Weather and Climate Extremes 14 (2016) 24–35

Contents lists available at ScienceDirect

Weather and Climate Extremes

journal homepage: www.elsevier.com/locate/wace

Attribution analyses of temperature extremes using a set of 16 indices

Nikolaos Christidis*, Peter A. Stott

Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK

ARTICLE INFO

Keywords:
Detection and attribution
Temperature extremes
Anthropogenic forcings

ABSTRACT

Detection and attribution studies have demonstrated that anthropogenic forcings have been driving significant changes in temperature extremes since the middle of the 20th century. Moreover, new methodologies have been developed for the attribution of extreme events that assess how human influence may have changed their characteristics. Here we combine formal statistical analyses based on optimal fingerprinting to attribute observed long term changes in temperature extremes with an ensemble-based approach for event attribution. Our analyses are applied to 16 indices constructed with daily temperature data that focus on different characteristics of extremes and together build up a more complete representation of historical changes in warm and cold extremes than previous studies. For each index we compute an annual value for all years of the post-1960 period using data from observations and experiments with a coupled Earth System model for the analysis of multi-decadal changes and a high-resolution atmospheric model for event attribution. The models indicate that anthropogenic forcings have influenced almost all indices in recent decades and led to more prominent changes in the frequency of extremes. The optimal fingerprinting analyses show that for most indices the anthropogenic signal is detectable in changes during 1961–2010 both in Europe and on a quasi-global scale. The weaker natural effect, resulting mainly from volcanic eruptions, is in most cases not detectable, with the exception of large scale changes in indices linked to the frequency of cold night-time extremes. Our event analyses estimate how anthropogenic forcings alter the chances of getting new record index values in Europe and find that such extremes would be markedly rare if human influence were not accounted for, whereas in the current climate their return times range from a few years to a few decades.

1. Introduction

Accumulating evidence from detection and attribution studies helped establish that anthropogenic forcings have significantly changed characteristics of daily temperature extremes in recent decades (Bindoff et al., 2013). Detailed assessments investigating temperature extremes in the context of anthropogenic climate change (Seneviratne et al., 2012), including studies of individual events (NAS, 2016), elicit great public and media interest, primarily because of the socio-economic impacts associated with extremes. For example, recent catastrophic heatwaves in Europe (Christidis et al., 2015a; Dole et al., 2011) exposed the vulnerability of communities, while an increased incidence of heat extremes worldwide would take its toll on human health (McMichael, 2013; Wolf and McGregor, 2013) increase fire risk (Yoon et al., 2015), exert stress on crops (Teixeira et al., 2013), exacerbate air pollution (Lelieveld et al., 2014) etc. Assessing the contribution of causal factors like anthropogenic forcings to observed changes in extremes or extreme events can be a valuable tool for decision making, e.g. by aiding effective adaptation planning, and an integral part of the developing climate services (Hewitt et al., 2012).

Attribution of extremes and extreme events is a growing research area marked by major advances over the last 10–15 years. The earlier work focussed on long term trends in simple indices of daily temperature extremes like the coldest and warmest day and night of the year (Hegerl et al., 2004). Christidis et al. (2005) applied an optimal fingerprinting methodology (Allen and Stott, 2003) to formally establish for the first time significant anthropogenic warming in daily temperature extremes since the 1950s. Subsequent work also considered more sophisticated indices from the extreme value theory that better represent the tails of the distribution and confirmed that the anthropogenic fingerprint is detectable in observed changes of both hot and cold extremes (Christidis et al., 2011; Zwiers et al., 2011). Apart from global changes, fingerprinting analyses demonstrated detectable anthropogenic warming in extremely warm and cold nights in several continental and sub-continental regions (Min et al., 2013; Wen et al., 2013). Detectable changes in the frequency of daily temperature extremes due to human climatic influences have also been found on global and regional scales (Morak et al., 2013).

* Corresponding author.
E-mail address: nikos.christidis@metoffice.gov.uk (N. Christidis).

http://dx.doi.org/10.1016/j.wace.2016.10.003
Received 18 August 2016; Received in revised form 21 October 2016; Accepted 25 October 2016
Available online 27 October 2016

While long term changes in extremes have been mainly investigated by fingerprinting analyses, the new science of event attribution has developed novel methodologies to quantify how anthropogenic forcings may change characteristics of specific extreme events (Stott et al., 2016). A series of annual reports published in the Bulletin of the American Meteorological Society (BAMS) since 2012 explaining extreme events of the previous year from a climate perspective showed a substantial influence on the frequency and intensity of heat events by human-caused climate change (Herring et al., 2015). The large volume of attribution studies of hot and cold high-impact events around the world that have been published both in BAMS and elsewhere in the literature underpin the conclusion of the Intergovernmental Panel on Climate Change (IPCC) that "it is very likely that human influence has contributed to the observed changes in the frequency and intensity of daily temperature extremes on the global scale since the mid-20th century" (Bindoff et al., 2013).

