

## Frequently Asked Questions

**FAQ 5.2 | How Unusual is the Current Sea Level Rate of Change?**

*The rate of mean global sea level change—averaging  $1.7 \pm 0.2 \text{ mm yr}^{-1}$  for the entire 20th century and between 2.8 and  $3.6 \text{ mm yr}^{-1}$  since 1993 (Chapter 13)—is unusual in the context of centennial-scale variations of the last two millennia. However, much more rapid rates of sea level change occurred during past periods of rapid ice sheet disintegration, such as transitions between glacial and interglacial periods. Exceptional tectonic effects can also drive very rapid local sea level changes, with local rates exceeding the current global rates of change.*

'Sea level' is commonly thought of as the point where the ocean meets the land. Earth scientists define sea level as a measure of the position of the sea surface relative to the land, both of which may be moving relative to the center of the Earth. A measure of sea level therefore reflects a combination of geophysical and climate factors. Geophysical factors affecting sea level include land subsidence or uplift and glacial isostatic adjustments—the earth–ocean system's response to changes in mass distribution on the Earth, specifically ocean water and land ice.

Climate influences include variations in ocean temperatures, which cause sea water to expand or contract, changes in the volume of glaciers and ice sheets, and shifts in ocean currents. Local and regional changes in these climate and geophysical factors produce significant deviations from the global estimate of the mean rate of sea level change. For example, *local* sea level is falling at a rate approaching  $10 \text{ mm yr}^{-1}$  along the northern Swedish coast (Gulf of Bothnia), due to ongoing uplift caused by continental ice that melted after the last glacial period. In contrast, *local* sea level rose at a rate of  $\sim 20 \text{ mm yr}^{-1}$  from 1960 to 2005 south of Bangkok, mainly in response to subsidence due to ground water extraction.

For the past  $\sim 150$  years, sea level change has been recorded at tide gauge stations, and for the past  $\sim 20$  years, with satellite altimeters. Results of these two data sets are consistent for the overlapping period. The globally averaged rate of sea level rise of  $\sim 1.7 \pm 0.2 \text{ mm yr}^{-1}$  over the 20th century—and about twice that over the past two decades—may seem small compared with observations of wave and tidal oscillations around the globe that can be orders of magnitude larger. However, if these rates persist over long time intervals, the magnitude carries important consequences for heavily populated, low-lying coastal regions, where even a small increase in sea level can inundate large land areas.

Prior to the instrumental period, local rates of sea level change are estimated from indirect measures recorded in sedimentary, fossil and archaeological archives. These proxy records are spatially limited and reflect both local and global conditions. Reconstruction of a global signal is strengthened, though, when individual proxy records from widely different environmental settings converge on a common signal. It is important to note that geologic archives—particularly those before about 20,000 years ago—most commonly only capture millennial-scale changes in sea level. Estimates of century-scale rates of sea level change are therefore based on millennial-scale information, but it must be recognised that such data do not necessarily preclude more rapid rates of century-scale changes in sea level.

Sea level reconstructions for the last two millennia offer an opportunity to use proxy records to overlap with, and extend beyond, the instrumental period. A recent example comes from salt-marsh deposits on the Atlantic Coast of the United States, combined with sea level reconstructions based on tide-gauge data and model predictions, to document an average rate of sea level change since the late 19th century of  $2.1 \pm 0.2 \text{ mm yr}^{-1}$ . This century-long rise exceeds any other century-scale change rate in the entire 2000-year record for this same section of coast.

On longer time scales, much larger rates and amplitudes of sea level changes have sometimes been encountered. Glacial–interglacial climate cycles over the past 500,000 years resulted in global sea level changes of up to about 120 to 140 m. Much of this sea level change occurred in 10,000 to 15,000 years, during the transition from a full glacial period to an interglacial period, at average rates of 10 to  $15 \text{ mm yr}^{-1}$ . These high rates are only sustainable when the Earth is emerging from periods of extreme glaciation, when large ice sheets contact the oceans. For example, during the transition from the last glacial maximum (about 21,000 years ago) to the present interglacial (Holocene, last 11,650 years), fossil coral reef deposits indicate that global sea level rose abruptly by 14 to 18 m in less than 500 years. This event is known as Meltwater Pulse 1A, in which the rate of sea level rise reached more than  $40 \text{ mm yr}^{-1}$ .

