Understanding Sea Levels

Reference is frequently made to sea level and rising sea levels in the teaching of Geography. However, sea level is a complex phenomenon that varies in the open ocean as well as along coastlines. It is important that students can distinguish between ocean sea level and relative sea level along coastlines and the causes and consequences of changes in each.

Understanding the complexities of sea level will assist students to understand variations in the environmental challenges they study throughout years 11 and 12 in topics such as Biophysical Interactions e.g. coastal erosion, saltwater seepage into coastal aquifers and sinking coastal cities. Many Megacities and Ecosystems at risk are impacted by relative sea level change that can be contributed to many causes, including climate change. Editor

WHAT DETERMINES THE LEVEL OF THE SEA?

Retrieved and adapted on 13 August 2020 from *Sea Level 101. What determines the level of the sea?* https://climate.nasa.gov/blog/2990/sea-level-101-what-determines-the-level-of-the-sea/

Did you know?

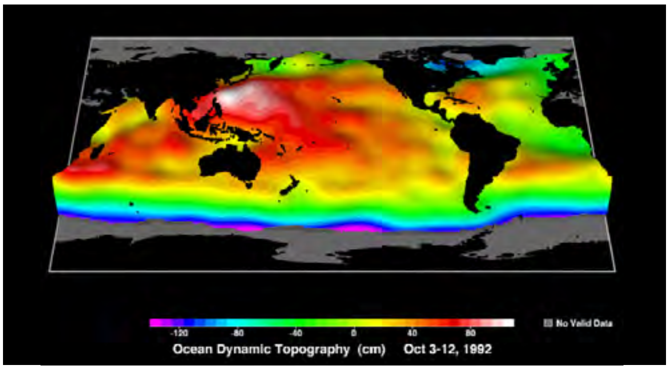
- Even in the absence of waves the ocean is not flat.
- Ocean topography is used to determine the speed and direction of ocean currents in the same way air pressure is used to calculate the speed and direction of winds
- Ocean currents flow around ocean hills and valleys, much like wind blows around areas of high and low pressure.
- Ocean topography can only be seen from space
- The ocean stores energy from the sun and moves it around the planet via currents

Waves in the bathtub

Most of the time, Earth's ocean looks pretty darn flat to those of us here on the ground, like the water in a bathtub. If you're on a boat at sea, the only topography you're going to notice on the ocean is waves. Generated by the friction between wind and water, wind waves range from tiny ripples on a calm sea to storm-generated monsters that can tower more than 30 meters high. Some wind waves are generated locally. Others, called swells, which result from winds that blew somewhere else in the past, travel across the ocean surface.

But even in the absence of waves, it turns out the ocean isn't really flat at all. It has hills and valleys just like land surfaces do, though they're relatively small — up to about 2 meters high.

The ocean's "dynamic" topography tells oceanographers the speed and direction of ocean currents in the same way that maps of atmospheric pressure are used by meteorologists to calculate the speed and direction of winds. It reveals the height of the ocean relative to the geoid, a surface where gravity is always uniformly pointed downward.



The dynamic ocean topography shown in this map varies by about 2 meters between its highest and lowest places. The colour scale corresponds to relief in centimetres. The vertical scale is exaggerated to illustrate the three-dimensional perspective of the topography. Credit NASA/JPL-Caltech

Factors influencing ocean topography

These small variations in ocean surface topography are influenced by many factors, including the temperature of the water, how much salt it contains (its salinity), the pressure of the atmosphere above the ocean surface, and ocean currents.

Ocean currents

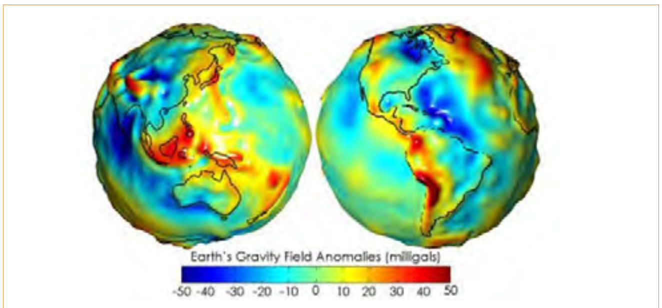
Currents move ocean waters around our planet over long distances, primarily in a horizontal direction, reshaping the ocean's surface and causing it to tilt. They're generated by various forces, including winds, breaking waves, ocean temperature, salinity, and a phenomenon known as the Coriolis effect (which causes water and wind to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere). Currents flow around the ocean's hills and valleys, much like wind blows around areas of high and low pressure in our atmosphere.

