Kevin E Trenberth; 7 November 2016

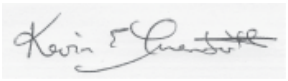
This is an Amicus Curiae Declaration in support of
The Commission on Human Rights of the Philippines
of Kevin E. Trenberth, Sc.D.:

1. My name is Kevin Trenberth. I reside in Boulder, Colorado. I am over 21 years of age and have personal knowledge of the statements contained herein. In this declaration, I provide information about the impacts of human-induced climate change on changing climate extremes. I am a distinguished senior scientist in the Climate Analysis Section at NCAR, the National Center for Atmospheric Research. The expert opinions I provide herein are my own and do not necessarily reflect the views of the National Center for Atmospheric Research or the National Science Foundation.

2. I have authored over 540 publications in the area of climate, and given hundreds of talks on the subject. I am among the most highly cited researchers in all of geophysics. I have extensively investigated global-scale climate dynamics, the observations, processes and modeling of climate changes from interannual to centennial time scales. I have particular expertise in El Niño, the hydrological and energy cycles, hurricanes and storms, and climate change. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I co-chaired the international Climate Variability and Predictability (CLIVAR) Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I have served as a member and officer of the Joint Scientific Committee that oversees the WCRP as a whole from 1998 to 2006. I chaired the WCRP Observations and Assimilation Panel from 2004 to 2010 and from 2010 to 2014 I chaired the Scientific Steering Group of GEWEX: the Global Energy and Water Cycle Experiment of WCRP. I remain involved in CLIVAR committees. I have been involved in global warming science and extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a lead author of individual chapters, the Technical Summary, and Summary for Policy Makers (SPM) of Working Group (WG) I for the Second, Third and Fourth Assessment Reports (SAR, TAR and AR4; IPCC 1996, 2001, 2007). I was a Coordinating Lead Author for the SAR and AR4, and in the latter I led Chapter 3 that dealt with observations of the surface and atmospheric climate change. I was a Review Editor of the Fifth IPCC Assessment Report (AR5) in 2013.

3. The IPCC is a body of scientists from around the world convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological
Organization (WMO) and initiated in 1988. Its mandate is to provide policy makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate and the effects of human activities on climate in particular. Major assessments were made in 1990, 1995, 2001, 2007, and 2013. Each new IPCC report reviews all the published literature over the previous 5 to 7 years, and assesses the state of knowledge, while trying to reconcile disparate claims and resolve discrepancies, and document uncertainties. The IPCC process is very open. The strength is that it is a consensus report. For the Policy Maker's Summary, scientists determine what can be said, but the governments help determine how it can best be said. Negotiations occur over wording to ensure accuracy, balance, clarity of message, and relevance to understanding and policy. The latest reports reaffirm in much stronger language that the climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening.

4. I am very concerned about the damage already occurring from climate change, not the least of which has affected the Philippines, especially through stronger and bigger typhoons. It happens that some of my research touches on this issue.



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The role of human-induced climate change on damaging climate extremes

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Summary

Weather and climate extremes happen all of the time, even in an unchanging climate. Yet there is a justifiably strong sense that some of these extremes are becoming more frequent, and that the main reason is human-induced climate change. Indeed, the main way in which climate change is likely to affect societies around the world is through changes in extremes.

How global warming affects extreme events

Changes in atmospheric composition from human activities, primarily the burning of fossil fuels and deforestation, enhance the greenhouse effect, although with important regional effects from aerosol particulates. Globally on a day-to-day basis these effects are 1 to 2% of the flow of natural energy through the climate system. However, because global warming is always heating the planet, there is a much bigger impact from the cumulative effects. Hence, all weather events are now occurring in an environment which has changed in significant ways.

The main memory of these changes is through the warming of the oceans and the loss of Arctic sea ice. Sea surface temperatures have warmed by more than 1°F since the 1970s, and over the oceans this has led to 4 to 6% more water vapor in the atmosphere. The warmer and moister environment in turn has likely led to a 5 to 10% effect on storms that exceeds previous bounds for extreme weather events.

Consequently, global warming has a direct influence on changes in precipitation and heavy rains, as well as contributing to increased temperatures and heat waves. Increased heating leads to greater evaporation and thus surface drying, thereby increasing intensity and duration of drought events. However, the water-holding capacity of air increases by about 4% per 1°F warming (or 7% per 1°C) , which leads to increased water vapor in the atmosphere, and this provides the biggest influence on precipitation. Storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones and hurricanes, supplied by increased moisture, produce more intense precipitation events, even in places where total precipitation is decreasing. In turn this increases the risk of flooding. At the same time, dry spells in between such events also increase.

There have also been observed changes in where it rains, with dry areas becoming drier (generally throughout the subtropics) and wet areas becoming wetter, especially in mid to high latitudes. This pattern is what we would expect from models that simulate global warming and is projected to continue into the future.

Conventional attribution

There is a tremendous desire to attribute causes to weather and climate events that is often challenging from a physical standpoint. The climate community has responded to the demand for timely information by attempting to perform attribution of climate extremes, partly through the IPCC reports but also through annual reports offering closer to real-time assessments and posing the question of whether the likelihood or strength of the event was affected by anthropogenic climate change.

