuracy GNSS receiver, using **RTK** (Real-Time Kinematic, corrected from a nearby base station) or **PPP** (Precise Point Positioning, corrected from satellite-delivered data), gives the antenna's height above the **reference ellipsoid** to better than 10 cm. To turn that into a tide:

1. Subtract the measured offset from the antenna down to the vessel's **common reference point (CRP)**.
2. Subtract the height of the CRP above the waterline, found from the vessel's **draught**. The draught changes as fuel and cargo are used, so it must be measured with calibrated sensors (a digital draught system, a depth sensor over the side, or a radar looking down at the water), not read from hull markings.
3. Correct for the vessel's pitch, roll and heave, from its motion sensor.

4. The result is the water level above the ellipsoid. Subtract the **separation** between the ellipsoid and the required datum, taken from a transformation model. The remainder is the tide above that datum.

The formula. IMCA S 027 Figure 3, which is also shown in the *GNSS Tide Calculations* video, puts the whole chain in one line:

```
X = \big(Y - (B - C)\big) - Z
```

Symbol	Meaning
X	Tide: the tidal correction to the vertical datum
Y	Height of the CRP above the ellipsoid, from GNSS, corrected for heave, pitch and roll. It is found from the antenna height minus A, the measured offset from CRP to GNSS antenna.
B	Measured distance from the CRP down to the keel
C	Vessel draught, so B − C is the height of the CRP above the waterline
Z	Known separation between the ellipsoid and the vertical datum, from a model such as VORF

A worked example, with invented figures: Y = 42.35 m, B = 9.80 m, C = 5.60 m and Z = 35.10 m. The CRP is 9.80 − 5.60 = 4.20 m above the waterline, so the waterline is 42.35 − 4.20 = 38.15 m above the ellipsoid. The tide is 38.15 − 35.10 = **3.05 m** above the datum.

The guideline names these separation models: **VORF** (UK Hydrographic Office, UK continental shelf), **BATHYELLI** (French continental shelf), the **DTU** global ocean tide and mean sea surface models (Technical University of Denmark), **VDatum** (NOAA, United States) and the global geoid models **EGM2008 / EGM2020**. Some give LAT or chart datum directly; others reach only the mean sea surface, so check which datum the project needs.

Reference surfaces worth knowing

Surface	Meaning
Reference ellipsoid	A smooth mathematical shape of Earth that GNSS heights are measured from

Surface	Meaning
Geoid	The level surface of Earth's gravity field that best matches mean sea level; water would not flow along it
Mean sea surface (MSS)	The average height of the sea above the ellipsoid, from satellite altimetry
Dynamic ocean topography	MSS minus the geoid: the long-term tilt of the sea caused by currents, winds and heating, from about −2.5 m to +1.2 m worldwide

Smoothing the noisy height

GNSS height is the weakest part of a satellite fix: the vertical is typically about 1.5 times noisier than the horizontal. Heights are therefore cleaned with a spike filter and then smoothed. The guideline's main points:

- **Filter length is a trade-off.** A longer window gives a smoother curve but flattens the peaks. Where the tidal range is large, a 20-minute window can clip high and low water so the true extremes never appear.
- **Real time, delayed or processed.** A real-time filter can only use past data. A quasi-real-time filter centres its window and outputs the result half a window late (for example, a 10-minute window output with a 5-minute delay). A post-processed filter uses data on both sides and usually gives the best result.
- **Common filters:** moving average, Savitzky–Golay, polynomial fit, finite impulse response, Gaussian low-pass.
- **Doodson X0 filter.** A special filter that removes the main tidal frequencies and leaves an estimate of mean sea level. It takes a weighted average of 39 hourly values (19 on each side of the centre), with weights of 0, 1/30 or 2/30 that add up to 1, so it needs at least 39 hours of data:

```
y(t) = \sum_{i=-19}^{19} W_i \, x(t-i)
```

Quality checks

The guideline's QA/QC checklist boils down to:

- **Redundancy:** at least two independent GNSS systems, compared throughout the job; antennas high on the mast with a clear sky view.
- **Right heights:** confirm whether the receiver outputs ellipsoidal or orthometric heights; a receiver's built-in geoid may be too coarse.

- **Offsets and sensors:** measure all offsets to the CRP by dimensional control survey; calibrate draught, heading and motion sensors, and set the heave filter for the local swell.
- **Error budget:** add up the expected errors of every component, so that a difference from another source can be judged as acceptable or not.
- **Independent comparison:** check GNSS tides against a second sensor or vessel, port tide gauges, predictions (remembering they ignore weather), earlier surveys reduced to the same datum, or a seabed pressure logger.

The whole workflow at a glance

end-to-end GNSS tide workflow · after the "Precision Blueprint" slide of the GN…

The five stages follow the *GNSS Tide Calculation Standard* slide deck, a visual summary of IMCA S 027. That deck also names the organisations behind the transformation models: VORF (UK Hydrographic Office), BATHYELLI (SHOM, the French hydrographic service), VDatum (NOAA), the DTU models (Technical University of Denmark) and EGM2008/EGM2020 (US National Geospatial-Intelligence Agency). It also stresses that where no real-time draught sensor is fitted, the vessel's squat and settlement must be logged and applied in post-processing.

Part 12. Tides in the Admiralty publications

On the bridge, tidal information comes from a small set of British Admiralty (BA) publications: the tide tables for heights and times, the charts and tidal stream atlases for streams, and the Pilots (Sailing Directions) for local warnings. This part is based on the course reader *Usage of BA Publications (Pilot, Tides etc.)*, which reproduces pages from the **1989** editions. The methods have not changed, but always use the current editions for real navigation.

Which publication tells you what

Publication	Tidal information it gives
Admiralty Tide Tables (ATT) Vol. 1	UK and Ireland and nearby European ports: daily high and low waters at standard ports, time and height differences for secondary ports, mean spring and neap curves, tidal levels (Table V)

Publication	Tidal information it gives
ATT Vols. 2 and 3	The rest of the world: the same for other ports, plus harmonic constants for the Simplified Harmonic Method (NP 159) and daily tidal stream predictions where streams don't follow the local tide
Admiralty charts	A tidal panel with MHWS, MHWN, MLWN and MLWS at key places, and tidal stream tables tied to lettered positions on the chart ("tidal diamonds")
Tidal stream atlases	Hour-by-hour pictures of stream direction and rate, referred to high water at a standard port
Pilots (Sailing Directions)	Local descriptions of streams (rectilinear or rotary, overfalls), surge warnings, sandwaves, under-keel clearance advice

The reader also contains extracts from the Admiralty List of Lights and a compass deviation table; these are not about tides and are left out here.

Rules printed in ATT Vol. 1

- **Time.** Predictions are in the standard time of the port; in the British Isles that is GMT (UT). Add one hour when British Summer Time is being kept.
- **Height.** Heights are in metres above chart datum, which in the British Isles is approximately LAT (Part 7).
- **Air pressure.** A pressure 34 mb away from average changes the level by about 0.3 m (roughly 1 cm per mb, as in Part 9). Low pressure raises the sea; high pressure lowers it.
- **Wind.** Onshore wind makes high waters higher than predicted; offshore wind lowers them. Wind also changes the times of high and low water.
- **Seiches.** A sudden weather change, such as a squall line, can set the water in a harbour oscillating, with periods from a few minutes to about two hours and heights up to a metre or more. Fishguard and Wick are named as harbours where seiches are common.
- **North Sea surges** grow from north to south: a surge that is under 0.9 m at Aberdeen may reach 2.4 m at the Humber and 3.0 m or more on the Dutch coast. Surges at neaps rarely cause trouble; small surges at equinoctial springs can be dangerous. On 31 January 1953 predicted high waters were exceeded by nearly 2.4 m between the Humber and the Thames and by more than 3.0 m in the Netherlands.
- **Negative surges** of more than 0.6 m occur about 15 times a year in the southern North Sea, 3 or 4 of them over 1 m. In 1982 the sea at Southend was 2.3 m below prediction. This matters most to deep-draught ships with small under-keel clearance.