Ocean currents happen in the open ocean and generally don't have a big impact on coastlines, with a few major exceptions, such as the Gulf Stream in the Atlantic Ocean along the U.S. East Coast and a similar Pacific Ocean current off the coast of Japan called the Kuroshio, which transports water northward up Japan's east coast and then due east. As our planet warms, it affects wind patterns that drive most of these currents, changing them.

Visualization of the Gulf Stream stretching from the Gulf of Mexico to Western Europe. Credit: NASA's Scientific Visualization Studio

Earth's geoid

While all of these factors are important drivers of ocean surface topography, there's an even larger force working to shape the ocean: changes in Earth's geoid. The geoid is the shape that Earth's ocean surface would take if the only influences acting upon it were gravity and Earth's rotation. Changes in the solid Earth affect Earth's gravitational field, causing the height of Earth's geoid to vary by up to 100 meters around the globe. For example, in places where Earth's crust is thick and dense, the gravitational pull causes extra water to pile up. In addition, the shape of the geoid is partly determined by geologic features on the floor of the ocean, including seamounts (underwater mountains) and valleys, which pull the water due to the force of gravity.

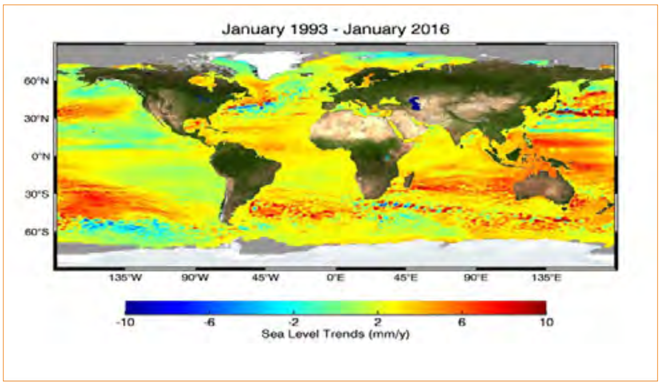


Measuring ocean topography: How and Why

Topographic features on the open ocean can only be seen from space, by specialised instruments called altimeters that precisely measure the height of the ocean surface. Since 1992, NASA has partnered with other U.S. and European institutions on multiple satellite missions to map ocean surface topography.

Measuring ocean surface topography allows us to understand ocean circulation (how our ocean stores energy from the Sun and moves it around our planet), accurately track changes in global sea level, and understand how the ocean joins forces with Earth's atmosphere to create our weather and climate, including phenomena such as El Niño and La Niña and weather patterns such as hurricanes and other storms.

Trends



For nearly 30 years, satellite altimeters have measured the sea surface height of our ever-changing ocean. This image shows the 23-year trend of rising seas across the globe from 1993 to 2016. Credit: NASA/JPL-Caltech

A look at a current map of trends in the nearly 30-year satellite record of global ocean surface topography reveals clear regional differences across the globe, with variations of up to 20 centimetres of sea level rise and fall from one place to another.

"Most of these 20–30 cm changes in sea level on the open ocean are cyclic, from natural things like El Niño and La Niña, or ocean currents speeding up or slowing down," he said. "They've always been part of the story and always will be. But what really matters to people at the coast are long-term changes in their relative sea level – that is, the height of the ocean relative to the land. Those are caused by the overall rise due to global warming, and the movement of the land. And both of those are here to stay."

LEFT: If our ocean had no tides or currents, the sea surface would assume the shape of the geoid. These "gravity anomaly" maps show where Earth's gravity field differs from a simplified Earth model that is perfectly smooth and featureless. Areas coloured yellow, orange or red are areas where the actual gravity field is large, such as the Himalayan Mountains in Central Asia (top left of the left-hand globe).

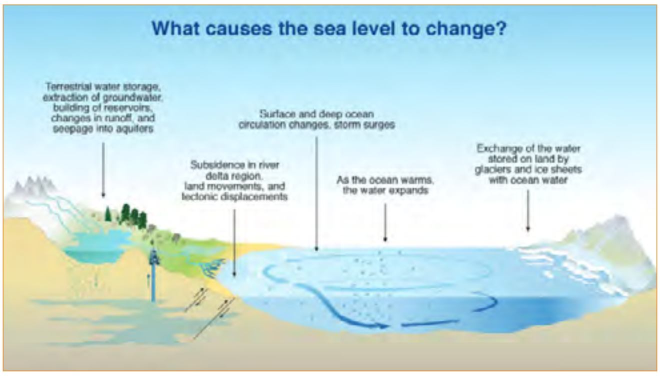
ALL SEA LEVEL IS 'LOCAL'

Retrieved and adapted on 13 August 2020 from *Sea level 101: All sea level is local* – https://climate.nasa.gov/blog/3002/sea-level-101-part-two-all-sea-level-is-local/

Did you know?

