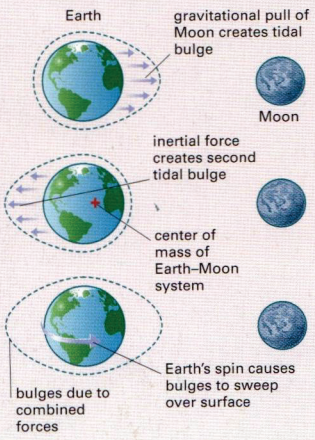
TIDES

TIDES ARE REGULAR RISES AND FALLS in sea level, accompanied by horizontal flows of water, that are caused by gravitational interactions between the Moon, Sun, and Earth. They occur all over the world's oceans but are most noticeable near coasts. The basic daily pattern of high and low tides is caused by the Moon's influence on Earth. Variations in the range between high and low tides over a monthly cycle are caused by the combined influence of the Sun and Moon.

HIGH AND LOW TIDES

Although the Moon is usually thought of as orbiting Earth, in fact both bodies orbit around a common center of mass—a point located inside Earth. As Earth and the Moon move around this point, two forces are created at Earth's surface: a gravitational pull toward the Moon, and an inertial or centrifugal force directed away from the Moon. These forces combine to produce two bulges in Earth's oceans: one toward the Moon, and the other away from it. As Earth spins on its axis, these bulges sweep over the planet's surface, producing high and low tides. The cycle repeats every 24 hours 50 minutes (one lunar day) rather than every 24 hours (one solar day), because during each cycle, the Moon moves around a little in its orbit.

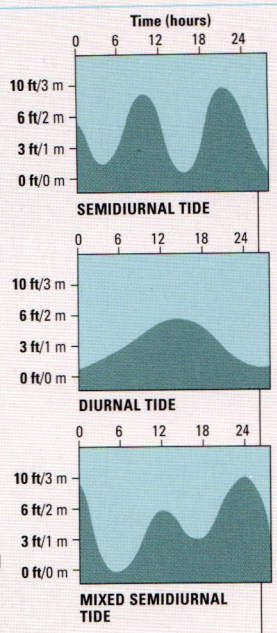


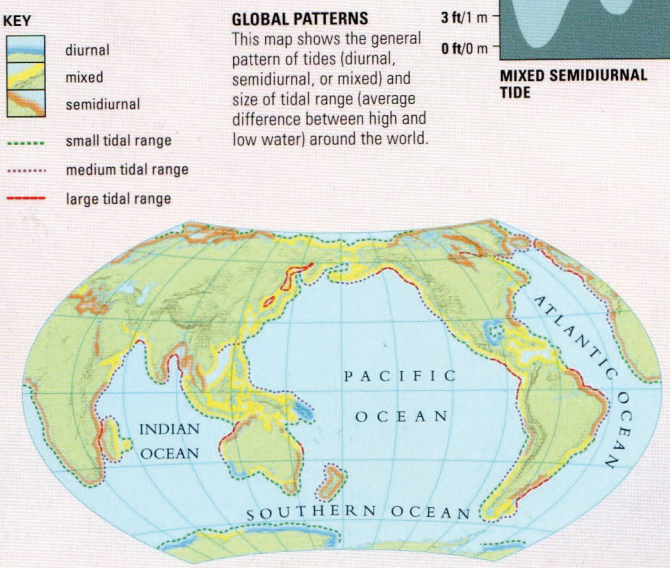
DAILY TIDES
The two ocean bulges caused by the gravitational interaction between Earth and the Moon are shown (much exaggerated) here.

TIDAL PATTERNS

If no continents existed and the Moon orbited in Earth's equatorial plane, the sweeping of the tidal bulges over the oceans would produce two equal daily rises and falls in sea level (a semidiurnal tide) everywhere on Earth. In practice, landmasses interfere with the movement of the tidal bulges, and the Moon's orbit tilts to the equatorial plane.

Consequently, many parts of the world experience tides that differ from the semi-diurnal pattern. A few have just one high and one low tide per day (called diurnal tides), and many experience high and low tides of unequal size (known as mixed semidiurnal tides). In addition, the tidal range, or difference in sea level between high and low water, varies considerably across the globe.