The new attribution study presented here has a threefold aim:

a) Provide a more comprehensive description of temperature extremes and examine how anthropogenic climate change might have influenced their different characteristics. This is achieved by employing the complete suite of the original 16 temperature extreme indices introduced by the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDI; http://etccdi.pacificclimate.org/). While some of these indices have been popular in attribution research, there is no study yet, to our knowledge, which has considered the entire range and about half of the indices are investigated here for the first time.
b) Produce a synthesis attribution assessment that examines the effect of human influence on both trends in extremes and extreme events. The popular fingerprinting methodology is employed to assess long term changes in characteristics of temperature extremes. The suite of indices used in the study leads to new definitions of extreme events. Most event analyses consider the mean temperature over a period and define a threshold above (or below) which an extremely hot (or cold) event occurs. For example, studies of the European heatwave of 2003 defined heatwaves using the summer mean temperature over a large European area (Stott et al., 2004; Christidis et al., 2015a). Here we look at the annual mean index value instead, which also provides a useful event definition. For example, a large number of tropical nights or frost days (two of the ETCCDI indices) in a region would define events that are more directly linked to certain health or agricultural impacts. The most suitable index for an attribution analysis would depend on the aspect of the event that the study concentrates on.
c) Utilise two of Hadley Centre's state-of-the art climate models in new analyses of temperature extremes. A major upgrade of the atmospheric model that forms the basis of Hadley Centre's event attribution system (Christidis et al., 2013) was recently undertaken by the EUCLEIA project (http://eucleia.eu). This resulted in a system that features the highest resolution global model used in event attribution studies. Shiogama et al. (2016) also employed a high-resolution model, which, however, has fewer vertical levels, while other high resolution analyses rely on regional models (e.g. Massey et al., 2015; Takayabu et al., 2015). A more complex Earth System model was utilised in the analyses of long term changes.

The remainder of the paper comprises a description of the data and methods used in the study (Section 2), a presentation of results (Section 3) and a discussion of the main findings and future developments (Section 4).

Table 1
The 16 ETCCDI indices of temperature extremes used in this study.

Abbreviation	Index description
FD	Number of frost days (Tmin < 0 °C)
SD	Number of summer days (Tmax > 25 °C)
ID	Number of icing days (Tmax < 0 °C)
TN	Number of tropical nights (Tmin > 20 °C)
GSL	Growing season length (Number of days between first span from the beginning of winter of at least 6 days with Tmean > 5 °C and first span of at least 6 days after the first month of summer with Tmean < 5 °C)
TXx	Maximum Tmax (warmest day)
TNx	Maximum Tmin (warmest night)
TXn	Minimum Tmax (coldest day)
TNn	Minimum Tmin (coldest night)
TN10p	Percentage of days when Tmin < 10th climatological percentile (base period 1961–99)
TX10p	Percentage of days when Tmax < 10th climatological percentile (base period 1961–99)
TN90p	Percentage of days when Tmin > 90th climatological percentile (base period 1961–99)
TX90p	Percentage of days when Tmax > 90th climatological percentile (base period 1961–99)
WSDI	Warm spell duration (Annual count of days with at least 6 consecutive days when Tmax > 90th percentile)
CSDI	Cold spell duration (Annual count of days with at least 6 consecutive days when Tmin < 90th percentile)
DTR	Daily temperature range (Mean difference between Tmax and Tmin)

2. Data and methodology

2.1. The HadEX2 dataset

The observations used in our study come from HadEX2, a global gridded dataset of 27 ETCCDI temperature and precipitation climate extreme indices (Donat et al., 2013). This is an extension of the original HadEX dataset (Alexander, 2006), which included considerably fewer stations and a smaller spatial coverage. Here we examine only temperature extremes and use the original set of 16 indices shown in Table 1. The indices describe different aspects of temperature extremes. While some of the indices that measure the intensity (TXx, TNx, TXn, TNn) and frequency (percentile based indices) of extremes have been popular in attribution studies, here we also consider those indices that employ critical temperature thresholds useful for impact studies. We also provide new analyses of changes in the growing season length and diurnal temperature range. HadEX2 and its predecessor have demonstrated significant changes since last century with extremes of the minimum daily temperature (TN) shown to have warmed more than those of the maximum temperature (TX). This asymmetry, also noted elsewhere in the literature (Morak et al., 2013), means that in a warming climate the temperature distribution does not simply shift as a whole to a warmer regime, but also changes in shape.

Although the HadEX2 data extend over the period 1901–2010, we only consider post-1960 years in this study. This is because some of the model experiments used in the analysis do not include earlier years, but also because the observational coverage was poorer in the early part of the dataset. We examine both global changes in extreme characteristics spanning the length of half a century (1960–2010), as well as regional changes in trends and in the present-day likelihood of extremes due to anthropogenic drivers. For illustration purposes we concentrate on a region that covers the European continent (30W-50E, 30-80N), which is of particular interest to the EUCLEIA project, though of course the same methodologies can also be applied to other regions.

European index timeseries are shown in Fig. 1 and the linear trends over the analysis period (1960–2010) averaged over the entire observational area and over Europe are listed in Table 2. The global trend patterns are illustrated in Fig. 2. Testing the hypothesis that the