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LETTER

Greater increases in temperature extremes in low versus high income countries

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Abstract

It is commonly expected that the world's lowest income countries will face some of the worst impacts of global warming, despite contributing the least to greenhouse gas emissions. Using global atmospheric reanalyses we show that the world's lowest income countries are already experiencing greater increases in the occurrence of temperature extremes compared to the highest income countries, and have been for over two decades. Not only are low income countries less able to support mitigation and adaptation efforts, but their typically equatorial location predisposes them to lower natural temperature variability and thus greater changes in the occurrence of temperature extremes with global warming. This aspect of global warming is well known but overlooked in current international climate policy agreements and we argue that it is an important factor in reducing inequity due to climate impacts.

Extreme weather events bring with them increased risk to life and property and this risk is exacerbated in low income countries where adaptive capacity is low (IPCC 2014). Adaptive capacity is limited in these countries due to poor resource availability, fragile political institutions, and/or social and cultural practices (IPCC 2014). However, in addition to this most low income countries are located near the equator (Harrington *et al* 2016) and therefore temperatures in these countries are already close to the upper threshold for human comfort (Sherwood and Huber 2010). Furthermore, the naturally lower temperature variability—or narrower probability distribution—of the tropics compared to the extra-tropics means that smaller changes in temperature are required in order for previous temperature extremes to be exceeded. For these reasons, low income countries in the tropics are particularly exposed and vulnerable to the effects of global warming.

The different challenges of climate change facing low versus high income countries have long been recognised (United Nations Framework Convention on Climate Change, 1992), however, the consequences of this climate inequity are often discussed in a future tense—as an impending ramification of geography and economics (e.g. Mendelsohn *et al* 2006, De Cian *et al* 2016, Harrington *et al* 2016). The simple latitudinal difference between the majority of the world's low and high income countries (figure S1 available at stacks.iop.org/ERL/12/034007/mmedia) suggests that differences in the increase in temperature extremes between these country groups should already be evident in observations. While much discussion surrounds climate inequity (Althor *et al* 2016, De Cian *et al* 2016) and the effect of latitude on climate change and variability is well known (Mendelsohn *et al* 2006, Harrington *et al* 2016, Mahlstein *et al* 2011) we find no quantitative comparison of historical temperature extremes between low and high income countries. This is particularly important as it is usually through extremes that the impacts of climate change are felt.

To address this issue we compare trends in temperature extremes in low and high income countries using two indices recommended by the Expert Team on Climate Change and Detection Indices (Zhang *et al* 2011). The hots days frequency index (TX90p) represents the percentage of days each year where maximum temperature (TX) exceeds the calendar day 90th percentile for a given base period (here we use the base period 1961–1990 as recommended by the World

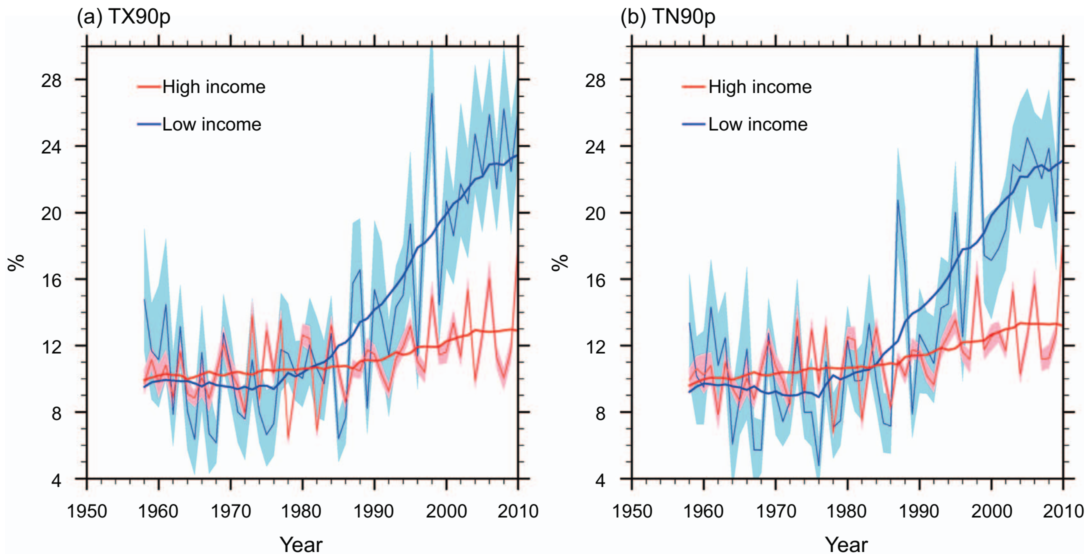

Figure 1. (*a*) The percentage of hot days (TX90p) each year experienced by low income (blue) and high income countries (red). (*b*) The percentage of warm nights (TN90p) each year experienced by low income and high income countries. Data taken from the 20th Century Reanalysis (Compo *et al* 2011), which consists of 56 ensemble members. Shading represents spread between ensemble members. Thick lines represent 20 year running means. See figures S2 and S3 for the same results from the European Reanalysis for the 20th Century (Poli *et al* 2016), and the Japanese 55 year Reanalysis (Kobayashi *et al* 2015), respectively.

Meteorological Organisation (1989)). The warm nights frequency index (TN90p) is the same as TX90p except that it corresponds to daily minimum temperatures (TN). Thus, TX90p and TN90p respectively represent the percentage of hot days and warm nights experienced each year, where 'hot days' and 'warm nights' are defined relative to each location's 1961–1990 climatology.

