World view

By Gavin Schmidt

Why 2023's heat anomaly is worrying scientists

Climate models struggle to explain why planetary temperatures spiked suddenly. More and better data are urgently needed.

When I took over as the director of NASA's Goddard Institute for Space Studies, I inherited a project that tracks temperature changes since 1880. Using this trove of data, I've made climate predictions at the start of every year since 2016. It's humbling, and a bit worrying, to admit that no year has confounded climate scientists' predictive capabilities more than 2023 has.

For the past nine months, mean land and sea surface temperatures have overshot previous records each month by up to 0.2 °C — a huge margin at the planetary scale. A general warming trend is expected because of rising greenhouse-gas emissions, but this sudden heat spike greatly exceeds predictions made by statistical climate models that rely on past observations. Many reasons for this discrepancy have been proposed but, as yet, no combination of them has been able to reconcile our theories with what has happened.

For a start, prevalent global climate conditions one year ago would have suggested that a spell of record-setting warmth was unlikely. Early last year, the tropical Pacific Ocean was coming out of a three-year period of La Niña, a climate phenomenon associated with the relative cooling of the central and eastern Pacific Ocean. Drawing on precedents when similar conditions prevailed at the beginning of a year, several climate scientists, including me, put the odds of 2023 turning out to be a record warm year at just one in five.

El Niño — the inverse of La Niña — causes the eastern tropical Pacific Ocean to warm up. This weather pattern set in only in the second half of the year, and the current spell is milder than similar events in 1997–98 and 2015–16.

However, starting last March, sea surface temperatures in the North Atlantic Ocean began to shoot up. By June, the extent of sea ice around Antarctica was by far the lowest on record. Compared with the average ice cover between 1981 and 2010, a patch of sea ice roughly the size of Alaska was missing. The observed temperature anomaly has not only been much larger than expected, but also started showing up several months before the onset of El Niño.

So, what might have caused this heat spike? Atmospheric greenhouse-gas levels have continued to rise, but the extra load since 2022 can account for further warming of only about 0.02 °C. Other theories put forward by climate scientists include fallout from the January 2022 Hunga Tonga–Hunga Ha'apai volcanic eruption in Tonga, which had both cooling effects from aerosols and warming ones from stratospheric water vapour, and the ramping up of solar activity in the run-up to a predicted solar maximum. But these factors explain, at most, a few hundredths of a degree in warming (Schoeberl, M. R. *et al. Geophys. Res. Lett.* **50**, e2023GL104634; 2023). Even after taking all plausible explanations into account, the divergence between expected and observed annual mean temperatures in 2023 remains about 0.2 °C — roughly the gap between the previous and current annual record.

> "If the anomaly does not stabilize by August, then the world will be in uncharted territory."

There is one more factor that could be playing a part. In 2020, new regulations required the shipping industry to use cleaner fuels that reduce sulfur emissions. Sulfur compounds in the atmosphere are reflective and influence several properties of clouds, thereby having an overall cooling effect. Preliminary estimates of the impact of these rules show a negligible effect on global mean temperatures — a change of only a few hundredths of a degree. But reliable assessments of aerosol emissions rely on networks of mostly volunteer-driven efforts, and it could be a year or more before the full data from 2023 are available.

This is too long a wait. Better, more nimble data-collection systems are clearly needed. NASA's PACE mission, which launched in February, is a step in the right direction. In a few months, the satellite should start providing a global assessment of the composition of various aerosol particles in the atmosphere. The data will be invaluable for reducing the substantial aerosol-related uncertainty in climate models. Hindcasts, informed by new data, could also provide insights into last year's climate events.

But it seems unlikely that aerosol effects provide anything close to a full answer. In general, the 2023 temperature anomaly has come out of the blue, revealing an unprecedented knowledge gap perhaps for the first time since about 40 years ago, when satellite data began offering modellers an unparalleled, real-time view of Earth's climate system. If the anomaly does not stabilize by August — a reasonable expectation based on previous El Niño events — then the world will be in uncharted territory. It could imply that a warming planet is already fundamentally altering how the climate system operates, much sooner than scientists had anticipated. It could also mean that statistical inferences based on past events are less reliable than we thought, adding more uncertainty to seasonal predictions of droughts and rainfall patterns.

Much of the world's climate is driven by intricate, long-distance links — known as teleconnections — fuelled by sea and atmospheric currents. If their behaviour is in flux or markedly diverging from previous observations, we need to know about such changes in real time. We need answers for why 2023 turned out to be the warmest year in possibly the past 100,000 years. And we need them quickly.

Gavin Schmidt is a climatologist and director of NASA's Goddard Institute for Space Studies in New York City. e-mail: gavin.a.schmidt@nasa.gov

WILLIAM D. HRYBYK