- Global sea level rise has multiple causes
- Sea level rise is local and relative
- Relative sea level rise affects coasts
- There are natural and human causes of relative sea level rise

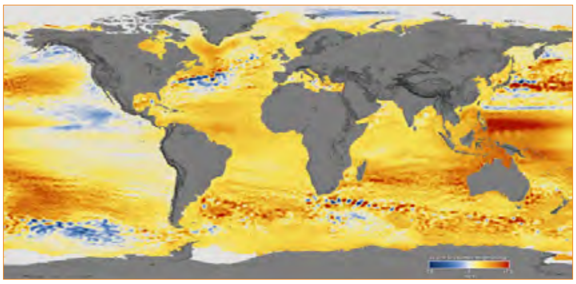
Global sea level rise is complex. To begin with, it has multiple causes, including the thermal expansion of the ocean as it warms, runoff of meltwater from land-based ice sheets and mountain glaciers, and changes in water that's stored on land. These factors combine to raise the height of our global ocean about 3.3 mm every year. That rate is accelerating by another 1 mm per year every decade or so.



Factors that contribute to sea level change. Credit: Intergovernmental Panel on Climate Change 2001

Uneven sea level rise and impacts

Another factor that makes sea level rise complex is that it's not uniform around the globe. If you look at a global map of sea level rise, you'll find it's happening rapidly in some places and more slowly in others. This means that although sea level rise affects coastal areas all over our ocean planet, some regions feel its effects sooner and more severely than others. This is reflected in future projections of sea level rise, with many cities in Asia expected to be among the hardest hit localities. Here in the United States, cities expected to see the worst impacts include New York, Miami and New Orleans, to name but a few.



Total sea level change between 1992 and 2014, based on data collected from satellites. Credit: NASA's Scientific Visualization Studio

Indeed, at any given place and time around our planet, sea level rise varies. But why is that? It turns out that when it comes to sea level rise, it's all local. And it's all relative

Factors causing relative sea level changes

"Relative sea level" **refers to the height of the ocean relative to land along a coastline.**

Common causes of relative sea level change include:

- Changes due to heating of the ocean, and changes in ocean circulation
- Changes in the volume of water in the ocean due to the melting of land ice in glaciers, ice caps, and ice sheets, as well as changes in the global water cycle
- Vertical land motion (up or down movements of the land itself at a coastline, such as sinking caused by the compaction of sediments, or the rise and fall of land masses driven by the movement of continental or oceanic tectonic plates)
- Normal, short-term, frequent variations in sea level that have always existed, such as those associated with tides, storm surges, and ocean waves (swell and wind waves). These variations can be on the order of meters or more.

Thermal expansion

When you heat up water, it expands and takes up more space. How much it expands depends on how deep the warming occurs as well as the temperature of the water to begin with. For example, in Earth's tropics, a 1-degree Celsius warming in the temperature of the top 100 metres of the ocean raises sea level there by about 3 centimetres. This thermal expansion of the ocean is responsible for between one-third and one-half of the overall global sea level rise observed over the last two decades. Because Earth's ocean isn't warming at the same rate everywhere, it results in regional differences in relative sea level rise, with areas that are warming faster seeing faster sea level rise.

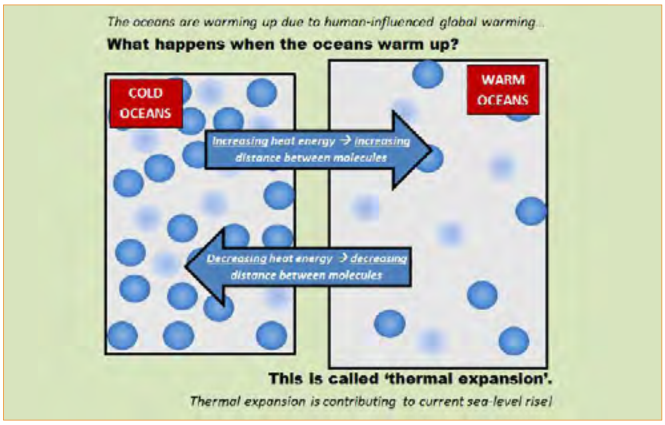
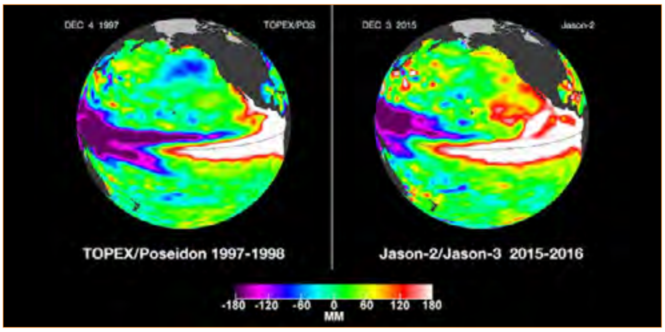