- **Chart tidal panels** show mean levels only. At extreme springs the range can be 20 to 30% larger than mean springs.
- **Springs lag the Moon.** The curve pages note, for example, that at Southampton and Vlissingen "springs occur 2 days after New and Full Moon".

Secondary ports: a worked example

Only a few **standard ports** have full daily predictions. For the many **secondary ports**, ATT Part II gives time and height differences to apply to a named standard port (the most suitable one, not necessarily the nearest). The reader's page for Dover gives these figures:

	HW differences (at Dover HW 0000 & 1200 / 0600 & 1800)	LW differences (at Dover LW 0100 & 1300 / 0700 & 1900)	MHWS	MHWN	MLWN	MLWS
Dover (standard port)	—	—	6.7 m	5.3 m	2.0 m	0.8 m
Richborough (differences)	+0015 / +0015	+0030 / +0030	−3.4	−2.6	−1.7	−0.7

Dover on Monday 6 February 1989 (new moon) had low water 0615, 0.9 m and high water 1057, 6.4 m. For Richborough:

1. **HW time:** the difference is +0015 at both reference times, so 1057 + 15 min = **1112**.
2. **HW height:** Dover's 6.4 m lies between MHWN (5.3) and MHWS (6.7), 1.1/1.4 = 79% of the way to springs. Interpolate the difference: $-2.6 + 0.79 \times (-3.4 - (-2.6)) = -3.2$ m. Richborough HW = 6.4 − 3.2 = **3.2 m**.
3. **LW time:** 0615 + 30 min = **0645**.
4. **LW height:** Dover's 0.9 m is 0.1/1.2 = 8% of the way from MLWS (0.8) to MLWN (2.0). The difference is $-0.7 + 0.08 \times (-1.7 - (-0.7)) \approx -0.8$ m. Richborough LW = 0.9 − 0.8 = **0.1 m**.
5. **Seasonal change in mean level:** listed as negligible for these ports, so no further correction.

When the time differences at the two reference times are not equal, interpolate between them in the same way. ATT Vols. 2 and 3 add one step: subtract the standard port's seasonal correction first, apply the differences, then add the secondary port's seasonal correction. Where the diurnal inequality is large, the differences are given for mean higher and lower high and low waters (MHHW, MLHW, MHLW, MLLW) instead of springs and neaps. A "p" instead of time differences means no standard port fits and the tide must be predicted with the Simplified Harmonic Method (NP 159).

Heights between high and low water: tidal curves

For standard ports ATT Vol. 1 prints **mean spring and neap curves.** The curve gives a **factor** for each hour before or after high water, where HW = 1 and LW = 0:

```
\text{height} = \text{LW height} + \text{factor} \times \text{range}
```

For example, if the curve gives a factor of 0.6 at HW −2 h on a day with LW 0.9 m and HW 6.4 m (range 5.5 m), the height is 0.9 + 0.6 × 5.5 = 4.2 m. Use the spring curve for ranges at or above mean springs and the neap curve at or below mean neaps, interpolating between them otherwise; never extrapolate beyond them.

Curves matter where the rule of twelfths fails (Part 10). The Southampton curve in the reader shows why: its mean spring range is 4.0 m (neaps 1.9 m), and the curve has a stand and a second high water, with the water staying near its high level for two to three hours. ATT Vols. 2 and 3 instead use standard cosine-shaped curves for rise or fall durations of 5 to 7 hours; outside that range, or where shallow-water corrections apply, use NP 159.

Tidal streams and currents

ATT separates **tidal streams**, which are astronomical and predictable, from **currents**, which around the British Isles are mostly caused by weather and can only be estimated.

- **European waters.** Streams are semidiurnal like the tide, so they are predicted from a standard port's high water using the chart's tidal stream tables and the tidal stream atlases. Daily predictions are not published.
- **Elsewhere.** Where streams bear no relation to the local tide, ATT Vols. 2 and 3 give daily times of slack water and of maximum rate with direction. The reader's example is in the Singapore Strait.
- **Rectilinear or rotary.** The Pilot describes each area. Off Lizard Point and Start Point streams are nearly rectilinear (flowing back and forth); off Penlee Point, Plymouth, they are rotary, turning clockwise.
- **Residual currents.** Weak wind-driven currents run eastward up the English Channel and southward along Britain's east coast. A strong gale can drive a temporary current of about 1 knot, which may continue after the wind drops.

Local warnings in the Pilot: Dover Strait

The Dover Strait Pilot extract shows how tide knowledge feeds into passage planning for deep-draught ships:

- Surges can raise the level in the southern North Sea 3 m or more above prediction, or lower it 2 m or more below.

- Sandwaves move into the traffic lanes, for example near Sandettié Bank, so charted depths may not hold.
- Under-keel allowance advice at the time: at least 4 m (IMO, 1982), or 6.5 m (5.7 m near Sandettié) for ships bound for Europoort, according to the Netherlands authorities. Check the current Pilot and Notices to Mariners for today's figures.

Part 13. Tidal calculations step by step

Every tidal calculation answers one of two questions: how much water will there be at a given time, or when will there be a given amount of water? This part collects the methods from the course materials, with their worked examples checked.

tidal terms on a chart · after Yachtmaster Notes "Tidal Terms" slide · not to s…

Term	Meaning
Charted depth	Depth of the seabed below chart datum, printed on the chart
Drying height	Height of a bank above chart datum; underlined on the chart, it is covered only when the tide is higher than it
Height of tide	Height of the sea surface above chart datum at a given moment
Depth of water	Charted depth + height of tide (or height of tide − drying height over a drying bank)
Rise of tide	Height of high water above chart datum
Range	Difference between a high water and the next or previous low water
Under-keel clearance (UKC)	Depth of water − draught
Elevation	Height of a light or object, measured above MHWS on Admiralty charts, not above chart datum

Time for a given height: the rule of twelfths backwards

The *Yachtmaster Notes* deck asks: when will the height of tide at Shoreham reach 2.7 m, with low water 0735, 1.0 m and high water 1346, 6.1 m?

1. Range = 6.1 − 1.0 = 5.1 m. Rise needed = 2.7 − 1.0 = 1.7 m, which is 1/3 of the range, or 4/12.
2. The first two hours give 1/12 + 2/12 = 3/12. One more twelfth is needed, and the third hour gives 3/12, so a third of that hour, 20 minutes.
3. Time = 0735 + 2 h 20 min = **0955**.

Using a standard port's tidal curve

The ATT curve (Part 12) has a height scale on the left, with low-water heights along the bottom and high-water heights along the top, and a time scale in hours before and after high water under the curve.

Height at a given time

1. On the height scale, draw a line from the LW height (bottom) to the HW height (top).
2. Write the HW time in the box under the curve and fill in the hours before and after it.
3. From the required time, go up to the curve, across to the sloping line, then down to read the height.

