Chapter 6
Oceans

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6.1 Origin of the oceans

It all began with the Big Bang. Hundred thousand years after the Big Bang the first electrons and protons hooked up to form Hydrogen (H). At that time, called the recombination period, the temperature was about 3 000 K [9].

Nuclear fusion only lead to Helium (He), heavier elements formed by collision ($T \sim 10^6$ K). Hydrogen runs out in the core of the bigger planets, He starts to form, then Carbon (C). If $T > 3 \cdot 10^6$ K iron can form; happens in Supernova's for instance. During supernova massive stars explode, as a result of instabilities following exhaustion of its nuclear fuel, and matter is scattered around the universe [9].

The distribution of rare gasses favours the idea of direct participation of comets, mixed with mantle-outgassed water, which is poor in deuterium. Terrestial water has a D/H ratio of $D/H \sim 1.56 \cdot 10^{-4}$, while comets have values about 2× that, $D/H \sim 3 \times 10^{-4}$.

Cometary water may have contributed as much as 50% of the Earth's water [8].

These two sources were homogenized by outgassing and mantle recycling in the first 100 Ma (million years). The solar system formed $4\,566 \times 10^6$ a ago, and the Earth's was about 95% completed in the first 30×10^6 a [8].

Ocean's were present 3 billion ($3 \cdot 10^9$) years ago; sediments provide the proof.

6.2 Ocean Circulation

The thermohaline circulation, Figure 6.1, brings warm ocean to northern lattitudes. The temperature in the northern hemisphere is about 10°C warmer due to ocean water heat transport [16].

Since the last glacial maximum (LGM), 30 ka to 19 ka ago, about 50 million km^3 has melted from land based ice sheets, raising the sea level by $\sim$ 130 m [10].

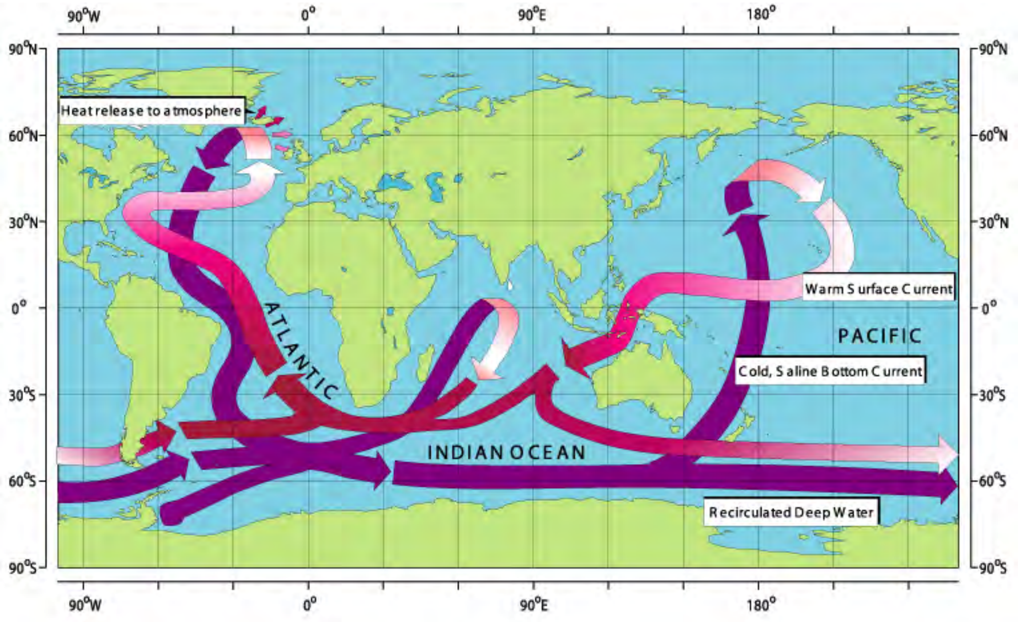

Fig. 6.1 The thermohaline circulation. Data from clivar.org.

6.3 Tsunamis

A tsunami (pronounced tsoo-nah-mee, isl. flódbylgja) is a wave train (series of waves) generated in a body of water by an impulsive disturbance that vertically displaces the water column. Earthquakes, landslides, volcanic eruptions, explosions, and even the impact of cosmic bodies, such as meteorites, can generate tsunamis. Tsunamis can savagely attack coastlines, causing devastating property damage and loss of life.

Tsunamis are unlike wind-generated waves in that they are characterized as shallow-water waves, with long periods and wave lengths. The wind-generated swell one sees at a beach, spawned by a storm out in the ocean and rhythmically rolling in, one wave after another, might have a period of about 10 seconds and a wave length of 150 m. A tsunami, on the other hand, can have a wavelength in excess of 100 km and period on the order of one hour.

