



Attribution of climate variations and trends to human influences and natural variability

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Past attribution studies of climate change have assumed a null hypothesis of no role of human activities. The challenge, then, is to prove that there is an anthropogenic component. I argue that because global warming is “unequivocal” and “very likely” caused by human activities, the reverse should now be the case. The task, then, could be to prove there is no anthropogenic component to a particular observed change in climate, although a more useful task is to determine what it is. In Bayesian statistics, this change might be thought of as adding a “prior”. The benefit of doubt and uncertainties about observations and models are then switched. Moreover, the science community is much too conservative on this issue and too many authors make what are called “Type II errors” whereby they erroneously accept the null hypothesis. Global warming is contributing to a changing incidence of extreme weather because the environment in which all storms form has changed from human activities. © 2011 John Wiley & Sons, Ltd. *WIREs Clim Change* 2011 1 000–000

INTRODUCTION

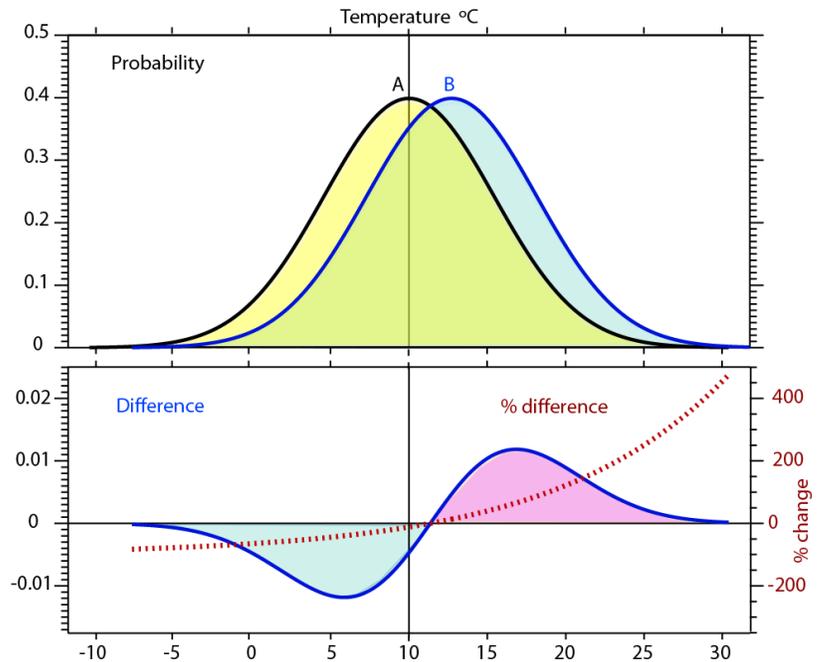
Humans are changing our climate. There is no doubt whatsoever. There are arguments about how much and how important these effects are and will be in future, but many studies (e.g., see the summary by Stott et al.¹) have demonstrated that effects are not trivial and have emerged from the noise of natural variability, even if they are small by some measures. So why does the science community continue to do attribution studies and assume that humans have no influence as a null hypothesis? Given that global warming is “unequivocal”, and is “very likely” due to human activities, to quote the 2007 IPCC report², shouldn't the null hypothesis now be reversed? Shouldn't the burden of proof be on showing that there is no human influence? Or in Bayesian statistics, shouldn't there be a change in the “prior”. In this article, the argument is made that we should indeed think twice about the way the attribution studies are done and the conclusions that are drawn.