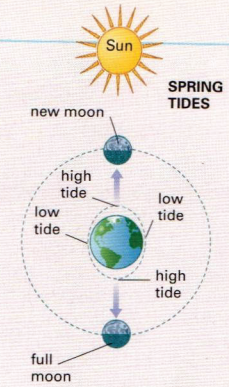




GLOBAL PATTERNS
This map shows the general pattern of tides (diurnal, semidiurnal, or mixed) and size of tidal range (average difference between high and low water) around the world.

INTERTIDAL LIFE

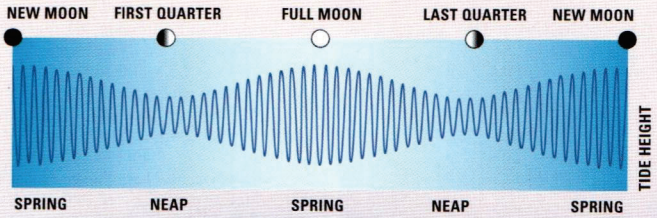
Compared to permanently submerged plants and animals, organisms living in the intertidal zone have to cope with many extra stresses. They need to adapt, for instance, to the problem of becoming dried out (desiccated) when the tide is out. They may also have to endure extreme cold on frosty winter nights and even predation by land animals. Mussels, for example, often have to wait for hours between high tides to feed. At low tide, their shells close tightly to prevent desiccation and to protect against predators.



MONTHLY CYCLE

In addition to the daily cycle of high and low tides, there is a second, monthly, cycle. In this case, the Sun and Moon combine to drive the cycle. As with the Moon, the interaction between Earth and the Sun causes bulges in Earth's oceans, though these are smaller than those caused by the Moon. Twice a month, at the times of new and full moon, the Sun, Moon, and Earth are aligned, and the two sets of tidal bulges reinforce each other. The result is spring tides—high tides that are exceptionally high, and low tides that are exceptionally low. By contrast, at the times of first- and last-quarter moon, the effects of the Sun and Moon partly cancel out, bringing tides with a smaller range, called neaps.

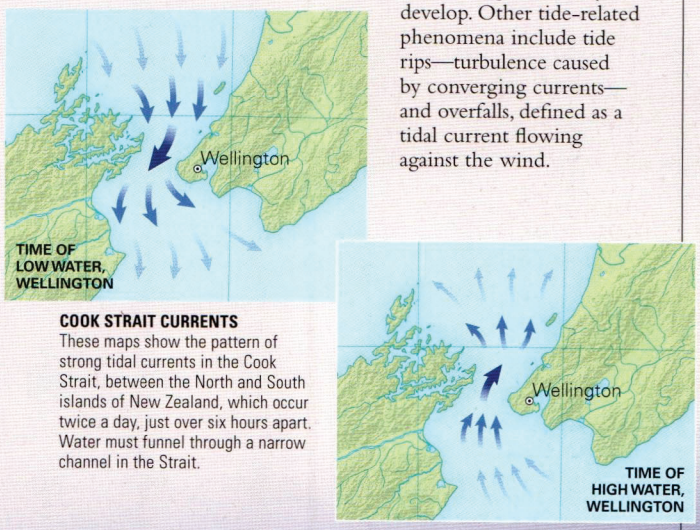
ALTERNATING SPRINGS AND NEAPS
Twice a month (top), the alignment of the Sun, Moon, and Earth creates spring tides. At other times (left), when the Sun and Moon lie at right angles, it creates neap tides. The alternation between springs and neaps can be seen in the 28-day tidal graph shown below.



TIDAL CURRENTS

The vertical variation in sea level that occurs locally with tides can happen only through horizontal flows of water, called tidal currents. Over each daily tidal cycle, the currents generally run fastest about halfway between high and low tide at that location—at intermediate times, they slow ("slack water") and then reverse direction.

The shape of a coast can have a crucial influence on current strength. Bottlenecks to water flow, such as narrow channels and promontories, are often associated with very powerful currents, called tidal races, that develop twice or four times a day. Where the flowing water meets underwater obstructions, phenomena such as whirlpools or vortices (spiraling, funnel-shaped disturbances), eddies (larger, flatter, circular currents), and standing waves may develop. Other tide-related phenomena include tide rips—turbulence caused by converging currents—and overfalls, defined as a tidal current flowing against the wind.



COOK STRAIT CURRENTS
These maps show the pattern of strong tidal currents in the Cook Strait, between the North and South islands of New Zealand, which occur twice a day, just over six hours apart. Water must funnel through a narrow channel in the Strait.

