How climate change affects extreme weather events

Research can increasingly determine the contribution of climate change to extreme events such as droughts

By **Peter Stott**[1,2]

Human-induced climate change has led to an increase in the frequency and intensity of daily temperature extremes and has contributed to a widespread intensification of daily precipitation extremes (*1*, *2*). But has it also made specific extreme weather and climate events—such as floods, droughts, and heat waves—more likely? Although it has been said that individual climate events cannot be attributed to anthropogenic climate change (*3*), a recent assessment by the National Academies of Science concludes that "this is no longer true as an unqualified blanket statement" (*4*). Robust event attribution can support decisions such as how to rebuild after a disaster and how to price insurance by quantifying the current risk of such events.

The first annual report explaining extreme events of the previous year from a climate perspective was published in 2011 with six contributions (*5*). The latest report explaining events of 2014 (*6*) included 32 papers looking at 28 different events from all seven continents, covering a greatly increased range of event type, location, and impact. According to the National Academies of Science, this rapidly advancing scientific capability now makes it possible to "make and defend quantitative statements about the extent to which human-induced climate change has influenced either the magnitude or the probability of specific types of event or event classes" (*4*).

Most researchers use one of two methods for event attribution. In the first, they perform coupled climate model runs to simulate the likely evolution of climate with and without anthropogenic climate change (see the figure, top panel). They then choose a suitable index (such as seasonal mean temperature over a particular region) and calculate the likelihood of exceeding this index with and without climate change. For example, Sun *et al.* used this method to analyze the summer of 2013, the hottest on record in eastern China. They found that the likelihood of such extreme temperatures had increased by a factor of >60 as a result of human-induced climate change (*7*).

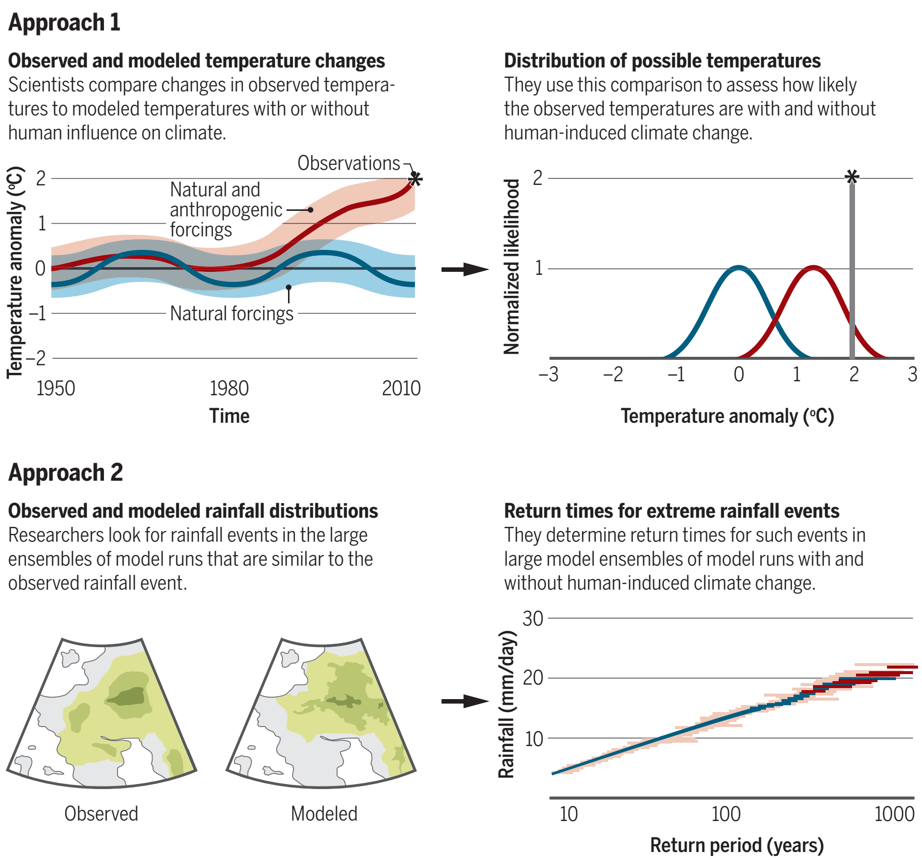
In the second method, researchers generate large ensembles of atmosphere-only models that sample the occurrence of the rare event of interest (such as rainfall in a river basin exceeding an extreme value), given observed sea surface temperature conditions (see the figure, bottom panel). They then compare the return periods of such events in ensembles with and without anthropogenic climate and calculate their changed likelihood. Using this method, Schaller *et al.* found no evidence that human-induced climate change had made the extreme precipitation in the Upper Danube and Elbe basins in May to June 2013 more likely (*8*).

A further proposed method assumes that the circulation regime or weather event is unchanged and determines whether climate change has altered its impact—for example, through altering the thermodynamic state of the atmosphere (*9*). A conditional approach to attribution can be helpful. Indeed, the second method described above estimates how the risk of events has changed, assuming that large-scale patterns of sea surface temperatures due to natural variability (for example, associated with El Niño or La Niña conditions) remain unchanged. But to relate recent events to their future likelihood of occurrence, attribution assessments cannot ignore the effects of circulation changes.

Attribution findings related to extreme temperature events tend to show much stronger evidence of human influence than for other types of events. This is because there tends to be a wealth of data on extreme hot and cold events, they can be captured accurately by models, and their relationship with anthropogenic climate change is usually well simulated. In contrast, extreme rainfall

Robust event attribution

Scientists use two main approaches to determine the contribution of climate change to extreme weather events.