More generally, there are perhaps two main kinds of attribution performed. The first relates the particular extreme event to the associated weather and weather patterns with statements such as 'the drought was caused by a blocking anticyclone'; 'the outbreak of tornadoes was caused by a displaced and active storm track and jet stream' but although useful, they are really a description of the event, not a cause and do not ask the questions 'Why did that weather phenomenon behave the way it did?' In particular, 'What influences external to the atmosphere were playing a role, and what climate factors were in play?'

The second kind of attribution relates to the objective of assessing the role of human activities, and especially of human-induced climate change, in the event. Results depend, however, upon how the questions are framed.

In the past the traditional way of approaching attribution tried to deal with all aspects of the problem. But the changes in weather phenomena and weather systems, where they go, and so forth have infinite variety (called weather) and any climate change signal is tiny (except in the case of the ozone hole). This has confounded the results. In particular, the conventional approach to attribution of climate events is to characterize the event and ask (i) whether the likelihood or strength of such events has changed in the observational record, and (ii) whether this change is consistent with the anthropogenic influence as found in one or more climate models. This approach has had considerable success with extremes that are strongly governed by thermodynamic aspects of climate change, especially those related to temperature, each finding providing another independent line of evidence that anthropogenic climate change is affecting climate extremes.

The conventional approach, however, is severely challenged when it comes to climate extremes that are strongly governed by atmospheric circulation, including local aspects of precipitation. It is inherently conservative and prone to false negatives, which underestimate the true likelihood of the human influence.

More fruitful scientific questions

In contrast to thermodynamic aspects of climate, forced circulation changes in climate models can be very non-robust, and physical understanding of the causes of these changes is generally lacking. Separating out the thermodynamic from dynamic effects may be a fruitful way forwards and result in a different set of questions to be addressed:

- Given the weather pattern, how were the temperatures, precipitation and associated impacts influenced by climate change?
- Given a drought, how was the drying (evapotranspiration) enhanced by climate change, and how did that influence the moisture deficits and dryness of soils, and the wildfire risk? Did it lead to a more intense and perhaps longer-lasting drought, as is likely?
- Given a flood, where did the moisture come from? Was it enhanced by high ocean temperatures that might have had a climate change component?
- Given a heat wave, how was that influenced by drought, changes in precipitation (absence of evaporative cooling from dry land) and extra heat from global warming?
- Given extreme snow, where did the moisture come from? Was it related to higher than normal SSTs off the coast or farther afield?
- Given an extreme storm, how was it influenced by anomalous SSTs and ocean heat content (OHC), anomalous moisture transports into the storm, and associated rainfall and latent heating? Was the storm surge worse because of high sea levels?

In other words, given the change in atmospheric circulation that brought about the event, how did climate change alter its impacts?

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At least in the present state of knowledge, in our view a more fruitful and robust approach to climate extreme-event attribution is to regard the circulation regime or weather event as a conditional state (whose change in likelihood is not assessed), and ask whether the impact of the particular event was affected by known changes in the climate system's thermodynamic state (for example sea level, sea surface temperature or atmospheric moisture content), concerning which there is a reasonably high level of confidence.

Examples

There are several events whose attribution has not been addressed but that received an enormous amount of media attention, one example being Super Typhoon Haiyan/Yolanda, the strongest recorded storm ever to reach land. The ocean heat content (OHC) and sea level in the region had increased a great deal since 1993 and especially since 1998. Consequently, as the typhoon approached the Philippines, it was riding on very high sea surface temperatures (SSTs) with very deep support through the high OHC, and the strong winds and ocean mixing did not cause as much cooling as would normally be experienced, probably helping the storm to maintain its tremendous strength. Moreover, the storm surge was undoubtedly exacerbated considerably by the sea levels, which were some 30 cm above 1993 values. Although natural variability played a major role, there was also a global component through increased OHC from the Earth's energy imbalance.

Conflicting results for the Russian heat wave in 2010 were to some extent reconciled by recognizing that each study was about different aspects. One study focused on dynamical aspects whereas the other was much more about the record high temperatures and thermodynamic aspects.

One study of the recent California drought found no significant trends in winter precipitation in recent decades, another pointed out the critical role of the record high annual mean temperatures in combination with record low annual mean precipitation for 2013 which led to increased evapotranspiration and more intense drought. The combination of these had impacts on water shortages, vegetation and agriculture, and increased wildfire risk. The odds of this combination have increased with human-induced climate change and anthropogenic warming has increased drought risk. Again these two studies are consistent with the view that the atmospheric circulation changes are not the dominant factor as far as the climate change aspects are concerned.

Hence the consequences are that things dry out quicker (stronger longer droughts) –as the atmosphere demands more evaporative moisture - and the extra moisture means heavier rains and greater risk of flooding, as observed in 2016 in hurricane Matthew and the earlier Louisiana floods. In fact it is the combination of natural variability (weather, El Niño etc.) and climate change when they go in the same direction that causes records to be broken. Hence there are more extremes of all sorts.

The changes in extremes have huge impacts on society and on ecosystems and the environment. The costs of the total events are in the tens of billions of dollars each year, but there is no clean separation as to how much should be ascribed to human influences. Of course the human costs and loss of life are also enormous. In one sense, the extreme event would not have happened without global warming, because otherwise the event would have been well within previous experience, and so the whole cost might be so assigned. Every event is different. They occur in different places and evolve very differently, whether floods, wild fires, or heat waves, but they all have one aspect in common, they would not have been as severe without the human influence.