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COMMENTARY
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The Inequality of Climate Change From 1.5 to 2°C of Global Warming

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Key Points:
- We use a signal-to-noise metric to examine changes in local climate between 1.5 and 2°C global warming
- The wealthiest areas of the world suffer far less local climate change than the poorest places if the 1.5°C target is breached
- Failing to limit global warming to 1.5°C will likely hamper sustainable economic development in the poorest regions of the world

Supporting Information:
- Supporting Information S1

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Abstract The Paris Agreement aims to keep global warming well below 2°C above preindustrial levels with a preferred ambitious 1.5°C target. Developing countries, especially small island nations, pressed for the 1.5°C target to be adopted, but who will suffer the largest changes in climate if we miss this target? Here we show that exceeding the 1.5°C global warming target would lead to the poorest experiencing the greatest local climate changes. Under these circumstances greater support for climate adaptation to prevent poverty growth would be required.

1. Main

The Paris Agreement was reached in December 2015 and has since been ratified by most member states, or parties, to the United Nation's Convention on Climate Change. The Agreement is more ambitious than the previous Kyoto Protocol in calling to limit the increase in global temperatures to 1.5°C above preindustrial levels. This will be a difficult task as the world has already experienced around 1°C of anthropogenic global warming to date (Haustein et al., 2017), although recent work has suggested it may still be achievable (Millar et al., 2017). Much of the impetus for the 1.5°C global warming target came from small island states concerned about sea level rise (Ourbak & Magnan, 2017). Here we show that the largest beneficiaries of reduced global warming, with respect to limiting perceptible temperature change, are people living in tropical regions. Conversely, if the 1.5°C Paris target is not met, then it will be populations and ecosystems in tropical regions, which tend to be less economically developed than higher-latitude regions, that will suffer the greatest changes. While the link between climate change and inequality has been drawn before (e.g., Harrington et al., 2016; Mahlstein et al., 2011; Schleussner et al., 2016), this is the first quantitative analysis for the policy-relevant Paris climate targets.

A simple metric for investigating possible climate changes is the signal-to-noise (S/N) ratio. This type of metric has been used in Time-of-Emergence studies (Frame et al., 2017; Hawkins & Sutton, 2012) as it incorporates both the local change in average temperature (the "signal") and the variability in temperature (the "noise") to provide a measure of the detectability and perceptibility of local climate changes. In regions of less variable climate, such as the tropics, smaller amounts of warming are required to have an adverse effect on flora and fauna as they are well adapted to the local climate (King et al., 2015; Mora et al., 2013). The S/N ratio may be used to measure this effect and has been applied to a diverse range of studies related to climate change, including analysis of impacts for individual species and ecosystems (Mora et al., 2013). Using an ensemble of state-of-the-art climate model simulations (Taylor et al., 2012) to select periods of global warming for the Paris target of 1.5°C above preindustrial and the higher 2°C target (King et al., 2017), we examine the S/N ratio between these targets. We simply define the signal as the average model warming of annual temperatures at each location between 1.5 and 2°C. The noise is defined as the average model standard deviation of annual temperatures in a preindustrial climate (see supporting information for further details). The model-ensemble median suggests that the largest S/N ratios, and thus the most perceptible climate changes, would generally occur in tropical regions between 1.5 and 2°C of global warming (Figure 1). In contrast, extratropical areas may experience similar signals of climate change, but as these regions experience greater year-to-year temperature variability and are well adapted to a more variable climate, their S/N ratios are lower than in the tropics. Similar results have been found previously (Hawkins & Sutton, 2012; King et al., 2015; Mahlstein et al., 2011, 2012; Schleussner et al., 2016), but it is remarkable that this difference in S/N ratios is so apparent for only a 0.5°C difference in global temperature.

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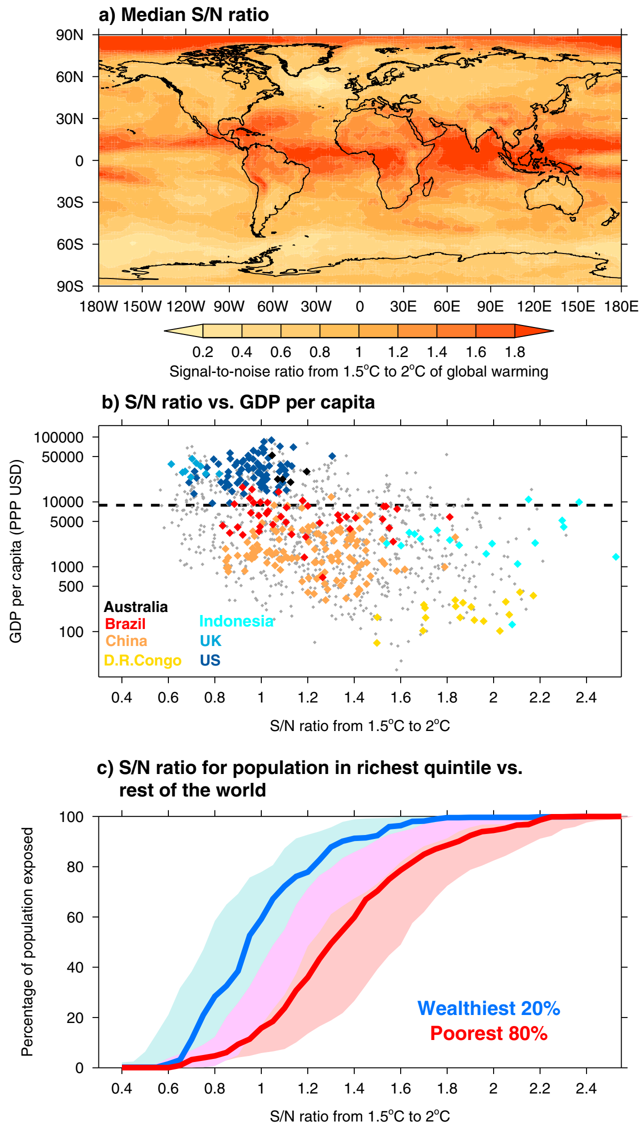