LOW TIDE AT BAMBURGH BEACH
Due to tides, large swaths of coast around the world are alternately covered and uncovered by the sea. This intertidal sandflat in Northumberland, England, has a tidal range averaging about 13 ft (4 m).

MINI-VORTEX
This mini-whirlpool, about 20 ft (6 m) wide and 16 in (50 cm) deep, would be called a "piglet" by experienced Old Sow watchers. Sometimes, several of these small vortices occur, rather than a single large whirlpool.

HUMAN IMPACT

SURVIVING THE OLD SOW

The Old Sow has caused about a dozen fatalities from drowning over the past 200 years. Most of these involved mariners who strayed too close to the whirlpool in small rowboats or sailboats. In recent times, a few people in powerboats have had anxious experiences when their engines have stalled. Experienced mariners advise that if caught in a whirlpool, the priority is to keep the boat on an even keel and avoid getting swamped. Most objects floating in a stable position will eventually spin clear.

ATLANTIC OCEAN NORTHWEST

The Old Sow Whirlpool

FEATURES
Tidal race, small whirlpools, occasional large whirlpool

TIMING
Four times daily

LOCATION Between Deer and Indian Islands, New Brunswick, Canada, and Moose Island, Maine, US

Situated in Passamaquoddy Bay on the US–Canada border, the Old Sow is one of the largest whirlpools in the world, and by far the largest in the Americas. Passamaquoddy Bay is at the lower end of the Bay of Fundy, which is famous for its strong tides. The Old Sow, when it appears, is located at a spot in the bay where various tidal streams flowing through the channels between different islands converge during the ebb tide or diverge during the flood tide. As they flow, these currents encounter underwater obstructions, such as ledges and small seamounts, so as they reach their maximum speed of up to 17 mph (28 km/h), the whole sea surface in this area becomes rough and disordered. Typical disturbances include standing waves, troughs (long depressions in the surface), and "boils" (smooth circular areas where water spouts up from deep below). Occasionally and unpredictably, the Old Sow itself appears, forming a vortex that can be 100 ft (30 m) wide and 10 ft (3 m) deep. More often, one or several smaller vortices, known locally as piglets, appear. As with all tidal disturbances, these phenomena are more powerful during a spring tide, which occurs a day or two after a full or new moon.

COASTAL SETTING
The Old Sow develops between Deer Island (top), Indian Island (right), and Moose Island (foreground).

ATLANTIC OCEAN NORTHEAST

Lofoten Maelstrom

FEATURES
Tidal race and large, weak eddy

TIMING
Four times daily

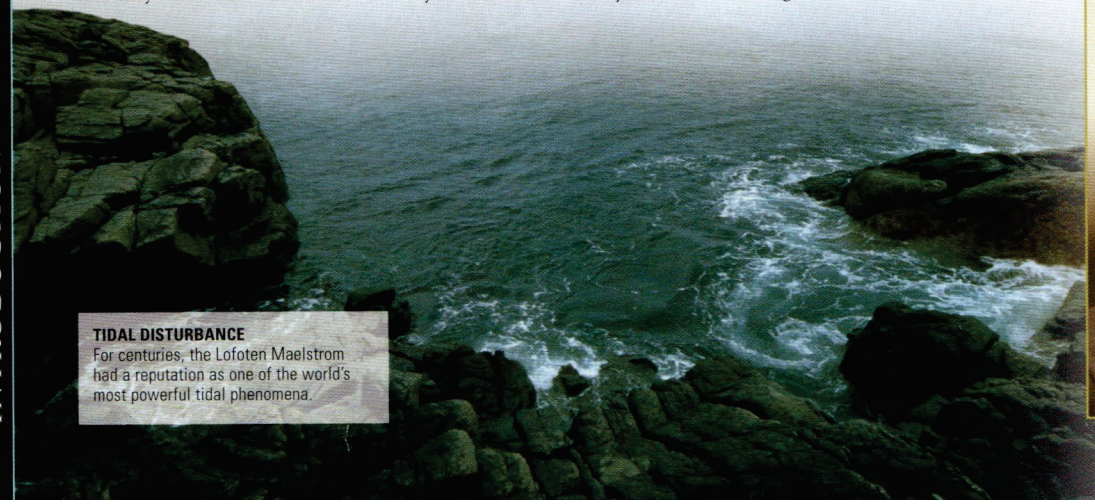
LOCATION Between Lofoten Point and Mosken in the Lofoten Islands, off northwest Norway