Time for a given height works the same way in reverse: from the required height go up to the sloping line, across to the curve, and down to read the time. There will usually be two answers, one on the rising tide and one on the falling tide.

The arithmetic behind the drawing is the factor formula:

```
\text{factor} = \frac{\text{required height} - \text{LW height}}
{\text{range}}
```

Find that factor on the curve to get the time, or read the factor at a time and turn it back into a height (Part 12). Use the curve rather than the rule of twelfths whenever the range is large or the curve is distorted.

Secondary ports by interpolation (Admiralty method)

The deck's example uses Calais as a secondary port of Dieppe on 7 August, when Dieppe has HW 1627, 7.4 m.

	HW time differences (Dieppe HW 0100 & 1300 / 0600 & 1800)	LW time differences (Dieppe LW 0100 & 1300 / 0700 & 1900)	MHWS	MHWN	MLWN	MLWS
Dieppe (standard port)	—	—	9.3 m	7.2 m	2.5 m	0.7 m
Calais (differences)	+0043 / +0057	+0105 / +0054	−2.2	−1.3	−0.5	+0.2

Time. Had Dieppe's HW been at 1300, Calais HW would be 1343; had it been at 1800, it would be 1857. The actual time is in between, so interpolate. The fraction of the interval is the same at both ports:

```
\frac{1627 - 1300}{1800 - 1300} = \frac{t - 1343}{1857 - 1343}
```

Working in minutes, 207/300 = 0.69, and 0.69 × 314 min = 217 min, so Calais HW = 1343 + 3 h 37 min = **1720**. The same can be done graphically: plot Dieppe times along the bottom and Calais times up the side, join (1300, 1343) to (1800, 1857), and read across from 1627.

Height. The Calais levels are 9.3 − 2.2 = 7.1 m at MHWS and 7.2 − 1.3 = 5.9 m at MHWN. Interpolate in the same way:

```
\frac{7.4 - 7.2}{9.3 - 7.2} = \frac{h - 5.9}{7.1 - 5.9}
```

This gives h = **6.0 m**. Repeating with MLWN and MLWS gives the Calais LW height of 1.7 m.

Secondary places by ratio (tables using factors)

Some national tide tables, such as the Australian ones in the course notes, give each secondary place a time difference for HW and for LW, a **ratio** (column 9) and a **constant** (column 10) instead of four height differences. The secondary height is:

```
h_{secondary} = h_{standard} \times \text{ratio} \pm \text{constant}
```

The notes' example (16 March) has a standard port with HW 10:33, 2.35 m and LW 04:28, 0.41 m. The secondary place has time differences −0025 (HW) and −0020 (LW), ratio 0.81 and constant +0.04:

	Time	Height
Secondary HW	10:33 − 25 min = **10:08**	2.35 × 0.81 + 0.04 = **1.94 m**
Secondary LW	04:28 − 20 min = **04:08**	0.41 × 0.81 + 0.04 = **0.37 m**

For heights between HW and LW, these tables provide **standard tidal curves**. Each curve is for one range and shows the height above low water for each hour before or after the nearest high water. The curves are cosine-shaped and last 6 h 12 min each side. The example asks for the height at 08:40:

- **Standard port:** 08:40 is 1 h 53 min before HW. The range is 2.35 − 0.41 = 1.94 m, and the curve gives about 1.6 m above LW. Height ≈ 0.4 + 1.6 = **2.0 m**.
- **Secondary place:** 08:40 is 1 h 28 min before HW. The range is 1.94 − 0.37 = 1.57 m, and the curve gives about 1.4 m above LW. Height ≈ 0.4 + 1.4 = **1.8 m.**

The notes print the standard-port addition as "+1.16 m", which is a slip for 1.6 m; only 1.6 m gives their total of 2.0 m. A cosine calculation confirms about 1.5–1.6 m.

When the tide has a different shape

A secondary port is assumed to share its standard port's curve, but that is not always true:

- **Tidal anomalies.** Where the tide reaches a place by two routes round an obstruction, the curve distorts. The best-known case in Britain is the Isle of Wight, which affects the tide between Swanage and Selsey: highs are indistinct, there is often a **double high water**, and the tables always give the higher one.
- **Different curve shapes.** For ports like these, the high water is too flat to time a curve from. Low water is usually better defined, so the ATT curves for these ports are timed from low water instead.

Will we ground? A clearance check

The deck's last height example: a yacht drawing 1.5 m is moored in 3 m of water at 0750 BST on 8 July. Will it ground at low water?

1. **Time:** convert to the table's time (GMT = BST − 1 h) and apply the secondary port's time difference to find the LW time.
2. **Heights:** apply the height differences: HW 4.2 − 0.4 = 3.8 m, LW 1.3 − 0.1 = 1.2 m. The height of tide at the time of mooring is 2.5 m.
3. **Fall to come:** 2.5 − 1.2 = 1.3 m, so the depth at LW is 3.0 − 1.3 = 1.7 m.
4. **Clearance at LW:** 1.7 − 1.5 = **0.2 m**. The yacht stays afloat, just.

Part 14. Tidal streams in navigation

The *Yachtmaster Notes* deck calls tidal streams the second, simpler part of tides: you need the direction (**set**) and speed (**rate**) of the stream to plot where you are and to decide which way to steer.

Where the figures come from

Streams for a whole area are referred to one standard port, such as Dover, Liverpool or Greenock, and to the hours before or after its high water.

Source	How it shows the stream	Accuracy
Tidal stream atlas	One chartlet for each hour from HW −6 to HW +6, with arrows for the set. Numbers such as "11,19" give the rate in tenths of a knot: neaps first (1.1 kn), springs second (1.9 kn).	Fairly coarse
Tidal diamonds	A lettered diamond on the chart, with a table giving set (°T) and spring and neap rates for each hour. In the deck's example, diamond A (51°20′.1N, 1°30′.0E) at HW −3 has set 037°, 1.9 kn springs, 1.1 kn neaps.	More accurate; use the diamond nearest you in the direction you are sailing

Rates between springs and neaps. Interpolate on today's tidal range at the standard port, not on the date. The deck's example has neap and spring rates of 1.1 and 1.9 kn and a day with LW 0.4 m and HW 5.6 m (range 5.2 m). Plotting the range between the port's mean neap and spring ranges gives about **1.7 kn**. As a formula:

```
\text{rate} = \text{neap rate} + \frac{\text{range} - \text{neap range}}
{\text{spring range} - \text{neap range}} \times (\text{spring rate} -
\text{neap rate})
```

Where am I? Estimated position

- **Dead reckoning (DR):** the position from course and distance run through the water alone.
- **Estimated position (EP):** add the tidal vectors for the time run to the end of the water track. The line from the start to the EP is the **ground track**, the third leg of the triangle.
- **Leeway:** a sailing boat going to windward slides sideways, away from the wind. Estimate it by comparing the angle of the wake with the fore-and-aft line, and apply it to the heading to get the **wake course** (water track) before adding the tide.

The deck's worked EP:

1. Fix 50°38′.1N, 01°18′.0E at 1945 BST, 19 June. The yacht sails 8 M on 320° (compass) in a westerly wind with 10° leeway. What is the EP at 2145?
2. **Heading:** 320°(C) = 314°(M) = 310°(T). The westerly wind pushes the boat to the east, so add the 10° leeway: water track **320°(T)**, 8 M.
3. **Tide from diamond H**, interpolated between springs and neaps: HW −5, 213°(T), 1.3 kn; HW −4, 203°(T), 0.9 kn. Lay both hourly vectors off from the end of the water track.