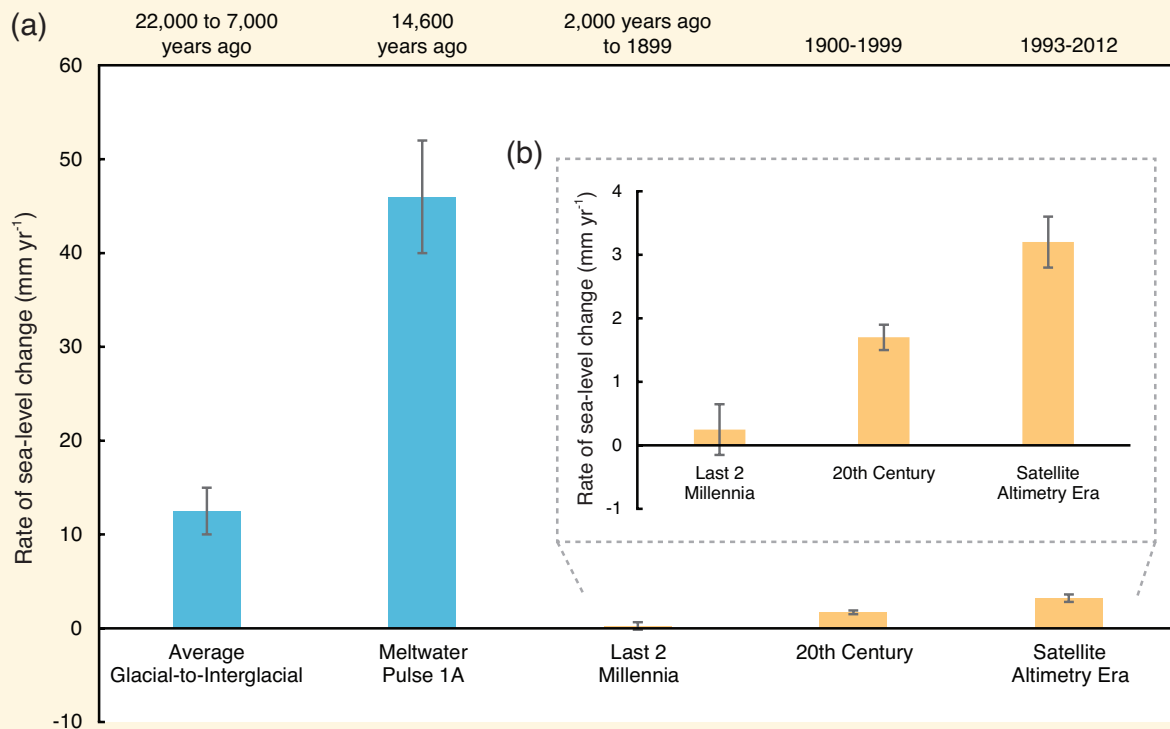
These examples from longer time scales indicate rates of sea level change greater than observed today, but it should be remembered that they all occurred in special circumstances: at times of transition from full glacial to interglacial condition; at locations where the long-term after-effects of these transitions are still occurring; at locations of

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FAQ 5.2 (continued)

major tectonic upheavals or in major deltas, where subsidence due to sediment compaction—sometimes amplified by ground-fluid extraction—dominates.

The instrumental and geologic record support the conclusion that the current rate of mean global sea level change is unusual relative to that observed and/or estimated over the last two millennia. Higher rates have been observed in the geological record, especially during times of transition between glacial and interglacial periods.



**FAQ 5.2, Figure 1 |** (a) Estimates of the average rate of global mean sea level change (in mm yr<sup>-1</sup>) for five selected time intervals: last glacial-to-interglacial transition; Meltwater Pulse 1A; last 2 millennia; 20th century; satellite altimetry era (1993–2012). Blue columns denote time intervals of transition from a glacial to an interglacial period, whereas orange columns denote the current interglacial period. Black bars indicate the range of likely values of the average rate of global mean sea level change. Note the overall higher rates of global mean sea level change characteristic of times of transition between glacial and interglacial periods. (b) Expanded view of the rate of global mean sea level change during three time intervals of the present interglacial.

(Stone et al., 2003). Elevation histories derived from central Greenland ice core data (Vinther et al., 2009; Lecavalier et al., 2013) have presented evidence for thinning from 8 ka to 6 ka but no integrated observation-based estimate for the total ice sheet is available. Contributions from mountain glaciers for this interval are unknown.

Resolving decimeter-scale sea level fluctuations is critical for understanding the causes of sea level change during the last few millennia. Three types of proxies have this capability: salt-marsh plants and microfauna (foraminifera and diatoms) that form distinctive elevation zones reflecting variations in tolerances to the frequency and duration of tidal inundation (Donnelly et al., 2004; Horton and Edwards, 2006; Gehrels et al., 2008; Kemp et al., 2009; Long et al., 2012); coral micro-atolls found in intertidal environments close to lowest spring tides

(Woodroffe and McLean, 1990; Smithers and Woodroffe, 2001; Goodwin and Harvey, 2008); and coastal archaeological features constructed with direct (e.g., fish ponds and certain harbour structures) or indirect (e.g., changes in water-table level in ancient wells) relationships to sea level (Lambeck et al., 2004b; Sivan et al., 2004; Auriemma and Solinas, 2009; Anzidei et al., 2011). Of these, the salt-marsh records are particularly important because they have been validated against regional tide-gauge records and because they can provide near-continuous records. The most robust signal captured in the salt-marsh proxy sea level records from both the NH and SH is an increase in rate, late in the 19th or in the early 20th century (Figure 5.17), that marks a transition from relatively low rates of change during the late Holocene (order tenths of mm yr<sup>-1</sup>) to modern rates (order mm yr<sup>-1</sup>) (see also FAQ 5.2). Variability in both the magnitude and the timing (1840–1920) of