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Why sea level is not level:
An introduction to paleo sea-level science

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The surface level of the ocean – what we call **sea level** – is not the same everywhere. Sea level may be rising in one location and falling in another, and by different amounts. Sea levels also change over time.

There are some changes that we can **observe on a daily basis**, like the rising and falling tides. Other **changes are slow and take decades, centuries, millennia, or even millions of years**. To understand the processes behind sea-level changes, scientists use both modern instrumental and geological (paleo) observations.

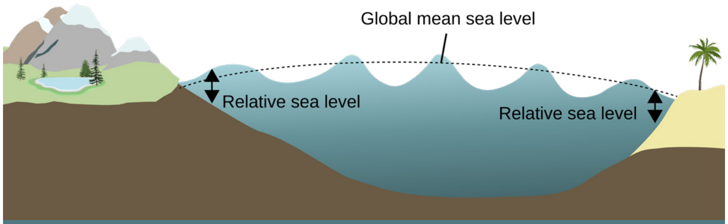


Figure 1: Illustrating the difference between global mean sea level and relative sea level.

Scientists average the height of the ocean's surface across the globe relative to the center of the Earth – we call this **global mean sea level**. Measurements of sea level in one specific location, made relative to land, are called **relative sea level**.

Sea-level rise is a threat to human society. Understanding how and why sea levels change is important to accurately predict what may happen in the future.

Processes of global and relative sea-level change

Short-term processes: *minutes, days, years*	Medium-term processes: *decades, centuries*	Long-term processes: *thousands to millions of years*

Some examples...

1 **Tidal cycles** and **waves** change relative sea levels. During storms, **storm surges** can cause coastal flooding.

2 **Tsunamis** and **sudden land-level changes** generated by earthquakes can cause extreme flooding.

3 Local **weather**, **climate**, and **ocean currents** can change relative sea levels.

4 An increase in ocean **temperature** and **saltiness** can cause the **ocean to expand**, causing global and regional sea levels to rise.

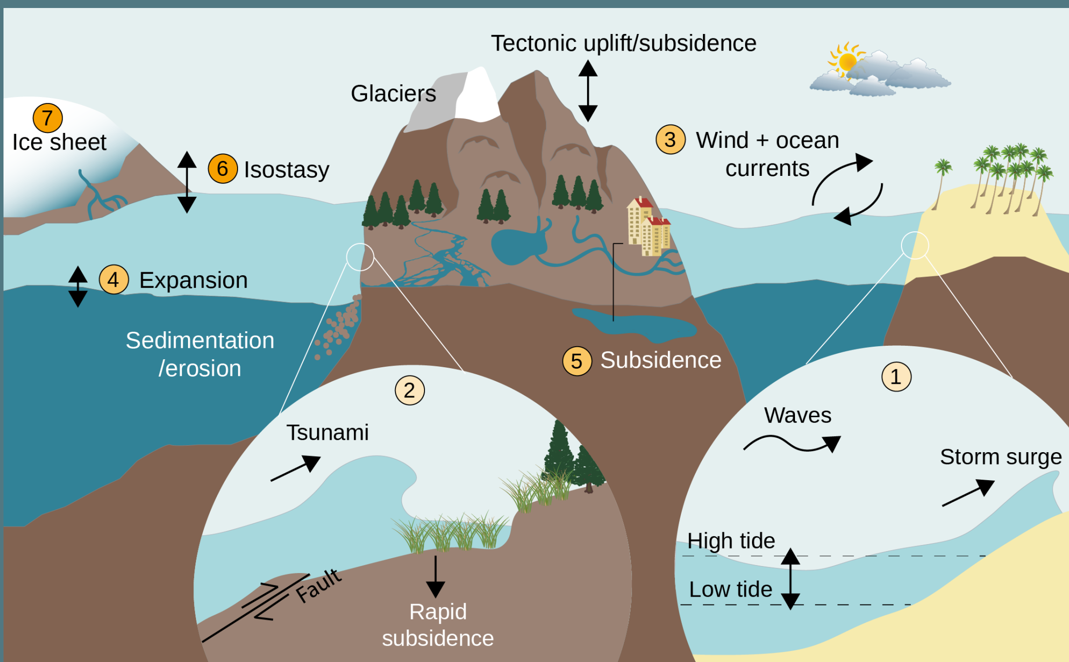


Figure 2: Processes of sea-level changes over space and time. Adapted from IPCC.[1]

5 **Extraction of groundwater** can cause land to subside, causing a rise in relative sea level.