Also known as the Moskenstraumen, the Lofoten Maelstrom is a complex pattern of sea-surface disturbances caused by tidal flows of water over a broad, submerged ledge of rock between two of the Lofoten Islands. These flows result from large sea-level differences that develop four times a day between the Norwegian Sea and the Vestfjord on the eastern side of the Lofoten Islands. The word "maelstrom" originates with the tidal phenomena in this area, and is derived from the Nordic word *male*, meaning "to grind." In Norse mythology, the Maelstrom was the result of a large salt-grinding millstone on the floor of the Norwegian Sea, which sucked water into its central hole as it turned. First described by the Greek explorer Pytheas in the 3rd century BC, the Lofoten Maelstrom is marked on many historical charts as an enormous and fearsome whirlpool. In 1997, a detailed study of tidal currents in the vicinity of the island of Mosken found that the reality is somewhat different. Although some strong tidal currents were measured, no obvious large whirlpool, with a vortex, was detected. Instead, the researchers found a weak eddy, about 4 miles (6 km) in diameter, to the north of Mosken. This eddy develops twice a day during the flood tide, when it moves in a clockwise direction, and twice on the ebb tide, when it moves slightly farther north and goes counterclockwise.

PEOPLE

JULES VERNE

The French novelist Jules Verne (1828–1905) made reference to the Lofoten Maelstrom in his tale of undersea exploration, *Twenty Thousand Leagues Under the Sea*. At the end of the novel, Captain Nemo and his submarine, *Nautilus*, are sucked down into the whirlpool, "whose power of attraction extended to a distance of twelve miles," suffering an unknown fate.



TIDAL DISTURBANCE
For centuries, the Lofoten Maelstrom had a reputation as one of the world's most powerful tidal phenomena.

ATLANTIC OCEAN NORTHEAST

Saltstraumen

FEATURES
Tidal race and small whirlpools

TIMING
Four times daily

LOCATION Between Saltenfjord and Skjerstadfjord, northwest coast of Norway

The Saltstraumen tidal race occurs on the northwest coast of Norway and is generally acknowledged to be the strongest and most extreme tidal current in the world. It forms at a bottleneck between the Saltenfjord, an inlet from the Norwegian Sea, and the neighboring Skjerstadfjord: its driving force is a difference in sea level of up to 10 ft (3 m) that develops four times a day between the two bodies of water. The channel at the center of the bottleneck—Saltstraumen itself—is a 2-mile- (3-km-) long strait between two headlands, with a width of just 500 ft (150 m) and a depth that varies from 65 to 330 ft (20 to 100 m).

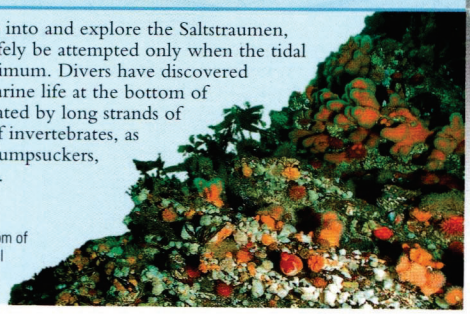
Twice a day, some 105 billion gallons (400 billion liters) of water roar through this strait on the flood tide, reaching maximum speeds of up to 25 mph (40 km/h), as tidal forces act to fill the 30-mile- (50-km-) long Skjerstadfjord. Twice a day, the waters flow out again through the same channel. The flows of water, and associated whirlpools, are equally strong during the ebb as the flood tide. Despite Saltstraumen's ferocity, the channel is regularly used by shipping. For short periods every day, the tidal flows slow almost to a halt, allowing large vessels to pass safely into and out of Skjerstadfjord. Smaller vessels do remain at risk from residual underwater currents during these periods of "slack water," but many experienced pilots still venture out. Saltstraumen offers both interesting opportunities for divers and excellent angling (see panel, below). Incoming tides carry large amounts of plankton through the channel, and fish of various sizes follow.

DANGEROUS WATERS
When the tidal race flows, the spinoff vortices, which can be 33 ft (10 m) across, are capable of pulling objects down to the rocky bottom of the channel.

DISCOVERY

LIFE BENEATH THE WHIRLPOOLS

It is possible to dive into and explore the Saltstraumen, although this can safely be attempted only when the tidal streams are at a minimum. Divers have discovered rich and colorful marine life at the bottom of the channel, dominated by long strands of kelp and a variety of invertebrates, as well as fish such as lumpsuckers, coley, and wolf-fish.