Figure 1. The greatest changes in temperature relative to variability occur in the tropics, and the poorest people would experience the most perceptible climate change from 1.5 to 2°C of global warming above preindustrial climate. (a) Map of the model median-average-simulated signal-to-noise (S/N) ratio from 1.5 to 2°C of global warming. (b) The relationship between model-median average local S/N ratios and gross domestic product (GDP) per capita (2010 estimates; United States Dollars Purchasing Power Parity) for all 2° grid boxes populated by more than one million people (also 2010 estimate). Several countries are highlighted with all other grid boxes shown in gray. (c) The S/N ratio experienced by a cumulative percentage of population in the richest 20% (blue) and the poorest 80% of the world (red). Median estimates are shown with shading representing the 90% confidence intervals (see supporting information for further details).

The wealthiest regions of the world tend to be located in the extratropics, while many of the world's poorest people live near the equator. Using gridded population and gross domestic product (GDP) data (Murakami & Yamagata, 2016), we find a strong inverse relationship between the S/N ratio at a location and the income of the people living there (Figure 1b). The first country to industrialize and emit large quantities of greenhouse gasses, the United Kingdom, would experience among the lowest average S/N ratio between the 1.5 and 2°C global warming targets of any nation. In contrast, less developed countries with much lower cumulative greenhouse gas emissions (e.g., http://cdiac.ess-dive.lbl.gov/trends/emis/meth_reg.html) experience greater changes in local climate between the 1.5 and 2°C warming levels. For example, the Democratic Republic of Congo, one of the world's poorest countries, would experience some of the largest changes in local climate at more than double the S/N ratio of the United Kingdom. Overall, the inverse relationship between a location's S/N ratio and its GDP per capita is strong (Spearman rank correlation of −0.43) and indicative of the inequality of potential future climate changes.

By grouping the S/N ratios experienced by the wealthiest 20% of the world's population and the rest of the world, we find a stark difference in local climate changes experienced between the 1.5 and 2°C global warming targets (Figure 1c). The median average S/N ratio between the targets that would be experienced by the wealthiest people on the planet is 0.94 (90% confidence interval: 0.77–1.22). In contrast, the average S/N ratio that a person in the rest of the world would experience is 1.3 (90% confidence: 1.06–1.59), 35% higher than for the average S/N ratio experienced by the wealthiest 20%. We have high confidence, given these statistics and the level of consistency in the relationship between S/N ratio and GDP per capita using individual climate models, that should the 1.5°C Paris target be exceeded it will be the poorest populations which would experience the greatest changes in local temperatures (see supporting information for further details).

This conclusion also holds for a wide variety of future socioeconomic projections, even beyond when the 1.5°C target is likely to be reached or exceeded (e.g., Henley & King, 2017). Using 2050 projections, under each of three shared socioeconomic pathways (SSPs; Riahi et al., 2017) ranging from a more sustainable future (SSP1) to a future with more regional rivalries (SSP3) we find that the inverse relationship between perceptibility of local climate change and the wealth of the location (Dellink et al., 2017; Leimbach et al., 2017) remains a robust characteristic. This is shown through aggregating locations by income decile (Figure 2) and by graphing the local S/N ratio and GDP per capita for each SSP (Figure S3). The correlation coefficients between S/N ratio and GDP per capita are very similar ranging from −0.5 to −0.52 across the three SSPs considered. The average S/N ratio experienced by a person in the poorest 80% of the world is 54% higher (best estimate) than that of a person in the wealthiest 20% of the world under SSP3. Whereas if a more sustainable pathway (SSP1) is followed, the difference between S/N ratios between the poorest 80% and the wealthiest 20% for the average person is reduced (to +42%, best estimate). It is clear that under conceivable scenarios for socioeconomic development over the next few decades the poorest parts of the world will experience greater levels of perceptible climate change than the wealthiest areas. The difference is significant and substantial and will result in inequality in climate change impacts should the 1.5°C Paris target be exceeded.