6 Land rises or sinks in response to changes in the **weight of water or ice** on top of it (called isostasy), causing a change in global and regional sea levels.

7 **Melting of ice sheets** (like Antarctica) adds a lot of water to the oceans, raising global sea level.

Why do we study past sea levels?

To learn about long-term processes

Humans have only been collecting sea-level data for a few hundred years at most. To understand medium- to longer-term processes, we need to look further back in time, before our observational record.

How have sea levels changed over hundreds, thousands, and millions of years? What caused those changes?

Scientific term: understanding temporal variability

To learn about geographical differences

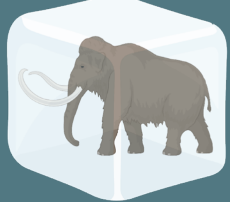
Our recorded history is also quite geographically skewed – our knowledge mostly comes from coastlines along the North Atlantic Ocean. This might be causing a bias in our understanding of sea-level processes.

Are sea-level changes different in different places? Why or why not?

Scientific term: understanding spatial variability

Fun (and not so fun) facts

- During our last ice age ~21,000 years ago, sea level was ~130 m (430 ft) below present sea level. Land masses were more connected around this time: you could walk from Europe, across Asia, to the Americas!

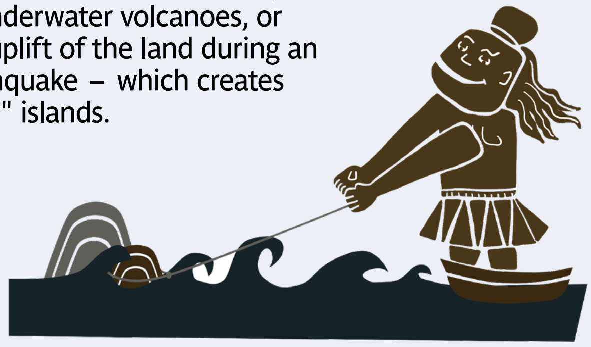


- The Antarctic Ice Sheet, if melted completely, could raise global sea levels by ~65 m (213 ft).

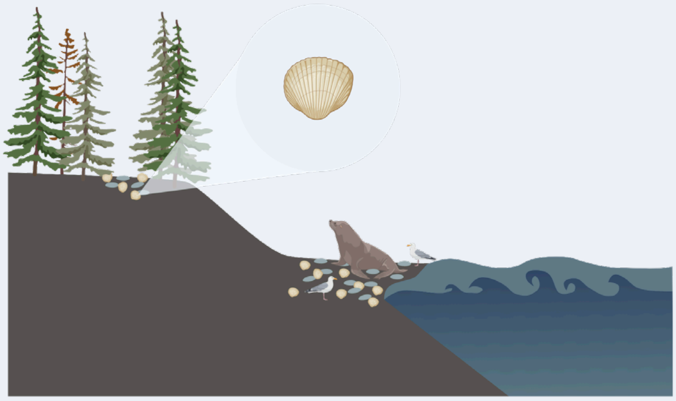
Tales from our predecessors

Many cultures around the world have rich oral and written histories that refer to memorable sea-level changes in the past.

Fishing up myths: demigods or Earth's furies?
In the Pacific, myths speak of demigods fishing up islands from the middle of the ocean. Researchers think this relates to the eruption of underwater volcanoes, or the uplift of the land during an earthquake – which creates "new" islands.



Seashells are meant to be by the sea!
Over 2000 years ago, Pythagoras found marine shells far inland of the modern seashore – evidence that the sea was no longer where it used to be.



Japanese legend: giant catfish causes earthquakes and tsunamis
"People attempting to capture Namazu, the giant catfish believed to cause earthquakes."

Source: UBC Library, Rare Books and Special Collections, QE537.2 J3 D57 1800z. Page 13

FROM PAST TO PRESENT: How do we measure sea level?

The instrumental period (~1800–present)

Tide gauges were first introduced in the late 17th to early 18th centuries, and are the oldest instrumental records of sea level that we have. Tide gauges measure relative sea level (see Fig. 1).

Since 1993, satellites have made it possible for us to monitor nearly the entire surface of our oceans. Satellite altimetry, unlike tide gauges, measure only changes in the sea-surface height. They do not record changes in relative sea level caused by movement of the land.