TEEMING WITH LIFE
Invertebrate life at the bottom of the channel includes colorful sponges and anemones.

ATLANTIC OCEAN NORTHEAST

Corryvreckan Whirlpool

FEATURES
Tidal race, standing waves, and whirlpools

TIMING
Twice daily

LOCATION Between the islands of Jura and Scarba, west coast of Scotland, UK

The most famous tidal phenomenon in the British Isles can be found in the Gulf of Corryvreckan. Twice a day on the flood tide, strong Atlantic currents and unusual underwater topography conspire to produce an intense tidal race. As the tide enters the narrow bottleneck at Corryvreckan, currents of up to 14 mph (22 km/h) develop. Underwater, these currents encounter a variety of irregular features on the seabed, including a conical obstruction known as the Pinnacle, which rises to within 95 ft (30 m) of the surface. The steep east face of this obstruction forces a plume of water to the surface, producing whirlpools and standing waves up to 13 ft (4 m) high, and the roar of the rushing water can be heard up to 3 miles (5 km) away. Classified as nonnavigable by the British Royal Navy, the Corryvreckan has caused numerous emergencies and sinkings.

SPIN-OFF VORTEX
In the whirlpool area, massive upthrusts of water occur in pulses, producing vortices that spin away with the tidal flow.

DISTURBED SEA
An area of disturbance begins to develop in the channel north of Jura, seen here with the island of Scarba lying behind it.

ATLANTIC OCEAN NORTHEAST

Slough-na-more Tidal Race

FEATURES
Tidal race with eddies and standing waves

TIMING
Four times daily

LOCATION Between Rathlin Island and Ballycastle Bay, County Antrim, Northern Ireland, UK

The Slough-na-more Tidal Race results from strong tidal flows of billions of gallons of seawater between the Atlantic Ocean and the Irish Sea, via a narrow channel. During spring tides, the tidal stream can attain a speed of 8 mph (13 km/h). Where it passes Rathlin Island, a complex of fast-moving currents, eddies, and standing waves is created. In contrast, the same sea area is usually calm during other phases of the tidal cycle. In 1915, the strength of the Slough-na-more Tidal Race forced the Irish steam coaster SS *Glentow* aground on the Irish coast, and the ship later broke up.

ATLANTIC OCEAN NORTHEAST

Needles Overfalls

FEATURES Tidal race and overfalls

TIMING Four times daily

LOCATION Needles Channel, northwestern coast of the Isle of Wight, England, UK

The Needles Channel is a 5-mile- (7-km-) long stretch of water between a line of chalk sea stacks on one side (the Needles) and an underwater reef on the other. This stretch of water is affected by short, breaking waves (overfalls) at the time of the maximum ebb or flood tide. If the wind is blowing in the opposite direction of the tidal stream, these overfalls are greatly exacerbated, producing an extremely rough sea.

ATLANTIC OCEAN EAST

Garofalo Whirlpool

FEATURES Tidal race, small whirlpools, and overfalls

TIMING Four times daily

LOCATION Strait of Messina, between the northeast coast of Sicily and the south coast of Italy

The Strait of Messina separates the "toe" of Italy from the Mediterranean island of Sicily. It varies in width from 2 to 10 miles (3 to 16 km) and is the site of numerous complex currents and small whirlpools that vary over the tidal cycle and hamper navigation through the Strait. In Italy, the small whirlpools that form are called *garofali*, but in the English-speaking world, the whole system of tidal disturbances is known as the Garofalo Whirlpool.

PACIFIC OCEAN NORTHEAST

Yellow Bluff Tide Rip

FEATURES Tide rip, standing waves, and eddies

TIMING Twice daily

LOCATION San Francisco Bay, California, US

A tide rip is a stretch of rough, turbulent water caused by a tidal current converging with, or flowing across, another current. Thus it differs from a tidal race, which occurs where a tidal stream of water accelerates through a narrow opening in a coast. An example of a tide rip occurs at a place called Yellow Bluff in San Francisco Bay, not far from the bay's entrance, the famous Golden Gate.