THE HUMAN INFLUENCE ON CLIMATE

The first step in any such study is to have a dataset: a time series that indicates the occurrence of something unusual that demands an explanation. This may be a trend over a certain period or it may be a specific event. “Detection” is the process of demonstrating that the event is unusual and indicative of a climate change. With a long homogeneous record, it may be possible to derive good statistics on how unusual such a phenomenon might be. For instance, the central Europe temperature anomaly for the 2003 summer months of June through August was 1.4°C hotter than the previous high temperature since 1780². This dramatic heat wave caused more than 50,000 deaths. While the 2003 temperature anomaly was a 5 standard deviation departure relative to the mean for an unchanging climate in this region, Schär et al.³ show how an event of this magnitude becomes much more likely given the observed warming of 1.25°C over this region. However, many datasets are not long enough or free from observational uncertainties and spurious effects from changes in the location of stations or instrument errors, which

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DOI: 10.1002/wcc.142

FIGURE 1 | A small change in the average temperature value can have a large effect on extremes. Top: The probability of different temperature readings when the mean temperature is 10°C and SD 5.6°C (black curve, A), and when the mean temperature rises 2.8°, to 12.8°C (blue curve, B) with the same spread. Bottom: the solid blue curve (scale left) is the difference in probability and the dashed red curve (scale right) is the percentage change.



add considerably to the apparent noise of natural variability.

The second step of “attribution” is to separate the human contribution from that of natural variability and this necessarily requires a model. Frequently the “fingerprint” of a particular forcing, such as that from human activities, is determined using a model, perhaps run many times to sort out the signal from the noise of natural variability. However, climate models are useful but far from perfect and their shortcomings need to be taken into account. Stott et al.¹ provide a nice summary of recent detection and attribution objectives and studies.

An issue that is poorly understood is how climate change is manifested in weather and climate events. Consider a simple example of a temperature distribution that is normal (such as the yellow domain in Figure 1) with a mean of 10°C and a standard deviation of 5.6°C. Then consider a climate change that retains the same distribution about the mean but increases the mean by 2.8°C (blue domain in Figure 1). Much of the new distribution overlaps with the old (green region). The change in frequency is given below along with the percentage change relative to the original frequency distribution. The percent changes are largest in the extremes in the tails of the distribution. Changing the shape of the distribution makes the changes in at least one of the tails even bigger. In other words, a

BOX 1

EXTREME CLIMATE EVENTS IN 2010

Many weather or climate extremes occurred in 2010 but especially notable are the following, listed approximately chronologically. Record snowfalls “snowmageddon” in the Washington DC area in February; flooding in New England in March, intense heavy rains and flooding in Tennessee (May), China, India (June, July) and Pakistan (July, August); the Russian heat wave and wild fires (July, August); the vigorous Atlantic hurricane season; record flooding in Colombia (October-December); drought in Brazil (October); cold outbreaks in Europe and the United States (December); and flooding in Queensland, Australia as the year came to an end. Many of these events are described in detail online at the NOAA National Climatic Data Center, State of the Climate, Global Hazards site: <http://www.ncdc.noaa.gov/sotc/hazards/2010/m> where m is the month. For Colombia, see also <http://climatesignals.org/2010/12/columbia-hit-by-heaviest-rains-in-countrys-history/>.

change in climate is most likely to be perceived by encountering new “weather” and breaking records:

changes in the extremes. There are many examples over the 2010 year (Box 1).

It is important to recognize that both natural variability and global warming from humans are pervasive. It is thus highly desirable to know how much of each we are experiencing, as it has implications for the future. The inherent natural variability is much larger in some variables and in regional variations than, say, for global mean temperature. Yet given our understanding of the climate system, it is not possible for changes in one variable to occur without changes in others, at least to some degree. So the question should not be is there a human component, but what is it? In many model studies, the metric of Fraction of Attributable Risk (FAR)⁴ is used to express the fraction of risk of a particular threshold being exceeded. Hence it builds in the ratio of the values in the two curves in Figure 1. Nevertheless, the null hypothesis of no human influence is often implied but is fraught with problems of interpretation⁵. With perfect data and models, assessing the human component is not a problem, but it is argued that sources of uncertainty in the observational record and models should not be preferentially assigned toward underestimating the human component, as occurs at present.