The paleo record (before ~1800)

Paleo archives can be dated, which allows us to extend the sea-level record further back in time to before the instrumental period. Examples are **archaeological remains**, **geomorphological features**, **sediment records**, and **fixed biological indicators**.

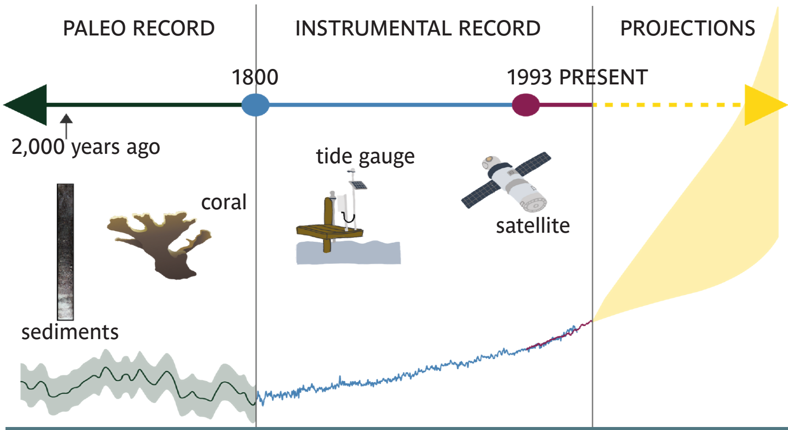
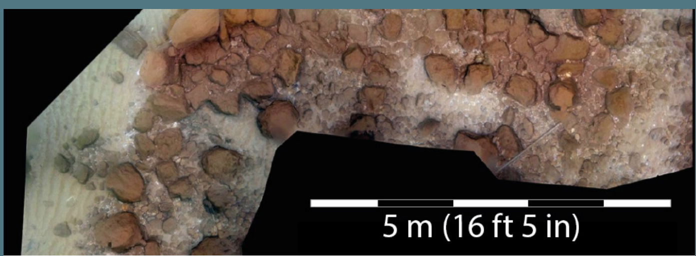


Figure 3: Adapted from IPCC Projection[1]; Paleorecord adapted from Kopp et al.[2]; Tide-gauge data from CSIRO[3]; Satellite data from NASA.[4]

Archaeological remains

Certain archaeological structures are built near sea level, such as piers and fishponds. Finding these abandoned structures where they can no longer serve their intended purposes indicates where sea level was in the past.



Submerged 7000-year-old sea wall off the Carmel coast, Israel. Adapted from Galili et al.[5]

Sediment records

Changes in the sediments and fossils within a sediment core tell us about changes in depositional environments through time, which can be linked to rising or falling relative sea levels.

Sediment core from Pulau Ubin, Singapore.
Source: Sarah Cates, Earth Observatory of Singapore.

Geomorphological features

Erosional or depositional landforms higher or lower than their modern equivalents tell us that relative sea level must have been different in the past, for at least long enough to have carved out these landforms at a different elevation.

