Decoding the Signal: Advances in Climate Change Attribution

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**Introduction**

The theoretical basis of anthropogenic climate change has been understood for decades. The sun radiates energy to the earth, and it is emitted back from the earth’s surface as infrared radiation, which we feel as heat. An increase in greenhouse gases from industrial, agricultural, and consumer emissions—primarily carbon dioxide (CO₂)—in the lower atmosphere leads to more of this heat being trapped in the earth’s atmosphere and less escaping into space. It is well documented that solar radiative output is not generating the rise in mean temperatures that we have seen in most regions of the globe since the Industrial Age.¹ In fact, we are in a comparatively inactive period of solar activity. We also know that the amount of CO₂ in our atmosphere has been steadily increasing, with observing sites now reporting 400 parts per million.²

Until recently, it has been difficult to separate the effects of natural climate patterns such as the El Niño-Southern Oscillation (ENSO) from anthropogenic change at a regional scale. These natural cycles have a pronounced effect on local weather and short-term climate, which makes it difficult for climate scientists to draw definitive conclusions about the relative contribution of anthropogenic forcings to regional weather events. It has also been difficult to conclusively account for short-term temporal effects such as the notorious “global warming hiatus,” for which several different explanations have been proposed.

Climate-change skeptics have interpreted the caution of the scientific community as a sign that, with respect to the existence of global warming itself, the “science is unsettled,” a claim that is both misleading and out of date. Climate and weather attribution has moved on from whether anthropogenic greenhouse gases are affecting the climate to precisely how it is happening—at a fine scale, both spatial and temporal. Recent advances in modeling and data-gathering have made it possible to identify the anthropogenic signal in temperature records at sub-continental and even semi-local scales. It is now possible to say with a high degree of confidence that increases in temperature extremes at regional and even semi-local scales are attributable to anthropogenic, rather than natural, change. It is also possible to say that many instances for which observed temperatures are cooler than climate models had predicted for a given locale have specific, identifiable causes that only temporarily mitigate the overarching greenhouse gas influence. The new frontier in attribution

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¹ *The Climate Institute* | Decoding the Signal: Advances in Climate Change Attribution

² *The Climate Institute* | Decoding the Signal: Advances in Climate Change Attribution
studies is “ironing out the kinks”—determining the effects of many contributing factors on comparatively small “wrinkles” in the climatic record.

**Overview of Modeling**

The basic approach of many attribution studies is to model a given dataset—decades of temperature data, for example, or sometimes a case study of a specific weather event—in climate models (the Coupled Model Inter-comparison Project, or CMIP, is the most commonly used framework in climate research). The models are configured both with and without anthropogenic forcing, the steady increase in greenhouse gas content in the atmosphere. The resulting modeled data are then compared to real, observed data via statistical methods. For years, climate scientists have been unable to account for multi-decadal global temperature data by running the climate models with only natural processes; they have had to use the models with anthropogenic forcing configured in order to generate a comparison dataset that is similar to real data.

The climate models, like all modern atmospheric computer models, can be configured in more complex ways too. Specific natural patterns, such as ENSO, can be turned on or off in model configuration settings. Atmospheric models are also linked to the earth's land surface, and phenomena such as volcanic eruptions can be inserted into the model data, as well as changes in terrain type. In recent years, the most advanced frontier in climate modeling has been to link the long-term climate models to short-term, very high-resolution weather models, in order to model specific weather events with and without various climatic parameters.

The fact that climate models can be configured in so many ways has made it possible for climate scientists to investigate comparatively short-term and small-scale climate phenomena. Small-scale effects are often sensitive to influences that operate at spatial scales smaller than global and temporal scales smaller than multidecadal. The global warming hiatus, a period in recent years in which the rate of warming decreased, is one such research problem that climatologists have been examining with these complex model options.

Another research topic that they have worked on increasingly in the past decade is regional, rather than global, temperature modeling. This particular topic has been challenging not because of
insufficient complexity in the climate models themselves, but largely because of data resolution limitations. The available observation datasets were too coarsely resolved in some regions of the globe for meaningful statistical analyses to be performed on them in isolation (though it was valid to use them as part of a global analysis). Rapid improvements in satellite data resolution, and many more in situ observations of weather conditions, have made it statistically valid to conduct climatic attribution studies at smaller geographic scales.

**Separating Natural and Anthropogenic Change**

Many studies over the years have examined the influences of anthropogenic and natural climate change in temperature records. Stott et al. wrote in 2006 that, while the anthropogenic warming was apparent in 20th-century temperature data, the climate models predicted more warming than actually occurred. They hypothesized that aerosols—that is, fine particulate matter—mitigated the effects of human-caused warming by reflecting solar radiation. This effect is responsible for the “volcanic winter” phenomenon that occurs when a volcano erupts violently, sending ash and dust high into the atmosphere, and it could also occur with enough artificial aerosols in the atmosphere. The United States CLIVAR Decadal Variability Working Group noted as recently as 2011 that aerosols from both natural sources (chiefly volcanoes) and human sources are difficult to model at sub-continental scales. This is an ongoing research topic in atmospheric science, but it further demonstrates that the “unsettled science” is actually related to smaller, shorter-term climate influences rather than a major driver such as anthropogenic greenhouse gas emissions.