Four times a day, strong movements of water occur through the Golden Gate—twice flowing into the bay on the flood tide and twice flowing out on the ebb tide. These currents can reach a speed of up to 5 mph (8 km/h) during spring tides. Inside the bay, the pattern of currents becomes more complex, as they either split (during the flood tide) or converge (during the ebb tide) from different parts of the bay. The currents are also modified by the varying depth of the water around the shoreline, by the shoreline's shape, and by subsurface obstructions. At Yellow Bluff, disturbances to the sea surface are most noticeable during the ebb tide, when the tidal streams are converging, and are characterized by such phenomena as extremely rough, fast-moving water, standing waves, and eddies. The spot is popular with extreme kayakers, who challenge themselves against the strong currents and surf on the standing waves.

PACIFIC OCEAN NORTHEAST

Skookumchuck Narrows Tidal Race

FEATURES Tidal race, small whirlpools, and standing wave on flood tide

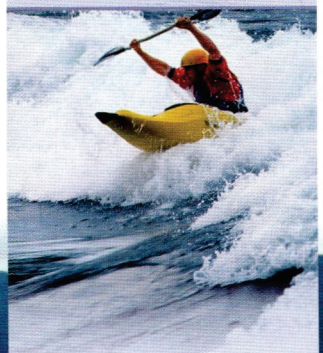
TIMING Four times daily; flood tide twice daily

LOCATION Skookumchuck Narrows, British Columbia, Canada

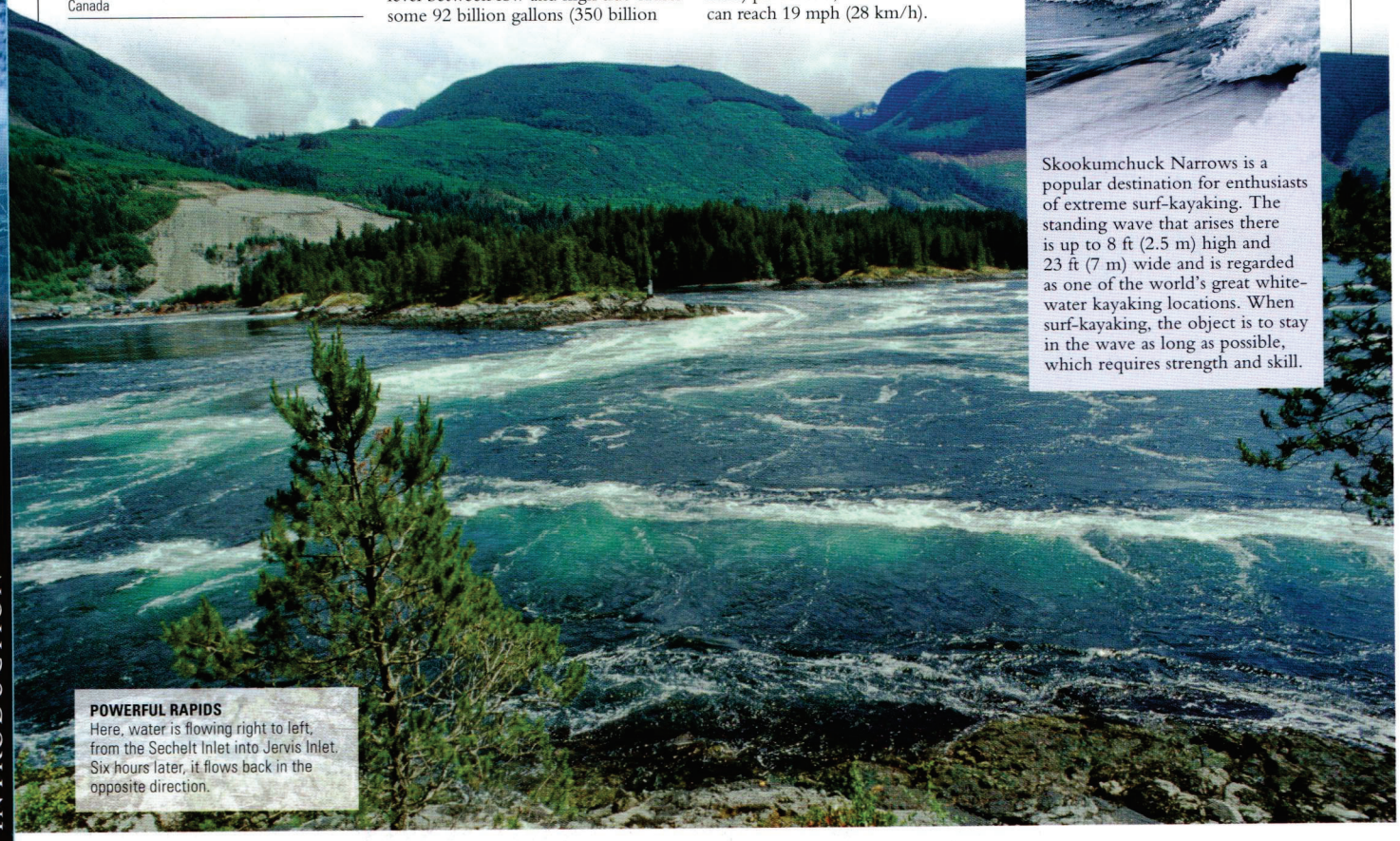
One of the world's most famous tidal races occurs at the Skookumchuck Narrows on British Columbia's Sunshine Coast, not far from Vancouver (*Skookum* is a native American word for "strong" and *chuck* means "water"). Four times a day, there is a strong tidal rush of water through this 1,000-ft- (300-m-) wide channel, which connects two inlets into the coast—the Sechelt and Jervis inlets. A 10-ft (3-m) difference in sea level between low and high tide causes some 92 billion gallons (350 billion liters) of seawater to rush through the gap, creating turbulence and some small whirlpools. On the flood tide, when water is flowing into the Sechelt Inlet (but not the ebb tide, when it flows out), the tidal stream across an outcrop of bedrock in the channel creates a large standing wave—a mound of breaking water that remains stationary at a particular spot on the surface. At its peak, the flow rate is about 4.75 million gallons (18 million liters) per second, and current velocities can reach 19 mph (28 km/h).