As a result of their long wave lengths, tsunamis behave as shallow-water waves. A wave becomes a shallow-water wave when the ratio between the water depth and its wave length gets very small. Shallow-water waves move at a speed v that is equal to the square root of the product of the acceleration of gravity ($g = 9.8 \text{ m s}^{-2}$) and the water depth d,

$$v = \sqrt{g \cdot d}. \tag{6.1}$$

For waves we also have that the velocity is equal to,

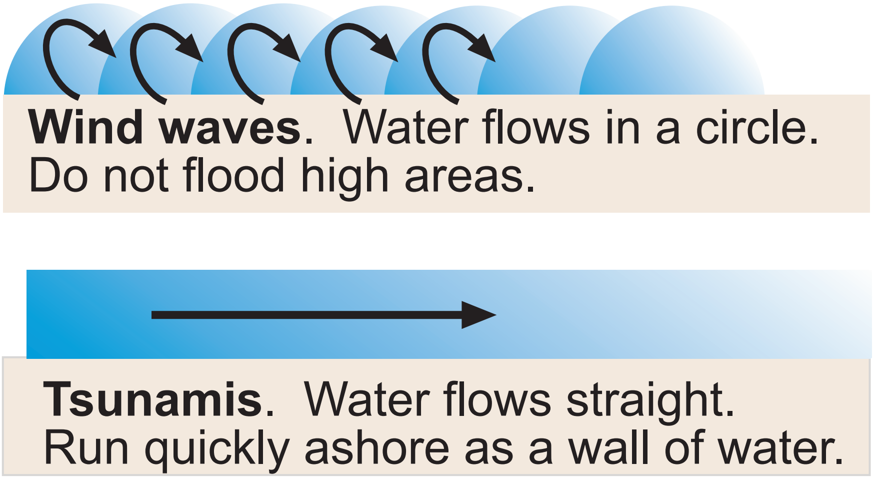

Fig. 6.2 Normal wind-generated waves have a short wavelength and do not travel far inland. Tsunamis on the other hand, have a very long wavelength, and will travel far inland as a wall of water.

$$v = \frac{\lambda}{T}, \tag{6.2}$$

where λ is the wavelength, and T the period.

The energy in a wave is proportional to the wavelength and square of the amplitdue,

$$E \propto \lambda A^2.$$

This allows us to calculate the amplitude of a wave as it reaches shore, if we know the period amplitude A_d in the open (deep) ocean. Then, we can calculate the velocity in both deep water (d_d) and shallow water (d_s), and the amplitude is then given by,

$$\frac{A_s}{A_d} = \sqrt{\frac{v_d}{v_s}}.$$

In the Pacific Ocean, for example, where the typical water depth is about 4000 m, a tsunami travels at over 710 km h^{-1}. Because the rate at which a wave loses its energy is inversely related to its wave length, tsunamis not only propagate at high speeds, they can also travel great, transoceanic distances with limited energy losses.

Tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water. When tectonic earthquakes occur beneath the sea, the water above the deformed area is displaced from its equilibrium position. Waves are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium. When large areas of the sea floor elevate or subside, a tsunami can be created.

A tsunami can be generated by any disturbance that displaces a large water mass from its equilibrium position. In the case of earthquake-generated tsunamis, the water column is disturbed by the uplift or subsidence of the sea floor. Submarine landslides, which often accompany large earthquakes, as well as collapses of volcanic edifices, can also disturb the overlying water column as sediment and rock slump downslope and are redistributed across the sea floor. Similarly, a violent submarine volcanic eruption can create an impulsive force that uplifts the water column and generates a tsunami. Conversely, supermarine landslides and cosmic-body impacts disturb the water from above, as momentum from falling debris is transferred to the water into which the debris falls. Generally speaking, tsunamis generated from these mechanisms, unlike tsunamis caused by some earthquakes, dissipate quickly and rarely affect coastlines distant from the source area.

As a tsunami leaves the deep water of the open ocean and travels into the shallower water near the coast, it transforms. As the water depth decreases, the tsunami slows (see Eq. 6.1). The tsunami's energy flux, which is dependent on both its wave speed and wave height, remains nearly constant. Consequently, as the tsunami's speed diminishes as it travels into shallower water, its height grows. Because of this shoaling effect, a tsunami, imperceptible at sea, may grow to be several meters or more in height near the coast. When it finally reaches the coast, a tsunami may appear as a rapidly rising or falling tide, a series of breaking waves, or even a bore.

Just like other water waves, tsunamis begin to lose energy as they rush onshore; part of the wave energy is reflected offshore, while the shoreward-propagating wave energy is dissipated through bottom friction and turbulence. Despite these losses, tsunamis still reach the coast with tremendous amounts of energy. Tsunamis have great erosional potential, stripping beaches of sand that may have taken years to accumulate and undermining trees and other coastal vegetation. Capable of inundating, or flooding, hundreds of meters inland past the typical high-water level, the fast-moving water associated with the inundating tsunami can crush homes and other coastal structures. Tsunamis may reach a maximum vertical height onshore above sea level, often called a runup height, of 10, 20, and even 30 meters.