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A probabilistic analysis of human influence on recent record global mean temperature changes

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ABSTRACT

December 2013 was the 346th consecutive month where global land and ocean average surface temperature exceeded the 20th century monthly average, with February 1985 the last time mean temperature fell below this value. Even given these and other extraordinary statistics, public acceptance of human induced climate change and confidence in the supporting science has declined since 2007. The degree of uncertainty as to whether observed climate changes are due to human activity or are part of natural systems fluctuations remains a major stumbling block to effective adaptation action and risk management. Previous approaches to attribute change include qualitative expert-assessment approaches such as used in IPCC reports and use of 'fingerprinting' methods based on global climate models. Here we develop an alternative approach which provides a rigorous probabilistic statistical assessment of the link between observed climate changes and human activities in a way that can inform formal climate risk assessment. We construct and validate a time series model of anomalous global temperatures to June 2010, using rates of greenhouse gas (GHG) emissions, as well as other causal factors including solar radiation, volcanic forcing and the El Niño Southern Oscillation. When the effect of GHGs is removed, bootstrap simulation of the model reveals that there is less than a one in one hundred thousand chance of observing an unbroken sequence of 304 months (our analysis extends to June 2010) with mean surface temperature exceeding the 20th century average. We also show that one would expect a far greater number of short periods of falling global temperatures (as observed since 1998) if climate change was not occurring. This approach to assessing probabilities of human influence on global temperature could be transferred to other climate variables and extremes allowing enhanced formal risk assessment of climate change.

Introduction

There is a clear upward trend in global temperatures from 1882 to 2013 with a number of short time periods of stable or falling temperatures (Fig. 1). Of particular note, from March 1985 to December 2013 there was an unbroken sequence of

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average monthly temperatures exceeding the 20th century average for each corresponding month resulting in a total of 346 months. Such a fact would seem to strongly support the hypothesis that global warming is occurring, but the question remains: how strong is this evidence (Bowman et al., 2010)? Even given these and other extraordinary statistics as well as the body of evidence synthesised in the Intergovernmental Panel on Climate Change (IPCC, 2007, 2013) regarding climate trends, detection and attribution, public acceptance of human induced climate change and confidence in the supporting science has declined since 2007 (Leiserowitz et al., 2011). The degree of uncertainty as to whether observed climate changes are due to human activity or are part of natural systems fluctuations remains a major stumbling block to effective adaptation action and risk management. Consequently, there are calls for alternative analyses to better understand climate change risks as well as improved approaches to effectively communicate this risk (Bowman et al., 2010). Previous approaches to attribute change to human influence include qualitative expert-assessment approaches such as used in the IPCC reports and use of 'fingerprinting' methods based on global climate models. Here we develop an alternative approach which provides a rigorous statistical assessment of the link between observed climate changes and human activities in a way that can inform formal climate risk assessment.

The approach used here allows us to make probabilistic statements about the likelihood of this anomalous warming occurring in the presence or absence of anthropogenic GHG emissions. In this regard it complements and extends existing climate change detection and attribution research using dynamic global climate model simulations and optimal fingerprint analysis (Hegerl and Zwiers, 2011; Berliner et al., 2000; Allen et al., 2000; Hansen et al., 2010; Easterling and Wehner, 2009) and professional assessments of the literature (IPCC, 2007). For example, a value of 95% for the probability of anthropogenic climate change was given by the IPCC whereas our approach progresses research on the statistical detection of climate change (Hansen et al., 2010; Rhamstorf and Coumou, 2011) to include the probability of that change.

Recent research has begun to inspect this issue through attribution studies including examination of the effect of the global warming trend on temperate extremes and variability (Rhamstorf and Coumou, 2011; Medvigy and Beaulieu, 2012; Barriopedro et al., 2011; Hansen et al., 2012). Rhamstorf and Coumou (2011) suggest an approximate 80% probability that the July 2011 heat record in Moscow would not have occurred without global warming. Hansen et al. (2012) use a statistical summary analysis to illustrate changes in the distribution of the surface air temperature anomalies around the globe from 1951 to 2010, normalised by local standard deviation estimates. Their analysis indicated that both the location and spread of this distribution increased over time, but because no statistical model was constructed they were unable to test for the statistical significance of these changes.

Both the approaches of Rhamstorf and Coumou (2011) and Hansen et al. (2012) are limited in their ability to make firm probabilistic statements about the changes that are observed because neither uses a validated statistical model in their analysis. The statistically robust approach used in this paper, incorporates time series modelling, validation and bootstrap simulation and provides a probabilistic assessment of global warming, strongly complementing the scientific evidence for the anthropogenic origin of recent climate change. Methods that account for temporal dependencies in climate data have been considered before in the statistical downscaling literature; see e.g. Charles et al. (2004), but their emphasis was on model skill and projections rather than attribution, which is essential for the current application.

To construct the statistical model we use GHG concentration, solar radiation, volcanic activity and the El Niño Southern Oscillation cycle as these are key drivers of global temperature variance (IPCC, 2007, 2013; Meinshausen et al., 2011; Allan, 2000; Benestadt and Schmidt, 2009; Gohar and Shine, 2007; Wang et al., 2005). This analysis uses recorded data (NOAA National Climate Data Centre, 2011) avoiding the uncertainties that can arise in the complementary climate model-based fingerprint studies (Hegerl and Zwiers, 2011).

Observations of short periods where global mean temperatures have fallen, even though atmospheric concentrations of GHGs were rising, have also raised questions as to the causal link between concentrations and warming (Plimer, 2009). The

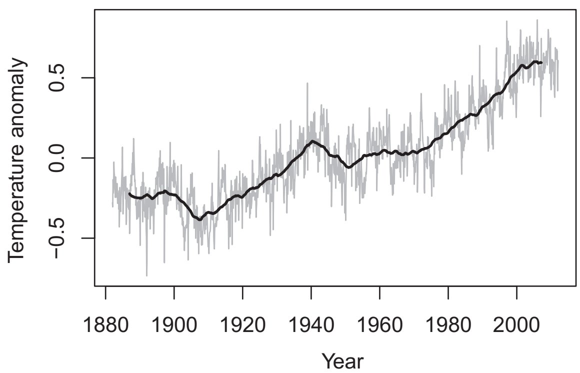

Fig. 1. Global monthly mean land and sea surface temperature anomaly: January 1882 to April 2012 time series relative to a 1901–2000 base period (grey line), and a 5 year running mean of this time series (black line) (*Source*: http://www.ncdc.noaa.gov/cmb-faq/anomalies.html). (Smith et al., 2008).