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events are often poorly observed, models can fail to represent them adequately, and their relationship with climate variability and change is often not well understood (*4*). Improved climate models, observational data sets, and theoretical understanding will be needed to improve the reliability of attribution findings for such events.

Recent initiatives, including the European project EUCLEIA (European Climate and Weather Events: Interpretation and Attribution) and the World Weather Attribution effort, seek to develop the science of event attribution. For such science to help societies become more resilient to climate variability and change, event attribution results need to be credible and relevant (*10*). Further improvements are needed in techniques for analyzing extreme events, tools to evaluate and communicate the robustness of event attribution results (*11*, *12*), and methodologies to link the effects of extreme events to their meteorological drivers (*13*). A model-based result by itself does not guarantee its utility (*3*). A convincing physically based storyline describing the event and its effects is also needed to support the legitimate use of such information for robust decision-making (*14*).

The increasingly routine nature of some temperature-based studies points the way toward an operational attribution capability in which trusted providers issue routine updates on recent events (*15*). The National Academies of Science recommended that such a capability be linked to the provision of probabilistic forecasts of extreme events at lead times of days to seasons or longer (*4*). Placing recent extreme events in the context of past and future climate variability and change would enhance the ability of societies to manage weather and climate-related risks. ■

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OCEAN BIOLOGY

Corals' microbial sentinels

The coral microbiome will be key to future reef health

By **Tracy D. Ainsworth**[1] *and* **Ruth D. Gates**[2]

In 2005, Pandolfi *et al.* (*1*) asked whether U.S. coral reefs would in the future be overgrown and dominated by algae as a result of rapid change in the marine environment. Over a decade later, an increasing number of reefs worldwide have declined, and severe and lasting environmental changes are altering the composition of coral reefs that were once pristine and resilient. In the past 2 years, many reefs around the world have suffered from repeated bleaching (see the photo) as a result of high water temperatures caused by a strong El Niño event combined with climate change. Corals that survive the multiple impacts of climate change and local disturbance will form the basis of future reefs that will differ in fundamental ways from those considered healthy today (*2*). Changes to the coral microbiome on these reefs will play a vital part in future coral reef health (see the figure).

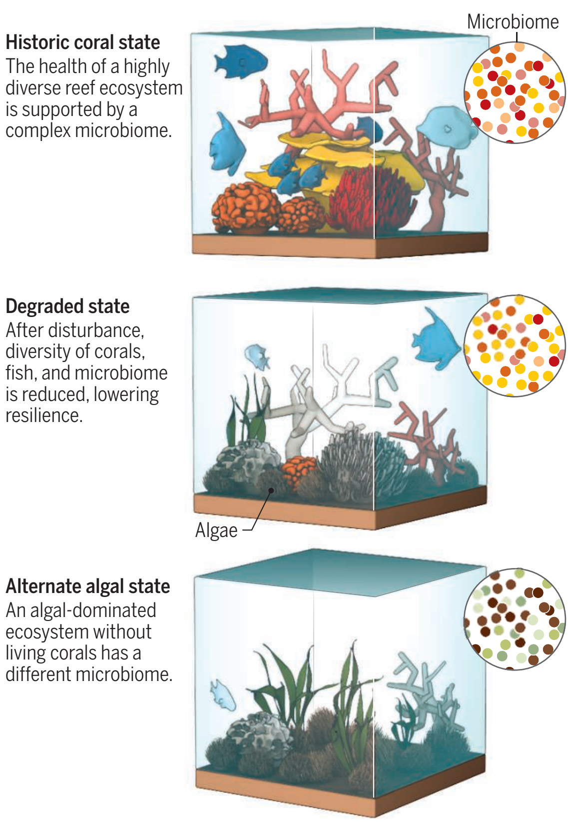
Microbial communities play central roles in animal health and ecosystem stability. Factors such as nutritional status, stress response, and disease are linked to shifts in the taxonomic composition of—and the interactions between—microbiomes and their hosts (*3*). There are also correlations between an organism's life span and its microbial complexity, structure, and function (*4*). Corals form integral and functionally important symbioses with prokaryotic microbes (forming a core symbiotic microbiome) (*5*). The implications of altered prokaryotic microbial partnerships for coral reefs are difficult to predict because little is known about the functional complexity of the undisturbed coral microbiome. However, knowledge from other systems suggests that altered microbiomes, representing a new stable state after disturbance, impair the host's metabolic state, disease resistance, and functional capacity (*6*).

One of the most extreme examples of the impacts of environmental stress on coral function is bleaching. Temperature stress of only 1°C above the physiological upper limit, as seen on coral reefs worldwide in the past 3 years, causes tropical reef corals to bleach. Bleaching reflects a reduced density of endosymbiotic algae (belonging to the dinoflagellate genus *Symbiodinium*) in the coral tissues. When these nutritionally beneficial endosymbionts are lost, coral health suffers and nutritional resources are depleted. These effects continue as long as adverse temperature conditions persist and can ultimately lead to the death of the coral.

In corals that bleach but survive, external conditions

Microbiome shifts

The shifting microbial complexity indicates the impact of climate change on the coral microbiome, host health, and population stability on coral reefs. The challenge to coral research is to understand the microbial contribution to alternate stable states on coral reefs.



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