4. **EP:** 50°42′.3N, 01°08′.2E. (A check by calculation gives the same position: 4.2′ north and 9.8′ west of the fix.)

Which way do I steer? Course to steer

course-to-steer construction · after the Yachtmaster Notes "Course to Steer" sl…

1. Draw the ground track from A to the destination B and estimate how long the passage will take.
2. From A, lay off the tidal stream for that time (A to C).
3. From C, swing an arc equal to the distance the boat will sail through the water in that time, to cut the ground track at D.
4. C to D is the **water track**: the course to steer through the water. Allow for leeway by steering that many degrees into the wind.
5. A to D is the distance made good in that time, which gives the **speed made good (SMG)**. The distance to go divided by SMG gives the **ETA**.

Net tide. On a long passage, such as a 12-hour Channel crossing, work out the whole tide for the trip at once. Add up the hourly vectors: the north-going and south-going streams largely cancel. Then steer one course for the whole crossing, which is usually shorter than correcting hour by hour. Use this with caution near traffic separation schemes, which must be crossed on a heading at right angles to the traffic flow.

Part 15. Practice exercises

These 21 exercises come from the course's *Tides exercises* sheet. They use the 1989 Admiralty Tide Tables pages reproduced in the *Usage of BA Publications* reader (from page 85, "Admiralty Tide Tables"), so work them with that reader open. The answers are the sheet's key. For exercises 1–11, every key obeys UKC = depth of water − draught.

Method for every exercise

1. **Convert board time (BT) to the table's time zone.** For example, BT = GMT + 0100 means the ship's clock is one hour ahead of GMT. Dover tables are in GMT, so subtract an hour.
2. **Find the HW and LW either side of that time** at the standard port. For a secondary port, first apply the time and height differences (Parts 12 and 13).
3. **Find the height of tide** from the port's tidal curve, or from the standard curves in Vols. 2 and 3.

4. **Depth of water = charted depth + height of tide.** A negative charted depth is a drying height: subtract it.
5. **UKC = depth of water − draught.** For "when can we pass" questions, work backwards: height of tide needed = draught + required UKC − charted depth, then find the time on the curve.

A. Depth of water and under-keel clearance

No.	Port	Date	Board time	Draught	Charted depth	Depth of water (key)	UKC (key)
1	Flushing (Vlissingen)	8 Nov	GMT+1: 0900	4.2 m	8.7 m	12.4 m	8.2 m
2	St Helier	10 Mar	GMT+1: 0330	3.8 m	5.0 m	5.3 m	1.5 m
3	Southampton	18 Jun	GMT: 1015	2.1 m	−0.4 m (dries)	3.7 m	1.6 m
4	Saint John, N.B.	10 Nov	GMT−4: 0830	6.8 m	12.4 m	20.1 m	13.3 m
5	Beira	19 Oct	GMT+2: 1900	3.1 m	−0.7 m (dries)	4.9 m	1.8 m
6	Plymouth	10 Jan	GMT: 0510	4.6 m	7.4 m	12.1 m	7.5 m
7	Southampton	17 Aug	GMT: 0820	2.5 m	3.8 m	6.1 m	3.6 m
8	Dover	16 Feb	GMT: 1745	4.3 m	7.7 m	11.2 m	6.9 m
9	Beira	18 Oct	GMT+2: 0845	5.1 m	11.3 m	15.8 m	10.7 m
10	Dar es Salaam	19 Aug	GMT+3: 1940	4.3 m	8.9 m	11.3 m	7.0 m
11	Vancouver Harbour	22 Jul	GMT−8: 1820	6.7 m	12.3 m	15.9 m	9.2 m

B. Passing a shoal

No.	Port	Date	Board time	Draught	Charted depth	Required UKC	Question	Key
12	St Helier	20 Apr	GMT+1	8.2 m	4.9 m	2.5 m	ETA 1400: earliest time to pass the shoal	1622
13	Southampton	25 Jun	GMT	4.5 m	4.3 m	2.0 m	ETA 1000: earliest time to pass the shoal	1103

No.	Port	Date	Board time	Draught	Charted depth	Required UKC	Question	Key
14	Dover	28 Jan	GMT	6.1 m fwd, 6.7 m aft	4.6 m	2.0 m	At 0100, 23 M from the shoal: speed needed to pass at the first HW of the day with a 30-minute margin	5.5 kn
15	Vancouver Harbour	29 Aug	GMT−8	4.8 m	3.6 m	2.5 m	Latest time after the second HW of the day to pass the shoal	2005
16	Dar es Salaam	23 Jul	GMT+3	3.8 m	2.7 m	1.5 m	At 0200, 23 M from the shoal: speed to pass as early as possible without delay	6.4 kn
19	Macuse (secondary to Beira)	25 Nov	GMT+2	2.9 m	2.2 m	1.5 m	At 0200, 11 M from the shoal: speed to pass as early as possible with a 30-minute margin	4.3 kn
21	St Peter Port (secondary to St Helier)	20 Mar	GMT	4.2 m	1.6 m	2.5 m	ETA 0200: when can we enter?	0240

For exercise 14, use the deeper (aft) draught of 6.7 m.

C. Secondary ports and soundings

No.	Port (standard port)	Date	Board time	Question	Key
17	IJmuiden (Flushing)	6 Oct	GMT+1	Times and heights of the first HW and LW	LW 0223, 0.2 m; HW 0651, 1.9 m
18	St Malo (St Helier)	4 Mar	GMT+1	Times and heights of the first HW and LW	HW 0406, 9.3 m; LW 1054, 4.1 m
20	Shimabara (Shimonoseki)	21 Jan	GMT+9	At 1130 the echo sounder reads 17.4 m, draught 4.7 m: what is the charted depth?	19.2 m

Exercise 20 works backwards. If the echo sounder measures from the keel, the depth of water is 17.4 + 4.7 = 22.1 m. Subtract the height of tide at 1130 to get the charted depth; the key of 19.2 m implies a height of tide of about 2.9 m.

Part 16. Tides and currents on the chart: Chart No. 1, Section H

Chart No. 1 is the key to the symbols and abbreviations on nautical charts, and Section H covers tides and currents. The version in the course pack is the US edition, pages 33–36. It combines the international (INT 1) symbols, numbered H1–H46, with US **supplementary national symbols**, lettered a–t.

Tidal levels (H1–H17)

These are the levels already explained in Parts 7 and 12, with their standard chart abbreviations:

No.	Abbreviation	Meaning
H1	CD	Chart datum: the datum for sounding reduction
H2 / H3	LAT / HAT	Lowest / highest astronomical tide
H4 / H5	MLW / MHW	Mean low / high water
H6	MSL	Mean sea level
H7	—	Land survey datum (the national height datum used on land)
H8 / H9	MLWS / MHWS	Mean low / high water springs
H10 / H11	MLWN / MHWN	Mean low / high water neaps
H12 / H13	MLLW / MHHW	Mean lower low / higher high water
H14 / H15	MHLW / MLHW	Mean higher low / lower high water
H16 / H17	Sp / Np	Spring tide / neap tide

Tidal levels and charted data (H20)

The H20 drawing shows what each number on a chart is measured from:

- **Charted depths** and **drying heights** are measured from chart datum; the US example uses MLLW as CD.