Diagram explaining the concept of thermal expansion of the ocean. Credit: Roseanne Smith

Circulations

Changes in ocean circulation also contribute to regional sea level differences. For example, in the United States, El Niño, a cyclical, naturally occurring ocean circulation pattern of warming and cooling can temporarily raise relative sea level along the West Coast by more than 30 cm for up to a couple of years. Similarly, along the U.S. East Coast, the speedup or slowdown of the major ocean current known as the Gulf Stream can temporarily add or subtract as much as 5 centimetres (of sea level height to local coastlines.



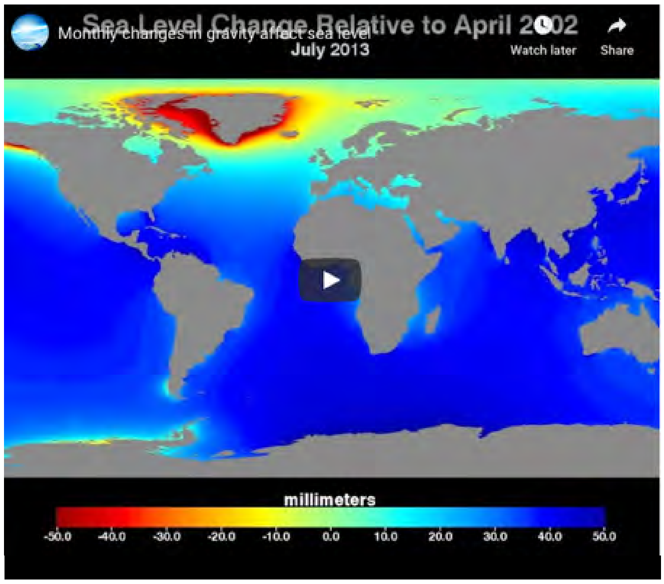
The El Niño of 2015-2016 was the biggest, so far, of the 21st century. This image shows a side-by-side comparison of Pacific Ocean sea surface height anomalies during the 2015-16 event with the famous 1997-1998 El Niño. Credit: NASA-JPL/Caltech

Melting land ice

Next, there's melting land ice in the Greenland and Antarctic ice sheets and Earth's glaciers and ice caps. The largest contribution is from Greenland, which loses hundreds of billions of tons of ice a year and is a major contributor to sea level rise across the globe. As Greenland loses ice, the land beneath its ice sheet rises as the weight of the ice sheet is removed. As a result, Greenland itself doesn't see any local sea level rise.

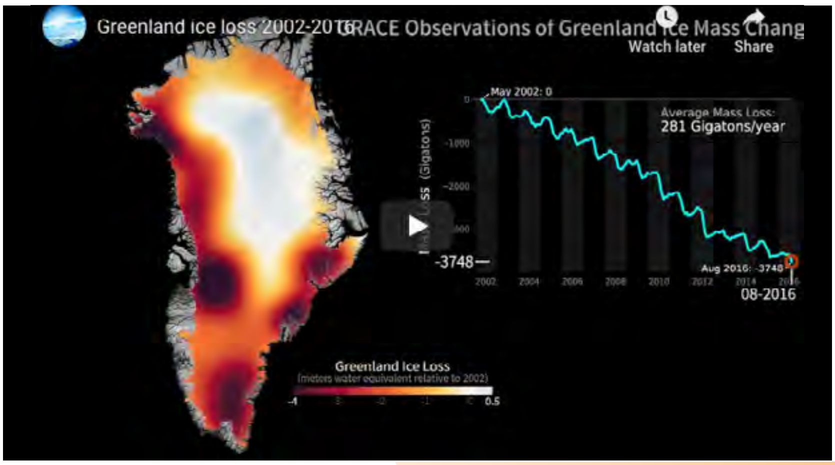
But all of its melted ice — currently averaging 281 gigatons a year has to go somewhere. Gravity causes it to flow into the ocean, causing sea level to rise thousands of miles away. Data from GRACE-FO tell us that melting land ice in glaciers, ice caps, and ice sheets contributed about two-thirds of global sea level rise during the last decade.