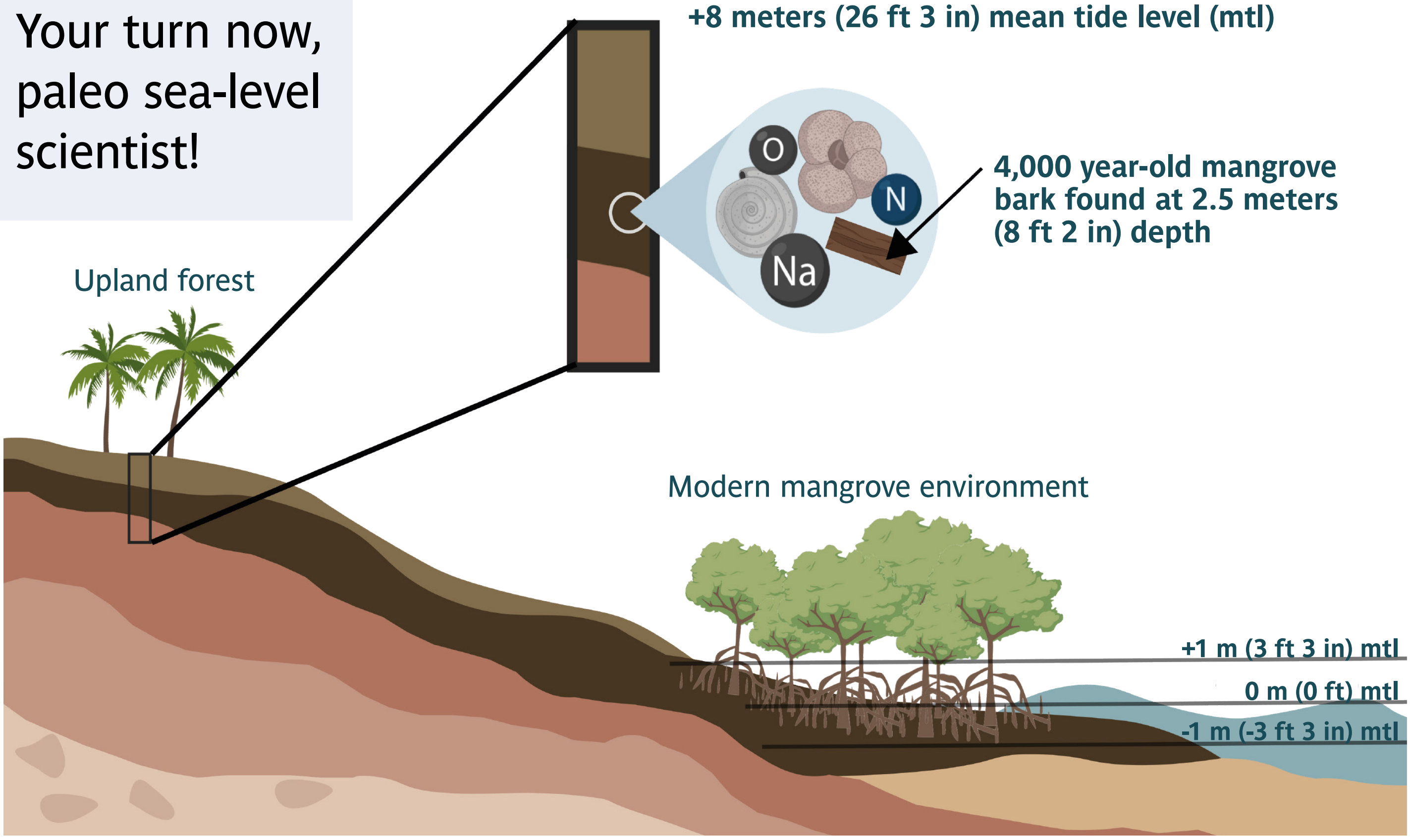
Tidal notches at Xiapu, China.
Source: Fangyi Tan, Earth Observatory of Singapore.

Fixed biological indicators

Fixed biological indicators are organisms that are attached to hard surfaces and/or grow at specific depths in the ocean (e.g. oysters, coral microatolls). Because they live in predictable habitats in relation to sea level, they can tell us about relative sea levels in the past.

Coral microatoll exposed at low spring tides.
Source: Fangyi Tan, Earth Observatory of Singapore.

Your turn now, paleo sea-level scientist!



Activity

Using the information provided in the text, illustration, and the equation below, answer these questions:

? Was relative sea level 4000 years ago higher or lower than today?

? What was the relative sea level (in feet or meters) 4000 years before present?

? Based on the elevation range that mangroves live in today, what is the possible elevation range that sea level could have been (in feet or meters)?

RSL = E – RWL

RSL: relative sea level

E: elevation of sample

RWL: midpoint of the vertical living range that a sea-level indicator occupies

Hint: Principle of uniformitarianism

The present is the key to the past. The processes that we observe today are the same processes that happened in the past.

Context

We visited an upland forest and drilled a sediment core into the ground. At 2.5 m (8 ft 2 in) depth within the core, we found fossils that indicate a former mangrove environment (mangrove bark, mangrove pollen). These fossils are 4000 years old. The top of the sediment core was 8 m (26 ft) above mean sea level.

Necessary assumptions

→ MANGROVE HABITATS HAVEN'T CHANGED

The habitats/elevation zone we find mangroves living in today were the same in the past.

→ THE TIDAL RANGE HAS REMAINED THE SAME THROUGH TIME

Where mangroves live is a function of the tidal range; the larger the tidal range, the larger the elevation range in which the mangroves can live.

In assuming that mangroves today occupy the same elevation zone as they did in the past, we are also assuming that the tidal range at the site has not changed.

Answers: Higher; RSL: 5.5 m (18 ft) above present sea level; range: 1 m (3 ft)