- **Height of tide** is the sea surface at any time above CD, and the **observed depth (sounding)** is the depth from the sea surface at that moment.
- **Charted heights** of objects and **charted vertical clearances** under bridges and cables are measured from a high-water level (MHW on US charts, as drawn).
- The **charted HW (coast) line** and the **charted LW (drying) line** mark where the shore meets those levels.

As the page itself warns, the planes of reference are not the same on every chart; they are defined in the notes under the chart title. Older British charts, for example, measure elevations of lights from MHWS (Part 13).

Tidal information printed on the chart (H30–H31)

- **H30, tidal levels table:** for each place (with latitude and longitude), heights above datum of MHWS, MHWN, MLWN and MLWS for semidiurnal tides, or MHHW, MLHW, MHLW and MLLW for diurnal and mixed tides.
- **H31, tidal stream table:** for each lettered diamond, the direction (degrees) and rate at springs and neaps (knots), for each hour from 6 hours before to 6 hours after HW at the reference port (Part 14).

Tidal stream and current symbols (H40–H46)

No.	Symbol	Meaning
H40	Arrow with a feathered (barbed) shaft, labelled with the rate, e.g. 2 kn	Flood stream (current) with rate
H41	Plain arrow with the rate	Ebb stream (current) with rate
H42	Arrow with a broken shaft	Current in restricted waters
H43	Arrow with a wavy shaft, with rates and season (e.g. 2.5–4.5 kn, Jan–Mar)	Ocean current with rates and seasons
H44	Wavy tick marks; "tide rips" wording on small areas	Overfalls, tide rips, races
H45	Small curled spirals	Eddies
H46	Magenta diamond with a letter (the "tidal diamond")	Position of tabulated tidal data, e.g. A

US supplementary symbols (a–t)

Letter	Abbreviation	Meaning
a / b / c / e	HW / HHW / LW / LLW	High water / higher high water / low water / lower low water
d	LWD	Low-water datum
f	MTL	Mean tide level
g	ISLW	Indian spring low water: an old low-water datum used in parts of the Indian Ocean and Asia
h / i	HWF&C / LWF&C	High-water / low-water full and change: the interval between the Moon's passage over the meridian and HW (or LW) on days of new and full moon. HWF&C is also called the "vulgar establishment" of the port, an old way of predicting the tide from the Moon.
j	CRD	Columbia River Datum
k	GCLWD	Gulf Coast Low Water Datum
l / m	Str / arrow	Stream / current in general, with rate
n / o / p / q	vel / kn / ht / fl	Velocity (rate) / knots / height / flood
r / s	Filled / open moon face	New moon / full moon
t	Star of numbered arrows	Current diagram: set and rate for each hour of the tidal cycle

Part 17. A spreadsheet tide calculator

The course's *Tides.xls* workbook automates the secondary-port method from Parts 12 and 13. Its **Pasir Gudang** sheet gives correct times and heights, but its local-time curve table puts each height against the wrong time; see the notes below.

What the workbook does

Sheet	Contents
Standart Port	Singapore predictions for 18 June 2026 (GMT, as entered): HW 0018 2.9 m, LW 0718 −0.1 m, HW 1435 2.5 m, LW 1926 1.4 m, next HW 0105 2.9 m. Converted to local time (zone −0800, so local = GMT + 8 h).
Secondary Port II	Pasir Gudang from Singapore, with one time difference for HW (+12 min) and one for LW (−4 min), and height differences +0.6, +0.4, +0.4 and +0.3 m at Singapore's MHWS 2.8, MHWN 2.2, MLWN 1.2 and MLWS 0.6 m
Secondary Port	A template with time differences for four reference times (Part 13), but see the notes below

The heights are found by the same straight-line interpolation as in Parts 12 and 13, extended beyond the spring and neap levels when a prediction lies outside them. The workbook's Pasir Gudang results check out by hand:

Event	Singapore (GMT)	Difference	Pasir Gudang (GMT)	Local time
HW	0018, 2.9 m	+12 min, +0.63 m	**0030, 3.53 m**	0830
LW	0718, −0.1 m	−4 min, +0.18 m	**0714, 0.08 m**	1514
HW	1435, 2.5 m	+12 min, +0.50 m	**1447, 3.00 m**	2247
LW	1926, 1.4 m	−4 min, +0.43 m	**1922, 1.83 m**	0322 (19 June)

For example, 2.5 m lies halfway between MHWN (2.2) and MHWS (2.8), so the difference is halfway between +0.4 and +0.6, which is +0.5 m.

The curve shortcut

To sketch the tide between high and low water, the workbook adds two points in each rise or fall: a quarter and three quarters of the way through in time, each 15% of the range from the nearer high or low water. This is a good shortcut: on a cosine-shaped tide the change after a quarter of the duration is $(1 - \cos 45°)/2 = 14.6\%$ of the range.

Notes before using it

1. **Heights and times swapped in the Pasir Gudang curve table.** The local-time table pairs each high-water time with the low-water height and the reverse. It shows 0.08 m at 0830 (actually HW, 3.53 m) and 3.53 m at 1514 (actually LW, 0.08 m). The HW and LW table above it is correct; the Singapore sheet's curve table is also correct.
2. **The "Secondary Port" template mixes data.** It uses Singapore's predicted heights with spring and neap levels of 13.2, 10.0, 3.5 and 0.9 m, which belong to a port with a much larger range. Its date (29 November 2026) and place name ("Hell") are placeholders, so its results are not meaningful until real data are entered.
3. **"Standart"** in the sheet names is a spelling of "Standard".

Part 18. Tidal currents in depth

Bowditch's Chapter 9 draws a sharp line: **tide** is the vertical rise and fall; **tidal current** is the horizontal flow. The tide rises and falls; the current floods and ebbs. A navigator needs the height and time of the tide for depth, and the time, speed and direction of the current for position, speed and course. The two are related in complicated ways, and the rest of this part explains why.

Rotary and reversing currents

idealised rotary tidal current (current rose) · after Bowditch Fig. 914a

- **Rotary currents** occur offshore, where nothing restricts the flow. The current never stops, but turns through all points of the compass each cycle: clockwise in the Northern Hemisphere, anticlockwise in the Southern, unless local conditions change it. The hourly arrows are called a **current rose**, and their tips trace a **current ellipse**. With a large diurnal inequality there are two ellipses of different size in 24 h 50 min.
- **Reversing currents** occur in rivers, straits and channels. The flow runs one way and then the other, with **slack water** at each turn and the greatest speed, **strength of flood** or **ebb**, about midway between slacks. In a pure semidiurnal current, flood and ebb each last about 6 h 13 min.
- **Hydraulic currents** run in a strait joining two tidal basins, such as the East River, New York. They are driven by the difference in water level between the two ends, and their speed varies roughly with the square root of that difference. They reach strength sooner and stay there longer, so slack water is short.

- **Mixed currents.** As the diurnal inequality grows, one flood (or ebb) can disappear altogether. On the US Gulf coast (Tampa, Galveston) there is only one flood and one ebb a day when the Moon is near greatest declination.

Words used: the **set** is the direction the current flows towards. The **drift** is its speed; "velocity" is often used loosely for speed too. The flood runs towards the shore or upstream; the ebb runs away from the shore or downstream.