Other researchers have held that the famously cooler-than-predicted temperatures and the “global warming hiatus” are attributable to natural climatic patterns instead of aerosols. Triacca et al. proposed that the ENSO cycle was the strongest influence on global temperatures until approximately the mid-20th century, whereas after that, greenhouse gases became by far the most dominant influence, especially in the Southern Hemisphere.

Recently, Murphy conducted a study using waveform analysis techniques to separate anthropogenic and natural signals from the temperature record, with the intent of accounting for the hiatus by this method. In the context of climate, repeating natural patterns such as ENSO and other global
circulation cycles can be represented as sine waves. When these patterns are mathematically removed from the original temperature data, it leaves behind the steadily increasing and non-repeating anthropogenic signal. Although Murphy was more skeptical of the degree of influence (not the existence) of anthropogenic global warming, and his analysis attributed the warming hiatus to the interplay of natural cycles, even this work found the greenhouse gas influence to be present and identifiable. The signal processing approach treats natural patterns as being independent of (not measurably influenced by) anthropogenic warming, which may not be strictly true, but that only implies that the effect of anthropogenic warming could be even larger than the signal processing could identify. The anthropogenic effect has been found, therefore, by multiple distinct methods of analysis.

**Temperature Attribution on a Regional Scale**

Another emerging field of climatology is regional and local attribution, both of temperature and of weather events. Until recently this was considered too difficult to model well, owing both to model and dataset limitations. However, the climate models have been steadily improved, and the amount of temperature data to which we have access has increased significantly in spatial extent in the last decade. The increase in data coverage in particular has brought about a veritable revolution in modeling. Formerly, it was considered scientifically irresponsible to make claims about a climatic effect in a small area or time frame. Natural climate patterns and small-scale human influences (such as changes in land use) were already known to have a profound effect on local conditions, and we simply did not have enough data points to make positive claims about regional effects of global warming. However, with the advances in modeling and data, what was once impracticable is now doable.

As an example of the limitations of the research, as recently as 2009, Christidis et al. wrote that

> “Although the human contribution to the global temperature change of the past few decades is well established, the effect of the anthropogenic forcings on sub-continental regional scales is still uncertain.”

Nonetheless, in their 2009 study, they still found that anthropogenic influence increased the probability of warming in all regions except for continental North America; natural cycles alone
could not explain the warming trends. Dean and Stott also wrote in 2009 that temperature records in New Zealand over the past 50 years cannot be explained only by natural cycles and that the anthropogenic warming factor was necessary to account for this regional data.

In 2011 Christidis et al. produced a new study of attribution analysis to attempt to account for regional daytime high temperatures with natural and anthropogenic climate change. This was a pivotal study for climate research. In their words, it was “the first that attempts to partition the observed change in warm daytime extremes between its anthropogenic and natural components and hence attribute part of the change to possible causes.” They found that the anthropogenic warming was required to explain the change in daytime high temperatures.

In 2013 Christidis and Stott produced an updated study with improved model configurations to attribute climate and weather extremes. Warm years in the historical record, both at global and regional scales, were more reliably modeled when anthropogenic greenhouse gases were included in the simulations.

In the past two years, Kim et al. modeled annual temperature extremes (highest and lowest daily maximum and minimum during a year for each reference point) from 1851-2010 for the entire globe. This study also used a sub-regional grid. The resolution of their dataset was 3.75° longitude by 2.5° latitude. They used robust statistical methods to compare the observed real-world temperatures to temperatures predicted by the climate models with only natural variability computed in the model, and natural and anthropogenic change computed. The climate models that calculated natural and anthropogenic influence accounted for all four types of temperature extremes—highest daily maximum, highest daily minimum, lowest daily maximum, and lowest daily minimum—much better than models that only looked at natural variability. Kim et al. also examined potential causes for the warming hiatus and found that, instead of aerosols, the Arctic Oscillation and Pacific Decadal Oscillation—two cyclical climate patterns—accounted for observed lowest daily minima being cooler than modeled. These patterns have regional effects. Once again, if climate scientists were unsure of the existence of a major influence with a long-term global effect, it would be invalid for them to draw any conclusions about factors affecting regional temperatures. However,
climatology has moved on from that big question, and climate scientists are working on answering the smaller questions.

**Conclusion**

As the sampling of studies shows, research has steadily improved in the past ten years, with a huge leap in progress occurring in the past five to six years. It is now possible to model human and natural climate influences at regional and semi-local scales across the globe, and to attribute observed warming to anthropogenic greenhouse gas emissions with a very high level of confidence. Indeed, this climate effect is required by the models to accurately simulate temperatures that have been observed at regional and local scales. Climate scientists now model natural influences and aerosols not to examine them as possible alternatives to the anthropogenic greenhouse effect as causes of warming, but instead, to account for blips of short-term and/or regional variation from the expected warming trend. In short, climatologists are now able to model short-term climate—climate over recent years—at regional and local scales and say with confidence what factors account for a trend.

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