ATTRIBUTION STUDIES

Perhaps the most obvious example of human influence on climate is the urban heat island effect associated with changing land use and concrete “jungles” in cities and urban areas. But such changes are very local and small on a global basis. Cities occupy less than 0.5% of land area⁶. However, there is also no doubt that human activities have changed and continue to change the composition of the atmosphere; in particular, concentrations of carbon dioxide have increased by 40% relative to pre-industrial values, the ozone layer has been greatly impacted by human-made chemicals, and there are changes in other greenhouse gases as well as visible pollution (aerosols). These changes produce heating and cooling of the climate system through their radiative forcing effects and influences on clouds². Moreover, the climate system is responding quantitatively to these forcings and global warming is “unequivocal” and “very likely” due to human activities². Besides, there is no other viable explanation to the observed temperature changes.

The strongest attribution studies have been for global mean temperature, and they have been repeated by many groups using different climate

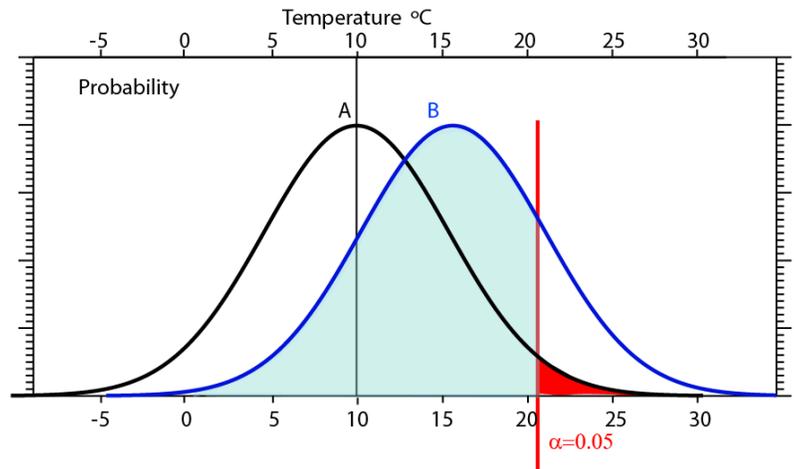
models which are required to separate out the human from natural components via numerical experimentation². But many other quantities have now been examined including temperature structure in the vertical, continental and regional temperatures, sea level pressure, water vapour, tropical sea surface temperatures, tropical storms, upper ocean warming, and some extremes¹. More recently a discernable human component in precipitation intensity and flooding has been determined^{7,8}.

There are several problems in these studies. 1) They are done one by one. 2) They require long homogeneous datasets to document a signal and noise that then should be reproduced by models in order to subsequently be able to take it apart. In the absence of adequate datasets, the results may not be significant or model estimates of noise have to be substituted. 3) Attribution relies on a signal-to-noise ratio: the signal from the human forcing vs the noise of natural variability. If the latter is estimated from models it may be underestimated and then give an apparent attribution that is not warranted. 4) Many attribution studies are not possible because aspects of the observed behaviour cannot be reproduced by models. This may be in part because of the chaotic atmospheric behaviour that limits predictability, but often there are inadequacies in the models^{9,10}. These relate to computer and resolution issues, as well as incomplete understanding, and thus depiction of the pertinent physics (such as clouds, or ocean mixing) and lack of the relevant phenomena (such as tropical storms). The simulations thus contain substantial regional errors: an Inter-tropical Convergence Zone (ITCZ) that migrates erroneously across the equator with the seasons and large errors in monsoon regions, and thus substantial errors in precipitation fields; poor simulations of blocking¹⁰ and teleconnections feedbacks¹¹, and so on. Often in such cases, it is incorrectly concluded that the events are due to natural variability instead of the correct finding that the tools are inadequate.