Adding a non-tidal current

River flow, ocean currents and wind add a steady current on top of the tide. The tidal pattern stays the same but is shifted by that current. The stream running with it is faster, and the one against it is slower by the same amount. On a reversing current this makes one slack earlier and the next later. If the non-tidal current is stronger than the tidal one, the current never reverses: it only speeds up and slows down. Bowditch's example is a reversing current with a 1.0-knot non-tidal ebb, which has only one flood a day; with about 2 knots there is no flood at all.

Current and tide do not keep step

- **Slack is not the same as high or low water.** That is roughly true only at the seaward entrance and the head of a tidal waterway. In long or narrow-mouthed inlets slack often comes midway between high and low water. Unimak Pass in the Aleutians keeps flooding well after the local high water.
- **Strong currents do not mean a large range.** Currents are weak in the Gulf of Maine, where the tides are large, but strong near Nantucket, where they are small. At any one place, though, the strength of the current varies with the day's range, just as in Part 14.
- **Across a channel.** The current usually turns 30–60 minutes earlier near the shore than in mid-channel. It is strongest mid-channel in a straight reach and near the outside of a bend, and weak or eddying on the inside of the bend.
- **With depth.** In estuaries with fresh water over salt, the flood often starts near the bottom an hour or two before it reaches the surface. It may even flood below while the surface still ebbs. That can act on a deep-draught ship's hull.
- **Extreme examples:** more than 5 knots in the Golden Gate, San Francisco; more than 13 knots in Seymour Narrows, British Columbia.

The US tide and current tables

The US National Ocean Service publishes tide tables in four regional volumes and tidal current tables in two. The chapter describes the older printed editions; today the same data are online. Their structure is the same as the Admiralty tables in Part 12:

Publication	Table 1	Table 2	Table 3	Table 4
Tide Tables	Daily HW and LW at reference stations	Time and height differences, or **ratios**, for subordinate stations	Height of tide at any time (sine-curve method)	Sunrise and sunset (Table 5: conversion to zone time)
Tidal Current Tables	Daily slack and maximum current times and speeds at reference stations	Time differences for slack and for maximum current, and speed ratios, for subordinate stations	Speed at any time between slack and maximum	Duration of slack: how long the current stays below 0.1–0.5 kn (Table 5: rotary currents, Atlantic volume)

For subordinate stations the height difference may be a figure to add, a ratio to multiply by, or both; when both are given, multiply first and then add, as in the Australian method in Part 13. The US Navy's worksheets (OPNAV 3530/40 for height of tide, 3530/41 for current) follow the same order as the method in Part 15: differences, then duration and time from the nearest tide, then range, correction from Table 3, height of tide, charted depth, depth of water, draught and clearance.

Tidal current charts and diagrams. Current charts show the hourly flow over a whole bay at spring tides; a correction factor scales it to other days. A **current diagram**, for example for New York Harbor, plots distance along a channel against time. Drawing a ship's speed line across it shows the current met along the whole passage, and helps choose the best time to start.

Without tables. If only the **mean high water lunitidal interval** (or high water full and change, Part 16) is known, add it to the time of the Moon's meridian passage for an approximate HW. Low water comes about 6 h 12 min before and after.

Part 19. Reading an hourly tide-height table

Tide-prediction software (the screenshot shows its "Heights" tab) can list the predicted height for every hour, which removes the need for the rule of twelfths or a tidal curve. The screenshot covers 13–20 July 2022; the port is not named, and the times are in the software's local time. Plotted, the hours show the whole spring–neap story of Part 4.

Tide_table.jpg (tide-prediction software, "Heights" tab) · hourly heights 13 Ju…

What the numbers show

Day (2022)	Lowest hourly height	Highest hourly height	Approximate range
14 July	−0.1 m (00:00)	2.4 m	2.5 m
15 July	−0.2 m (01:00)	2.5 m	2.7 m
16 July	−0.1 m (02:00)	2.5 m	2.6 m
17 July	0.0 m (02:00)	2.4 m	2.4 m
18 July	0.1 m (03:00)	2.3 m	2.2 m
19 July	0.2 m (04:00)	2.3 m	2.1 m

- **Springs and neaps.** Full moon was on 13 July 2022, close to perigee. The largest ranges come one to two days later (14–16 July), the lag Part 4 describes. By last quarter on 20 July the lows have risen to about 0.4 m and the highs dropped to about 2.2 m: neaps.
- **About 50 minutes later each day.** The morning low moves from about 00:00 on 14 July to 01:00, 02:00, 02:00, 03:00 and 04:00 on the following days: roughly an hour a day in whole-hour steps, matching the 24 h 50 min lunar day.
- **Two tides a day of similar size:** semidiurnal, with only a small diurnal inequality.
- **A lopsided curve.** Each high water is flat for three to four hours (for example 2.3–2.4 m from 06:00 to 08:00 on 14 July), but the fall to low water takes only about four hours. This is the stand and shallow-water distortion described in Parts 8 and 13. At a port like this, the rule of twelfths would be wrong by several tenths of a metre, so use the hourly heights.

The boxed hours: 14 July, 00:00–02:00

Time	Height	Rise in the hour	Rule of twelfths for a 2.5 m range
00:00	−0.1 m	—	—
01:00	0.1 m	0.2 m	1/12 = 0.2 m
02:00	0.8 m	0.7 m	2/12 = 0.4 m

1. **Below chart datum.** At 00:00 the height is negative, so the depth everywhere is 0.1 m **less** than charted (Part 13): a charted 3.0 m patch has only 2.9 m over it.
2. **Slow start, then fast.** The first hour after low water adds only 0.2 m, as the rule predicts. The second adds 0.7 m, nearly twice what the rule gives. The flood here is short and steep, so waiting even one extra hour after low water makes a large

difference.

Worked questions

1. **A vessel needs a height of tide of at least 2.0 m** (the dashed line) to cross a bar on 14 July. When can it cross?
   - Morning: the table first reaches 2.0 m or more at 05:00 (2.1 m) and last shows it at 09:00 (2.0 m). The window is roughly **05:00–09:00**; between hourly values, interpolate or allow a margin.
   - Evening: from 16:00 (2.0 m) until 21:00 (2.1 m), falling to 1.5 m by 22:00. The window is roughly **16:00–21:00**.
2. **Depth over a charted 1.2 m shoal at 15:00 on 15 July?** The height at 15:00 is 1.1 m, so depth = 1.2 + 1.1 = **2.3 m**.
3. **Why can't this table give heights for any port nearby?** It is the prediction for one station. For another place you need that place's own prediction, or secondary-port differences (Parts 12 and 13).