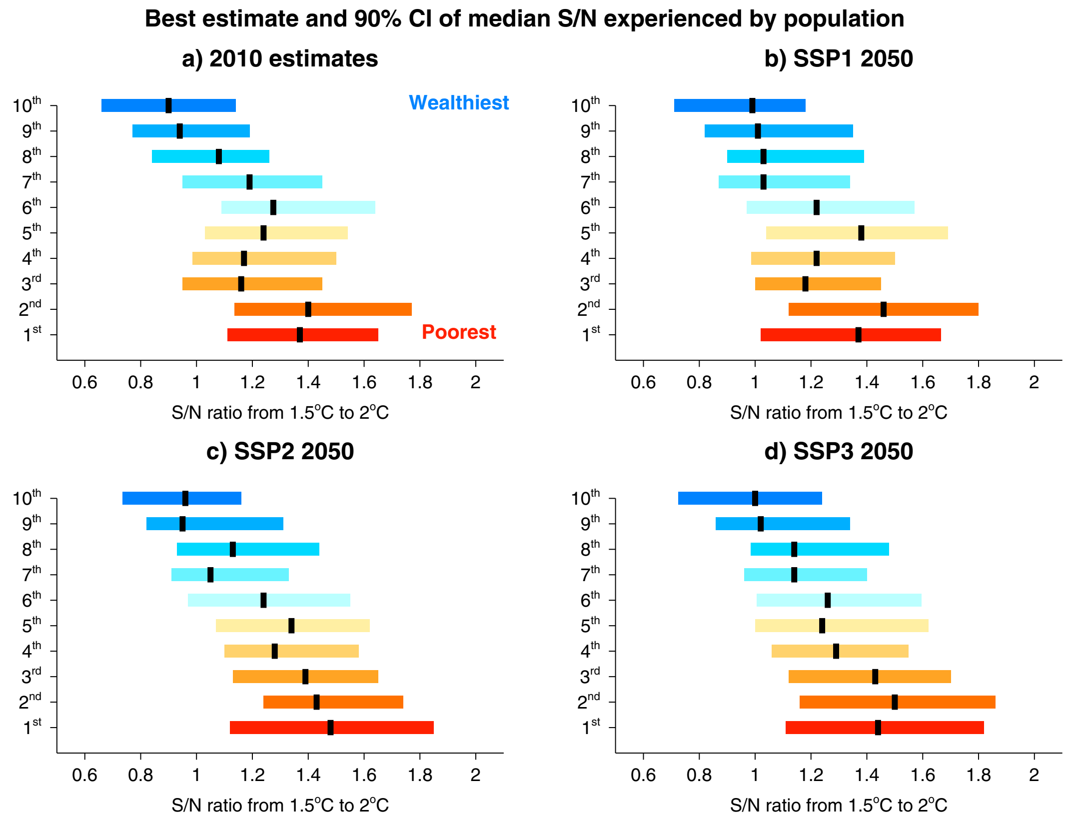

Figure 2. Under future socioeconomic pathways the inequality in perceptible climate change remains. The best estimate (black lines) and 90% confidence intervals (CI, colored bars) on the median signal-to-noise (SN) ratio experienced by populations of each income decile for (a) 2010 gross domestic product (GDP) and population estimates (total population: 6.9 billion), (b) 2050 SSP1 GDP and population estimates (total population: 8.4 billion), (c) 2050 SSP2 GDP and population estimates (total population: 8.9 billion), and (d) 2050 SSP3 GDP and population estimates (total population: 9.4 billion). Note that uncertainty arises from a combination of both uncertainty in the spatial pattern of the S/N ratio across the model ensemble and the overall global-average S/N ratio which differs between models (see supporting information for more details).

The United Nations' Sustainable Development Goals (UN SDGs; United Nations, 2015) include aims to eradicate extreme poverty (Goal 1), reduce inequality both within and between nations (Goal 10), and to strengthen action to combat the impacts of climate change (Goal 13). Previous studies have already noted the projected exacerbation of economic inequalities at a highly aggregated scale with unmitigated warming (Burke et al., 2015). However, our results illustrate from a physical climate perspective that limiting global warming to the Paris target of 1.5°C, rather than a higher 2°C target, would be perceptibly beneficial for low-income nations. The "avoided" S/N ratio (Frame et al., 2017) is shown to increase most for people from the poorer income deciles (Figure 2). Keeping global warming to low levels, such as the 1.5°C Paris target, therefore represents an even greater constraint as to whether other SDGs can be successfully achieved (Nilsson et al., 2016) and suggests present estimates of synergies across SDGs with Goal 13 (Pradhan et al., 2017) may be underestimated.

Conversely, if further action is not taken to strengthen the Nationally Determined Contributions and develop a pathway to meet the global warming targets of the Paris Agreement (Rogelj et al., 2016), then the greatest shifts in climate will be experienced by the poorest (Figure S3). Under such a scenario, support for climate adaptation in developing countries would need to be expanded to both limit the worst impacts of climate change (Hochrainer-Stigler et al., 2014; Mechler et al., 2014) and maintain economic development in these countries.

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