TYPE I AND TYPE II ERRORS

Prior to the 2007 IPCC report², it was appropriate for the null hypothesis to be “there is no human influence on climate” and the task was to prove that there was. The burden of proof is high and to prove that there is a human influence requires statistical tests to exceed the 95% confidence level (5% significance level) to avoid a chance finding of a false

FIGURE 2 | For a 1 SD (5.6°C) shift in the distribution (due to climate change) from A to B, only values of B to the right of the two-tailed 5% significance level ($\alpha = 0.05$ in red) would be considered significant under a null hypothesis of no change. All the values in the blue area of the B distribution would not.



positive. These limits are arbitrary and often make no sense⁵. To declare erroneously that the null hypothesis is not correct is called a Type I error, and the science is very conservative in this regard about making such an error. Scientists are thus prone to make what are called Type II errors whereby they erroneously accept the null hypothesis when it is in fact false, see Fig. 2.

It has become clear that some aspects of the observed changes in climate are robust across models while some are not. The robust aspects are those that might be labelled “thermodynamic” and thus relate to warming. They include temperature changes for global, continental, land vs ocean, and polar regions, but they also include water vapour via the Clausius-Clapeyron equation that determines the water holding capacity of the atmosphere as a function of temperature. The parts that are not as robust are those associated with dynamics and the atmospheric circulation in particular. The inherent internal natural variability of the latter is simply much larger relative to any signal expected at the current time¹².

The water holding capacity of the atmosphere goes up at about 7% per degree K. The actual water vapour amounts will follow this provided relative humidity remains about the same, as seems to be the case over the oceans where there are no water availability restrictions, but with somewhat smaller changes over land^{13–17}. Over oceans, it is estimated that increases in total column water vapour are about 4% since the 1970s^{2,13}. Accordingly, the supply of moisture to storms also increases, with the exact amount depending on the changes in winds, thereby increasing the intensity of precipitation

(rain and snow)^{18,19}. This probably largely accounts for the outcomes of attribution studies dealing with heavy rains and floods^{7,8}. These changes are universal so that all storms are now operating in an environment that has changed, and even a “normal” storm must have heavier precipitation than it would have had 40 years ago. It includes hurricanes, such as Katrina, which has been estimated to have 6 to 8% more precipitation owing to human influences²⁰. In regions where sea surface temperatures (SSTs) are below normal because of short-term natural variability, because the human component is inherently multi-decadal, the precipitation intensity is likely still higher than it would otherwise have been.

Consider further precipitation, which has large natural variability. The first approach of a null hypothesis of no change due to humans typically results in an outcome suggesting that it cannot be rejected. Often this is interpreted to mean that there is no increase in precipitation by human influences, although the correct interpretation is that there is simply not enough evidence (not a long enough time series) or the noise is too large. A null hypothesis that there has been a change is trickier because one has to hypothesize something specific, such as “precipitation has increased by 5%” and then prove that it hasn’t. However, the large variability means that this second approach also concludes that a 5% increase in precipitation cannot be disproved. Given that global warming is happening and is pervasive, the first approach should no longer be used. As a whole the community is making too many Type II errors.

WEATHER VERSUS CLIMATE

It is frequently stated that “*climate is what we expect and weather is what we get*” which is sometimes probably erroneously attributed to Mark Twain but seems more likely attributable to Robert A. Heinlein in the 1973 science-fiction novel, *Time Enough For Love*. This is a statistical statement and does not deal with the physics or dynamics of climate. My own preference is to define weather as the phenomena that occur in the atmosphere, many of which arise from instabilities such as convective or baroclinic instability. Then climate is where the atmosphere systematically interacts with the rest of the climate system and external influences. The latter include the sun and human effects. The climate system includes the atmosphere, oceans, land and terrestrial system including all the lakes and rivers, and the cryosphere: the glaciers, ice caps, ice sheets and sea ice. Hence El Niño is inherently a climate phenomenon and weather patterns change with the phase of El Niño-Southern Oscillation (ENSO). The diurnal cycle and the seasons are, of course, climate phenomena. One does not have to use the conventional 30 year averages to define climate, and indeed doing so in an era of climate change causes difficulties by failing to recognize trends during the 30 years and by failing to provide a stable base for assessing human influences.