Key terms

Term	Meaning
Amphidromic point	A point of almost no tidal range around which the tide rotates
Chart datum (CD)	The level from which charted depths are measured, at or near LAT
Co-range line	A line joining places with the same tidal range
Co-tidal line	A line joining places where high water occurs at the same time
Declination	The Moon's (or Sun's) angle north or south of the Equator
Diurnal inequality	The difference in height between the two high (or low) waters of one day
Ebb / flood	The falling / rising tide and its current
Form factor (F)	(K1 + O1) / (M2 + S2); classifies a tide as semidiurnal, mixed or diurnal
GNSS	Global Navigation Satellite System (GPS, Galileo, GLONASS, BeiDou)

Term	Meaning
Harmonic constituent	One regular component of the tide, such as M2 or K1
Kelvin wave	A tide wave that travels along a coast, highest against it, steered by Earth's rotation
Lunar day	24 hours 50 minutes: the time for a place to return under the Moon
Macro-, meso-, microtidal	Spring range above 4 m, 2–4 m, below 2 m
Neap tide	Small-range tide at first and last quarter (quadrature)
Perigean spring tide	A spring tide with the Moon near perigee; one of the highest of the year
Quadrature	Moon at right angles to the Sun as seen from Earth
Rule of twelfths	1-2-3-3-2-1 twelfths of the range per hour over a six-hour rise or fall
Slack water	The brief period of little or no tidal current at the turn of the tide
Spring tide	Large-range tide near new and full moon (syzygy)
Storm surge	A rise (or fall) of sea level caused by low pressure and wind in a storm
Syzygy	Sun, Earth and Moon in a line
Tidal datum	A reference level derived from long-term tide observations

Term (Admiralty publications)	Meaning
ATT	Admiralty Tide Tables (Vol. 1: UK and Europe; Vols. 2 and 3: rest of the world)
Standard port	A port with full daily predictions in the tide tables
Secondary port	A port predicted by applying time and height differences to a standard port
NP 159	The Simplified Harmonic Method of tidal prediction, used where differences are not good enough

Term (Admiralty publications)	Meaning
Tidal stream	Horizontal movement of water caused by the tide; predictable
Current	Non-tidal movement of water, mostly caused by weather or river flow
Rectilinear / rotary stream	A stream that flows back and forth / one that turns steadily round the compass
Seiche	An oscillation of water in a harbour or basin, set off by a sudden weather change
Negative surge	Water level well below prediction, caused by weather

Term (calculations and navigation)	Meaning
Charted depth / drying height	Depth below, or height above, chart datum as printed on the chart
Depth of water	Charted depth + height of tide
Under-keel clearance (UKC)	Depth of water − draught
Rise of tide	Height of high water above chart datum
MLHW / MHLW	Mean lower high water / mean higher low water: the other two levels of a mixed tide
Low water datum (LWD)	Mean height of the lower low waters at springs; an older choice of chart datum
Set / rate	The direction a tidal stream flows towards, and its speed
Dead reckoning (DR)	Position from course and distance through the water only
Estimated position (EP)	DR corrected for tidal stream and leeway
Leeway	Sideways drift of a boat away from the wind
Water track / ground track	Path through the water / path over the ground
Speed made good (SMG)	Speed along the ground track
Net tide	The sum of the hourly tidal vectors over a whole passage

Term (Bowditch, Chapter 9)	Meaning
Tractive force	The part of the tide-generating force along the Earth's surface; it moves the water
Stand	The period at high or low water when the level hardly changes
Bore	A breaking wave of the rising tide travelling up a river
Priming / lagging	High water coming earlier / later than the Moon alone would give, because of the Sun

Term (Bowditch, Chapter 9)	Meaning
Tropic / equatorial tides	Tides with the largest / smallest diurnal inequality, when the Moon is at greatest declination / on the Equator
Lunitidal interval	Time from the Moon's meridian passage to the next high (or low) water
Rotary / reversing current	A current that turns round the compass / one that flows back and forth with slack between
Current rose / ellipse	Hourly current arrows / the curve their tips trace
Hydraulic current	A current in a strait driven by the level difference between its two ends
Strength of flood / ebb	Greatest current speed between two slacks
Drift	Speed of a current
Reference / subordinate station	US terms for standard / secondary port

Check your understanding

1. The Sun is 27 million times more massive than the Moon. Why is its tide only about half as big?
2. Why is there a high tide on the side of Earth facing away from the Moon?
3. High water at a port is at 08:00 today. Roughly when will it be tomorrow morning?
4. Which moon phases bring spring tides, and which bring neaps?
5. A port has K1 = 0.30 m, O1 = 0.20 m, M2 = 0.45 m and S2 = 0.15 m. What type of tide does it have?
6. What is found at an amphidromic point, and which way does the tide rotate around it in the Northern Hemisphere?
7. Classify a coast with a spring range of 3 m. Give the example from the slides.
8. In a flood-dominated estuary, which way does sand tend to move, and why?
9. Air pressure falls 20 hPa below average. Roughly how much higher than predicted will the sea be?
10. Low water is 0.8 m at 12:00 and high water is 4.4 m at 18:00. Use the rule of twelfths to estimate the height at 15:00.
11. In a GNSS tide calculation, what two vessel measurements connect the antenna height to the waterline?

12. Why can a long smoothing window be a problem where the tidal range is large?
13. Tide tables for a UK port give high water at 1430. British Summer Time is in force. What time should you use?
14. Dover HW is 6.0 m. For a secondary port the differences are −2.6 m at MHWN (5.3 m) and −3.4 m at MHWS (6.7 m). What is the secondary port's HW height?
15. Why does ATT Vol. 1 print a tidal curve for Southampton instead of letting you use the rule of twelfths?

Answers

1. Tides depend on the difference in pull across Earth, which falls with the cube of distance. The Sun is about 390 times farther away, which more than cancels its extra mass.
2. Earth's centre is pulled toward the Moon more strongly than the far-side ocean, so that water is left behind as a second bulge.
3. About 08:50, since the lunar day is 24 hours 50 minutes.
4. Springs: new moon and full moon (syzygy). Neaps: first and last quarter (quadrature).
5. F = (0.30 + 0.20) / (0.45 + 0.15) = 0.83, so mixed, mainly semidiurnal.
6. Almost no tidal range. The tide rotates anticlockwise (in most basins), once per tidal cycle.
7. Mesotidal (2–4 m); the Georgia coast, USA.
8. Landward: the flood is shorter, so flood currents are faster, and sediment moves with the strongest currents.
9. About 20 cm (about 1 cm per hPa).
10. Range 3.6 m, one twelfth 0.3 m. After three hours: 1 + 2 + 3 = 6 twelfths = 1.8 m, so 0.8 + 1.8 = 2.6 m.
11. The measured offset from the antenna to the common reference point (CRP), and the CRP's height above the waterline from the draught.
12. It flattens the peaks and troughs, so the true high and low water never appear in the result.
13. 1530: the tables are in GMT, so add one hour for BST.
14. 6.0 m is halfway from MHWN to MHWS, so the difference is halfway from −2.6 to −3.4, that is −3.0 m. HW = 6.0 − 3.0 = 3.0 m.
15. Southampton's tide has a stand and a double high water, so it does not follow the smooth six-hour shape the rule of twelfths assumes.

GNSS self-test (from the course's IMCA S 027 study guide)

1. What are the main forces that drive the tides, and which body has the greater influence?
2. How does the barycentre of the Earth–Moon system help create the second tidal bulge?
3. Why do predicted tides sometimes differ from observed water levels?
4. What are the two meanings of mean sea level, in geodesy and in tidal analysis?
5. What is dynamic ocean topography, and what causes it?
6. Why is vertical GNSS positioning harder than horizontal?
7. What is convolution, applied to GNSS heights?
8. What is the trade-off in choosing a filter's time span?
9. How does a processed solution differ from a real-time one?
10. What is the Doodson X0 filter for?