HUMAN IMPACT

SURF-KAYAKING



Skookumchuck Narrows is a popular destination for enthusiasts of extreme surf-kayaking. The standing wave that arises there is up to 8 ft (2.5 m) high and 23 ft (7 m) wide and is regarded as one of the world's great white-water kayaking locations. When surf-kayaking, the object is to stay in the wave as long as possible, which requires strength and skill.



POWERFUL RAPIDS
Here, water is flowing right to left, from the Sechelt Inlet into Jervis Inlet. Six hours later, it flows back in the opposite direction.

PACIFIC OCEAN NORTHWEST

Naruto Whirlpool

FEATURES
Tidal race and whirlpools

TIMING
Four times daily

LOCATION Naruto Strait, between the islands of Shikoku and Awaji, Japan

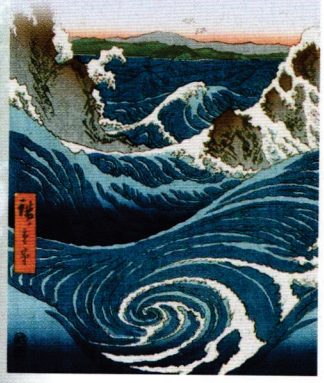
The Naruto is a spectacular system of whirlpools that develops four times a day in a narrow channel separating the island of Shikoku (one of Japan's main islands) from Awaji Island, a much smaller island lying off Shikoku's northeastern coast. The channel, called the Naruto Strait, is one of several that join the Pacific Ocean to the Inland Sea, which is a large body of water lying between Shikoku and Japan's largest island, Honshu. Four times a day, billions of gallons of water move into and out of the Inland Sea through this channel, generated by tidal variations in sea level between the Inland Sea and the Pacific Ocean of up to 5 ft (1.5 m).

The tidal flows can reach speeds of up to 9 mph (15 km/h) during spring tides (that is, twice a month, around the time of a full or new moon). They create vortices up to 65 ft (20 m) in diameter where they encounter a submarine ridge. These vortices are not stationary but tend to move with the current, persisting for 30 seconds or more before disappearing. The whirlpools can be viewed from Awaji Island, from sightseeing boats that regularly negotiate the rapids, or from a ⅘-mile- (1.3-km-) long bridge that spans the Naruto Strait.

HUMAN IMPACT

ARTISTIC INSPIRATION

The Naruto Whirlpool has existed since ancient times. It is mentioned many times in Japanese poetry and is possibly the only tidal phenomenon to feature in a well-known piece of art, namely *Whirlpool and Waves at Naruto, Awa Province*, by the 19th-century Japanese artist Utagawa Hiroshige (a fragment is shown below).



TROUBLED WATERS
A walkway hanging beneath the Oonaruto Bridge, which spans the Naruto Straits, provides an excellent view of the whirlpools below.