When certain unusual events occur in weather, a common statement made to the media is to assign a cause of the event to a meteorological phenomenon. It may be that heavy rainfall is assigned to a certain synoptic situation or a particular storm, the jet stream gets its share of the blame, or drought is blamed on a persistent anticyclone. This is really a description of how the event transpired but it is not causal. From a climate perspective the questions should be “why did the anticyclone persist?” Or “what changed the odds of the storm occurring in this place and time?” “Why was the jet stream located where it was and with the observed strength?” Often the answer does relate to known preferred patterns of variability such as the North Atlantic Oscillation (NAO) or ENSO that are reviewed in Chapter 3 of IPCC². So ENSO relates to anomalous SSTs whose changes are known to have a human component²¹. However, the NAO, which has dominated winter patterns in the Northern Hemisphere in its negative phase in 2009-10²² and 2010-11, is generally regarded as primarily an atmospheric phenomenon. Nevertheless, the extreme nature of the negative phase of the NAO raises questions about whether external influences

tilted the odds, such as from autumn snow cover²¹ perhaps linked to diminishing Arctic sea ice, or via stratospheric changes²³, perhaps associated with ozone depletion.

Mark Twain in the 1890s did say “*Everybody talks about the weather, but nobody does anything about it.*” My response, as quote in *USA Today*, 3 June 2011 in regard to the Mississippi flooding and the extensive tornado outbreaks was “*Now humans are doing something about the weather: global warming is contributing to an increased incidence of extreme weather because the environment in which all storms form has changed from human activities.*” Instead the common statement by many scientists that “a single event cannot be attributed to climate change although the odds of such events has increased” or something to that effect, overlooks the pervasive climate change that has occurred with its primary memory in the warming ocean and ice loss.

Some examples of 2010 events noted in Box 1 are analyzed in detail elsewhere²⁴, where we come to rather different conclusions than in some published studies. Given the record high SSTs (with an anthropogenic component) in several areas in 2010 and nearby record flooding events in Pakistan, Colombia and Queensland²⁴, a key question is what other consequences were there with regard to the atmospheric circulation? A basic point is that much is known and understood. Large climate anomalies in one place are unlikely to be divorced from other large anomalies occurring elsewhere at the same time because the atmosphere is global. To ignore these other events is negligent. But the models do not simulate many phenomena or patterns of variability very well, and this must be factored into any conclusions. Often there are many links in a chain of causality and a task is to sort out the contributions. Given the poor performance of models in simulating several of these links¹¹, it is likely not possible to disprove the empirical evidence that human influences played a role.

CONCLUSION

The climate has changed from human activities. A useful, but not fully correct way to think about climate change is that given in Fig. 1 whereby there is a shift in values so that the basic weather systems remain much the same. In particular, the atmospheric environment is now warmer and moister than it was prior to about 40 years ago. All storms develop in this changed environment. However, most of the time, the resulting weather is within the realm of previous experience (Fig. 1). Yet

all storms are different than they would have been. It is only when extremes occur that we notice the differences. Weather and natural variability dominate all events but there is a small, significant and growing anthropogenic component. The times when extremes break records are especially the cases when natural variability, such as El Niño, is working in the same direction as human-induced warming. This was especially the case for 2010 during and following²⁵ the El Niño event²⁴.

Attribution studies are very important but must not prejudice the results by failing to properly account for data and model shortcomings, and the task is to estimate the human component because it has implications for the future. The result of bad and misleading statements about attribution, of which there have been many, is to grossly underestimate the role of humans in climate events of note in recent times to the detriment of perceptions about climate change and subsequent policy debates.

ACKNOWLEDGMENTS

This research is partially sponsored by NASA grant NNX09AH89G. I thank Jim Hurrell for comments. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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FURTHER READING

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