Answers

1. The gravity of the Moon and the Sun. The Moon has about twice the Sun's effect because it is so much closer (Part 1).
2. Earth and Moon turn about their common centre of mass, the barycentre. In that turning frame, the centrifugal effect on the far side outweighs the Moon's weakened pull, so the water there bulges away from the Moon (Part 2).
3. Predictions assume average weather. Air pressure (about 1 cm per millibar) and wind change the real level (Part 9).
4. In geodesy, the height of the mean sea surface above the geoid. In tidal analysis, the still-water level averaged over a month or a year and measured against a benchmark on land.
5. The mean sea surface minus the geoid: a lasting tilt of the sea surface caused by steady currents, winds and heating. Worldwide it ranges from about −2.5 m to +1.2 m.
6. Satellite geometry makes the vertical about 1.5 times noisier than the horizontal, and heave and draught changes add more noise.
7. Fitting a formula to groups of neighbouring data points to smooth them, improving precision without distorting accuracy.
8. A longer span smooths more but flattens the peaks and troughs. Where the range is large, the true high and low water can disappear.
9. A real-time filter uses only past data. A processed solution also uses data after each point, so it is centred better.
10. To damp out the main tidal frequencies and estimate mean sea level. It uses a weighted average of 39 hourly values, 19 on each side of the centre.

Essay topics (no model answers)

- How the alignment of Sun, Earth and Moon and the shape of the sea floor and coasts control the tide.
- How the ellipsoid, the geoid and tidal datums fit together, and why models such as VORF or EGM2008 are needed.
- The methods for measuring a vessel's draught, and why a timestamped draught log matters.
- Comparing filters (moving average, Savitzky–Golay, Doodson X0): cutting noise without losing the signal.
- A complete QA/QC plan for GNSS tide measurement: redundancy, antenna siting and outside checks.

Corrections to the source material

The lesson fixes these points in the original slides and guideline, so the text above will not match them word for word.

Where	Original	Corrected
Slide 1	m1, m2 = "gravitational pull" of each planet	m1, m2 are the **masses** of the two bodies; tide-raising force falls with the cube of distance
Slide 1	Sun "93.5 million miles" away	Mean distance about 93.0 million miles (149.6 million km)
Slide 2	Centrifugal force makes the ocean bulge at the Equator	Tidal bulges come from the difference in the Moon's and Sun's pull across Earth; the equatorial bulge is a separate, permanent effect of Earth's spin
Slide 3	Moon orbits every 27 days 8 hours	27 days 7 hours 43 minutes against the stars; the 50-minute daily delay follows from the 29.5-day cycle of phases
Slide 5	18.6-year variation "because of the Earth's axial tilt from 28.5° to 18.5°"	Earth's tilt stays near 23.4°; it is the Moon's greatest monthly declination that swings between about 18.3° and 28.6° as its 5.1°-tilted orbit precesses over 18.6 years

Where	Original	Corrected
Slide 7	Tn = 2L/(gh)^1/2 is the "point of oscillation"	It is the natural period of a closed basin (Merian's formula)
Slide 8	MLW = "mean low range"; MHWS = "mean high spring tide"	MLW = mean low water; MHWS = mean high water springs
Slide 11	"Tide Tables" slide is blank	Replaced by Part 10
IMCA S 027, glossary	RTK = "Real-time Kinetic"	RTK = Real-Time **Kinematic**

Where	Original	Corrected
Tide calculations between high and low water (PDF), standard port	Adds "+1.16 m" to LW and gets 2.0 m	The curve reading is about 1.6 m (as the sheet's own step 3 says); 0.4 + 1.6 = 2.0 m
Yachtmaster Notes deck, "Variation of Tidal Heights"	Springs at full moon are slightly smaller than at new moon	There is no general rule: which is larger depends mainly on whether that full or new moon falls near perigee
Tides notes (Australian)	Diurnal tide period "about 25 hours"	About 24 h 50 min (one lunar day); 25 hours is a rounding

Where	Original	Corrected
IMCA S 027 Figure 3 (also in the *GNSS Tide Calculations* video)	Y = "HPR corrected CRP height above **geoid**"	Y must be the height above the **ellipsoid**, as the figure's own dimension line shows; otherwise subtracting Z, the ellipsoid-to-datum separation, would be wrong

Where	Original	Corrected
GNSS Tide Calculation Standard deck, equation slide	Y = "GNSS antenna height above the geoid"	In IMCA S 027, Y is the CRP height (antenna height minus offset A), and it must be above the ellipsoid

Where	Original	Corrected
Same deck, Doodson X0 slide	Needs "exactly 39 continuous hours"	IMCA S 027 says at least 39 hours of hourly data
Tides.xls, Pasir Gudang sheet	Curve table pairs HW times with LW heights and the reverse	See Part 17

Where	Original	Corrected
Bowditch Ch. 9, art. 925, moving-low formula	R "in feet" while R0 is in metres	The formula is a ratio, so R has the same unit as R0
Bowditch Ch. 9, art. 912	National Tidal Datum Epoch "presently 1960 through 1978"	Superseded by 1983–2001 (the chapter is from an older edition)
Bowditch Ch. 9, art. 907	"Tsientang Kaing"	Qiantang River (Tsientang Kiang in older spelling), near Haining, China

The tidal-curve figure on slide 4 (from Briggs et al., 1997) is not reproduced; Part 5 uses curves drawn for this lesson instead.

Sources

- *Intro to Tides* (09_Intro_to_Tides.ppt), 11 slides, provided by the author.
- International Marine Contractors Association, *IMCA S 027: Guidelines on the use of GNSS for tide calculations*, June 2021 (PDF provided by the author).
- NOAA National Ocean Service, Tides and Water Levels tutorial: What causes tides, The lunar day, Tidal variations, Types and causes of tidal cycles.
- Standard references cited in the text (not re-checked online for this lesson): Briggs, D. et al. (1997) *Fundamentals of the Physical Environment*; Davies, J. L. (1964) "A morphogenic approach to world shorelines"; Postma, H. (1961) "Transport and accumulation of suspended matter in the Dutch Wadden Sea"; Friedrichs, C. T. and Aubrey, D. G. (1988) "Non-linear tidal distortion in shallow well-mixed estuaries".
- *Usage of BA Publications (Pilot, Tides etc.)*, course reader provided by the author, reproducing extracts from the 1989 Admiralty Tide Tables Vols. 1–3, Admiralty List of Lights, Channel Pilot and Dover Strait Pilot (scanned; text read by OCR and checked against the page images for the figures used).

- C. Walls, *Tides, Heights and Streams* (Yachtmaster Notes, 1999), 31-slide deck provided by the author.
- *Tides* notes and definitions (Australian tide tables, including semidiurnal and diurnal tidal planes), *Example calculation* and *Tide calculations between high and low water*, provided by the author.
- *Tides exercises* (21 exercises with answer key), provided by the author.
- *Chart No. 1*, Section H "Tides, Currents" (US edition, pp. 33–36), provided by the author.
- *GNSS Tide Calculations*, 7-minute video overview of IMCA S 027, provided by the author (reviewed from its slides; the narration was not transcribed).
- *Real-Time Precision: The IMCA GNSS Tide Calculation Standard*, 13-slide visual summary of IMCA S 027, provided by the author.
- *Study Guide: GNSS for Tide Calculations*, provided by the author (its IMCA M 252 dynamic-positioning and RADius sections are outside this lesson's scope).
- *Tides.xls*, secondary-port calculator workbook, provided by the author.
- N. Bowditch, *The American Practical Navigator*, Chapter 9 "Tides and Tidal Currents" (articles 900–940), provided by the author.
- *Tide_table.jpg*: hourly predicted heights, 13–20 July 2022, from tide-prediction software, provided by the author (port not stated).