As land ice in Greenland, Antarctica and elsewhere melts, it changes Earth's gravity field and slightly shifts the direction of Earth's rotation. This causes uneven changes in sea level across the globe. Each melting ice mass around the world creates its own unique pattern of sea level change in the global ocean. For example, when ice melts in Antarctica, the amount of sea level rise it generates in California and Florida is up to 52 percent greater in those locations than if the global ocean just filled up uniformly, like water in a bathtub. Scientists use gravity data from the GRACE-FO mission to calculate patterns of sea level change associated with the loss of ice from glaciers, ice caps and ice sheets, as well as from changes in land water storage.



An animation showing "sea level fingerprints," or patterns of rising and falling sea levels across the globe in response to changes in Earth's gravitational and rotational fields. The movement of water across our planet can cause localised bumps and dips in gravity, sometimes with counterintuitive effects. Melting glaciers, for example, actually cause nearby sea level to drop; as they lose mass, their gravitational pull slackens, and sea water migrates away.

This animation shows that since 2002, sea level is dropping around rapidly melting Greenland (orange, yellow). But near coastlines at a sufficient distance, the added water causes sea levels to rise (blue). Credit: NASA-JPL/Caltech



The mass of the Greenland ice sheet has rapidly declined in the last several years due to surface melting and iceberg calving. Research indicates that between 2002 and 2016, Greenland shed approximately 280 gigatons of ice per year, causing global sea level to rise by 0.8 mm per year.

These images show changes in Greenland ice mass since 2002. Orange and red shades indicate areas that lost ice mass, while light blue shades indicate areas that gained ice mass. White indicates areas where there was very little or no change in ice mass since 2002. The largest mass decreases of up to 30 centimetres per year occurred along the West Greenland coast. Credit: NASA

Land subsidence and uplift

Then there's vertical land motion along coastlines. When land sinks (a process known as subsidence), it causes a relative increase in sea levels. When land rises (known as uplift), it results in a relative decrease in sea levels.

A number of factors, both natural and human-produced, cause land to rise or sink, including:

- Adjustments related to the rebound of land during and following the retreat of past ice sheets in North America and Eurasia at the end of the last Ice Age (known as isostatic, or post-glacial, rebound). The retreat of the ice sheets lightened the load of mass on the underlying mantle deep below Earth's surface, causing Earth's surface there to slowly rise. Land areas that were once near the edge of these ancient ice sheets, such as along the U.S. eastern seaboard, are today falling, exacerbating sea level rise there.
- Plate tectonics. Earth is divided into multiple slowly moving tectonic plates that interact with each other along plate boundaries. At some plate boundaries, the motion of one plate under, over, or past another, results in vertical uplift or subsidence of the land surface above.
- Natural or human-produced compaction of sediments, such as those caused by pumping groundwater, or oil and gas. Subsidence related to groundwater withdrawal can be especially pronounced in areas with large populations and extensive agriculture. Sediments can also be compacted by construction activities by humans or by the natural settling of new soils. In the United States, subsidence is a major factor in relative sea level rise along parts of the Gulf and East Coasts.

Oceanographer and climate scientist Josh Willis of NASA's Jet Propulsion Laboratory in Southern California says that when it comes to relative sea level rise at any particular coastal location, subsidence is the most immediate consideration.

> *"People in coastal areas need to know what the land is doing right now where they live," he said. "Is it sinking? If so, how fast? When you combine a sinking coastline with sea level rise caused by other contributing factors, you're in trouble. Remember, scientists are projecting feet of global-mean sea level rise in this century. But in some places, land can sink by one foot in a decade. We have to understand all of these pieces before we can project future sea level rise at a beach near you."*
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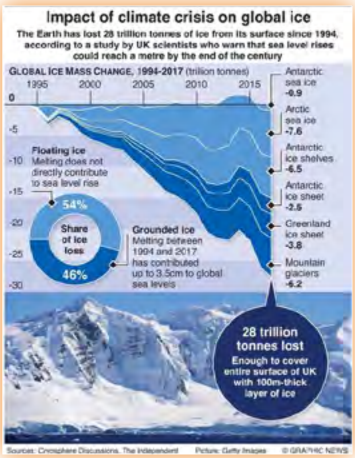
> Source: https://climate.nasa.gov/blog/2990/sea-level-101-what-determines-the-level-of-the-sea/

Children play in the flooded streets of Kampung Melayu, Penang.
Source: Wikimedia Commons



Skills activities linked sea levels, melting glaciers and climate change are included in the Stage 6 Skills section