IN DEPTH

Sailors on 19th century ships measured ocean temperatures with buckets. Correcting bias in those records would reduce uncertainty over how much Earth has warmed.

CLIMATE CHANGE

Is the world 1.3°C or 1.5°C warmer?

Global warming's uncertainty hinges on old logbooks from merchant ships

By **Paul Voosen**

Last month's announcement that 2023 was the hottest year in history was no surprise. But it came with one: No one knows exactly how much the world has warmed. One group of climate scientists found the planet has warmed 1.34°C over the 1850–1900 average, whereas another found temperatures had risen 1.54°C.

In the past, such differences often came down to how groups created a global average and filled in temperatures for remote areas without weather stations, such as polar regions. But the current disagreement is not over present temperatures, but rather the past. The warmth of the ocean in the late 19th century is a key part of the baseline against which the warming of the planet is measured—and figures are at odds. The tension has spurred a flurry of new efforts to identify and correct bias in old temperature logs recorded by sailors. "The impetus to resolve this is getting bigger," says Robert Rohde, the lead scientist of Berkeley Earth, one of the five main groups that produce a global temperature record.

The 0.2°C discrepancy between models does not call into question the human-driven warming of the past century. And mitigating climate change is just as urgent for 1.34°C of warming as for 1.54°C, says Gavin Schmidt, director of NASA's Goddard Institute for Space Studies, which also produces a global temperature record. But a key symbol is at stake: the arbitrary 1.5°C threshold for "dangerous" climate warming, which policymakers settled on in the 2015 Paris agreement. Climate scientists may never be able to say precisely when the world has passed that milestone, Schmidt says. "There's enough uncertainty to make it problematic."

No estimate of global temperature is possible without including the oceans, which cover 70% of the planet's surface. Today, researchers average data from satellites, weather stations, and buoys to estimate temperatures across the planet's surface.

But ocean temperature records in the 19th century were few and far between. A global record began in the 1850s thanks to a controversial figure, Matthew Fontaine Maury, a superintendent at the U.S. Naval Observatory who avidly supported slavery and would go on to serve the Confederacy (*Science*, 3 September 2021, p. 1070). Maury wanted the United States to keep up with powers like the United Kingdom's East India Company, which had discovered optimal shipping routes by measuring powerful ocean currents. So he encouraged merchant sailors to collect weather observations, including measurements of water temperature from buckets heaved to the deck; if captains shared the data with the government, they would receive naval charts in return.

IMAGE: LEEMAGE/CORBIS VIA GETTY IMAGES

The practice spread to other navies and merchant marines. Over time, wooden buckets gave way to canvas and rubber ones, and when steam ships took over, sailors began to measure water temperatures first through engine intake valves and later with sensors along the hull. Each method biased the reading: Canvas buckets, for example, exposed the water to evaporative cooling, whereas intake valves, warmed by the ship itself, heated the water.

Today, two organizations maintain these historical sea surface temperature records: the U.S. National Oceanic and Atmospheric Administration (NOAA) and the U.K.'s Met Office. They both catalog the same underlying data, but differ in how they approach a key question. "How to correct the bucket temperature?" says Boyin Huang, a NOAA oceanographer who leads work on the historic baseline and will present its sixth version at this month's Ocean Sciences Meeting in New Orleans. NOAA does so by cross-checking the bucket temperatures with air temperatures taken at the same place and time, whereas the Met Office relies on a "bucket model" to estimate the water's temperature before it was scooped up.

Each method has its flaws. The Met Office, for example, makes assumptions about what type of bucket was used when it wasn't documented. Meanwhile, air temperatures have their own biases, which depend on the weather and time of the observations—and even the height of the ship decks, which grew taller over time.

Underscoring doubts about NOAA's data set, it shows less ocean warming over the past 170 years than the Met Office record, suggesting that the land warmed far faster than the ocean during this time, to a degree that climate models show to be implausible. Each of the five global temperature groups must pick one of the two baselines, even though they are starkly different. "They can't both be right," Rohde says.

Duo Chan, a climate scientist at the University of Southampton, says using temperatures from nearby island or coastal weather stations to adjust shipboard observations can better compensate for the bucket biases. It has the additional benefit of removing two strange trends: cooling that began in the late 1800s, followed by rapid warming from 1910 to World War II. Remove these artifacts, he says, and "you get a much smoother temperature evolution." His proposed corrections also line up better with temperature records inferred from tree rings and corals.

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Duo Chan, University of Southampton

Other techniques for weeding out bias are more painstaking. Elizabeth Kent, a climatologist at the U.K.'s National Oceanography Centre, and colleagues hunt for overlooked details in the logbooks that can help them identify unknown ships and infer their data collection methods. For example, a zigzagging vessel—a sign of tacking in the wind—is likely a sailing ship that sampled with buckets. There's a lot of work to be done with existing records, she says. "It's a massive mix of stuff we know well and some that's a horror show."

Grouping ships from different countries and looking for differences in measurements when those fleets cruised the same stretch of ocean at the same time can also reveal bias, Chan says. This led to the discovery that, after the 1930s, temperature measurements from Japanese ships tended to be 0.35°C colder than those from other countries. This wasn't because of any oddity in Japanese data collecting. Rather, when the U.S. Air Force was digitizing these records after World War II, putting them on punch cards, it dropped the decimal to save space. "They floored everything to the whole degree," Chan says.

A staggering number of logbooks have yet to be digitized, says Ed Hawkins, a climate scientist at the University of Reading. The U.K.'s National Archives has 6 million pages that are so far untouched, for example. "We could at least double the quantity of data we have available," Hawkins says.

Machine reading and other artificial intelligence techniques could accelerate the work. But science agencies haven't pressed for this, Kent says, and the field lacks the hands to make progress. "For the importance of these data sets, the number of people working on it is just unimaginably small," she says. "People think it's all done, it's all fine."

Refining the records offers more than just increased certainty about the pace of global warming today, Chan says. It could help illuminate how ocean warming varies from basin to basin and shed light on a puzzling observation—the eastern Pacific Ocean's seeming resistance to warming, a matter of importance for those who study the future of the El Niño climate pattern (see story, p. 472). Better records would also help shore up models' projections of global warming, Chan says. "If we do not know the past," he says, "we cannot give much credit to the predictions we make." ■