

# Which cities will sink into the sea first? Maybe not the ones you expect

**The Earth isn't solid – which makes it hard to predict how the submerging of our coastlines will unfold**

Better scientific understanding of global warming makes the discussion about its geopolitical consequences increasingly urgent. Put simply, there are going to be winners and losers: hotter places and colder places; wetter places and drier places; and, yes, places that disappear under the sea. But the reality is a bit more complicated. In particular, are sea levels going up or down? The answer seems clear when you consider that Antarctica has lost 3 trillion tonnes of ice in the last 25 years.

Yet to understand what is going on we first have to recognise that the Earth isn't solid. It started life as a ball of hot liquid about 4.5bn years ago and our planet has been cooling ever since. Right at the centre of the Earth is a solid core of metal made of iron and nickel at a temperature of approximately 5,000C. But this core is surrounded by an approximately 2,000km-thick ocean of molten metal, again mostly iron and nickel. Surrounding this is a layer of rock called the mantle that is between 500C to 900C, and at these red-hot temperatures the rock behaves like a solid over short periods of time (seconds, hours, and days) but like a liquid over longer time periods (months to years) – so the rock flows, even though it is not molten. On top of the fluid mantle floats the crust, which is like the skin of the Earth. It is a relatively thin layer of cool rock that is between 30 to 100km thick and contains all the mountains, forests, rivers, seas, continents – our world.

Since the crust is floating on the fluid mantle, if you increase its weight by, for instance, building up kilometres of ice on top of it, then it sinks further into the mantle. This is what has happened to the landmasses of Antarctica and Greenland, which are both covered in 2km to 3km of thick ice. If global warming were to cause all that ice to melt, then the sea level of the oceans would rise by more than 50 metres, submerging all the coastal cities of the world and making hundreds of millions of people homeless. This seems obvious. What is less obvious is how it might unfold.

If the whole ice sheet covering Antarctica melts, the release of its weight will destress the rocks below, which, because they float on the mantle, will bob up. This is called post-glacial rebound. The position with Greenland is similar: the crust below it is being weighed down by the 3 million trillion litres of water held in the ice sheet, and if that ice sheet all melts then parts of the North American tectonic landmass will rise up. If the resulting increase in the height of the continent is bigger than the sea level rise, then major flooding may be avoided. Working out which scenario is more likely is vitally important for future generations, because one of these results will start to play out if global warming intensifies.

What we know is this: the global mean sea level has risen 20cm since the beginning of the 20th century. Some of this has been owing to the water thermally expanding as the oceans have got hotter – since hotter liquids take up more volume (this is how liquid thermometers work). Some of the rise in sea level has been due to the Greenland and Antarctic ice sheets melting, and some due to other glaciers melting. The rising sea levels are global: they affect everyone with a coastline, from tiny Pacific islands that would be entirely submerged to a huge country such as Bangladesh, for which a one-metre rise in sea levels would result in nearly a fifth of the country being submerged and 30 million people being displaced. But while rising sea levels affect everyone, the post-glacial rebound affects only the coasts connected to parts of the Earth's crust weighed down by the Greenland and Antarctic ice sheets.

It is hard to overestimate the importance of this issue, and we badly need more data and scientific understanding of these liquid processes. A limited number of specialised satellites, such as CryoSat, GRACE and ICESat-2 – just launched by Nasa – are being used to monitor ice thickness and to develop models of post-glacial rebound. What the science predicts is that if the ice melts first in the northern hemisphere, then Greenland may bounce up higher than the average sea level, as will parts of North America, and so sea levels there may initially go down. If the opposite happens, and the Antarctic ice melts before the Greenland ice sheet, then it is the southern tectonic plates that will bounce up first and the whole of North America's eastern coast will go under water first. The big unknowns are how quick the ice will go in each location, and how fast the post-glacial rebound will be.

We need to get a better understanding of these processes fast, because if we don't it may be too late to avert catastrophe. These issues don't dominate news agendas but they should. Recently the French environment minister resigned, citing the president's lack of progress and urgency on climate change issues. In doing so, he voiced the concern of the whole scientific community about world leaders – we need a step change in governmental action. But there's the rub: not all governments feel urgent about it. And why? Perhaps it's because, as the issue of post-glacial rebound shows, there will be winners and losers from global warming. For instance, countries such as Russia will be less affected by sea level rises, and may benefit from a more temperate climate. In contrast, the US may not only suffer from new drought zones, but its low-lying eastern coast is threatened by the accelerating loss of Antarctic ice. As the 21st century continues and the ice continues to melt, it will become clearer which countries have a greater incentive to mitigate climate change, and the resulting geopolitics has the potential to drive division and conflict.

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