To calculate trends in TX90p and TN90p we use data from three state-of-the-art global atmospheric reanalyses covering the period 1958–2010 (see Supplementary Information). These products integrate available observations into numerical weather forecast models to provide global coverage of climate data that are physically consistent with observations. To identify low and high income countries we use 2010 Gross National Income (GNI) per capita (adjusted to current USD) from the World Bank (World Bank 2016a), along with the World Bank's classifications for national income for the same year (World Bank 2016b) to classify countries as low, lower-middle, middle-upper or high income earning (figure S1). Here we compare low income and high income earning countries, though our conclusions are similar when comparing low and lower-middle income earning countries to middle-upper and high income earning countries. Weightings based on 2010 global population densities (Center for International Earth Science Information Network—CIESIN—Columbia University, 2015) are applied to our calculations to minimise the influence of large, sparsely populated areas in certain countries (see Supplementary Information for more details). It is important to note that while figure S1 shows that most low income countries reside at low latitudes, not all low latitude countries are low income earning. Similarly, not all high latitude countries are high income earning.

Figure 1(*a*) shows that the occurrence of hot days each year has been increasing at a faster pace in low income countries than in high income countries since the 1980's. While we only show data from one reanalysis here, all three products show similar results (see figures S2 and S3 for remaining reanalyses). Averaging across all three reanalyses, low income countries have experienced an increase in the percentage of hot days each year from 10% during 1961–1990, to 22% in 2010 (i.e. from 37 d to 80 d per year), while high income countries experienced a corresponding average increase from 10% to 15% (i.e. from 37 d to 55 d per year). Thus low income countries have experienced more than twice the increase in the number of hot days occurring each year compared to high income countries.

The increase in hot days shown in figure 1(*a*) is closely mirrored by an increase in warm nights (figure 1(*b*)). Warm nights have, however, increased faster on average than hot days, consistent with global trends (Donat *et al* 2013). Low income countries experienced a mean increase between reanalyses from 10% during 1961–1990 to 26% in 2010 (i.e. from 37 d to 95 d per year), while high income countries experienced a mean increase from 10% to 16% (i.e. from 37 d to 58 d per year).

Increases in warm nights can contribute substantially to heatwave mortality (Karl and Knight 1997), as during heatwaves the human body depends upon night time temperatures to cool. In low income countries where air conditioning is uncommon, increases in warm nights limit the reprieve from increasing day time temperatures. This can also be a problem for low socio-economic groups in high income countries (e.g. Hayden *et al* 2011). The larger increase in the occurrence of day and night time extremes in low income countries (figure 1) contributes to a larger increase in the number of heatwave days experienced compared to high income countries (figure S4). While the ability of the human body to acclimatise to temperature change may mediate the effects of increasing hot days, warm nights and heatwaves, physiological limits and higher tropical humidity place tight constraints on the extent to which acclimatisation can take place (Sherwood and Huber 2010, Kjellstrom *et al* 2016).

It is noteworthy that the use of percentile based indices such as TX90p and TN90p forces both low and high income countries to exhibit the same percentage of hot days and warm nights during the base period 1961–1990 (that is, on average 10%; figure 1). Thus as far as changes in temperature extremes are driven by changes in mean temperature, low income countries have very likely experienced greater increases in the occurrence of extremes compared to high income countries since before the 1980's, though uncertainties in reanalyses prevent this from being conclusively shown. Two of the reanalyses used here contain data back to 1900, however, their agreement decreases prior to the 1950's, particularly over Africa (Donat *et al* 2016, figure S5). Furthermore, while the causes of increasing extreme temperatures are dominated by changes in mean temperature, changes in the shape and scale of the probability distribution may also play a role in some regions (Donat and Alexander 2012, Hansen *et al* 2012, Rhines and Huybers 2013).

Our results have several important implications. Firstly, low income countries have already suffered disproportionately from global warming and have done so for decades. Recent research based on modelling shows that low income populations should expect more severe temperature extremes earlier than high income populations as greenhouse gas emissions continue (Harrington *et al* 2016) and that low latitude countries experience significant changes in summer temperatures at lower levels of global warming (Mahlstein *et al* 2011). Our results build on these findings by showing, based on observationally constrained data, that increases in the frequency of hot extremes in low income countries already out paces that of high income countries. Combined with previous work (e.g. Mahlstein *et al* 2011, Althor *et al* 2016, De Cian *et al* 2016, Harrington *et al* 2016), our results should increase the pressure on 'free rider' countries—those that contribute disproportionately to greenhouse gas emissions but have limited exposure to its climatic effects—to support climate adaptation in low income countries. Secondly, if the rate of change in temperature extremes remains the same in low income countries, then within two decades the number of hot days experienced each year will very likely triple compared to the 1961–1990 average (figure 1). In regions where temperatures are already near the threshold for human comfort, and where there is a large dependence on outdoor labour and agriculture (IPCC 2014), such changes may be socially and economically destabilising (Hsiang and Burke 2014). Lastly, while the United Nations Framework Convention on Climate Change recognises climate inequity through the principle of common but differentiated responsibilities (United Nations Framework Convention on Climate Change 1992), it does not take into consideration the faster growth in temperature extremes that most low income countries have already experienced due to global warming (figure 1). Our findings give weight to arguments developed by many low income countries to justify an increase in their adaptation finance as they have already experienced disproportionately adverse impacts from global warming—and are likely to continue to do so. Our findings also lend support to calls for explicit loss and damage compensation. We suggest that mechanisms to distribute various types of human and financial resources currently in place through existing international climate agreements may be inadequate and that considering a country's historical climate trends can more fairly inform compensation.

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