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AUTHOR(S):

Shiogama, Hideo; Fujimori, Shinichiro; Hasegawa, Tomoko; Takahashi, Kiyoshi; Kameyama, Yasuko; Emori, Seita

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# ENVIRONMENTAL RESEARCH COMMUNICATIONS

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LETTER • **OPEN ACCESS**

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## Environmental Research Communications



### LETTER

# How many hot days and heavy precipitation days will grandchildren experience that break the records set in their grandparents' lives?

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Hideo Shiogama<sup>1</sup> , Shinichiro Fujimori<sup>2</sup> , Tomoko Hasegawa<sup>3</sup> , Kiyoshi Takahashi<sup>4</sup> ,  
Yasuko Kameyama<sup>4</sup> and Seita Emori<sup>1</sup>

<sup>1</sup> Earth System Division, National Institute for Environmental Studies, Tsukuba, Ibaraki 305-8506, Japan

<sup>2</sup> Department of Environmental Engineering, Graduate School of Engineering, Kyoto University, Kyoto 615-8540 Japan

<sup>3</sup> College of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-Higashi, Kusatsu, Shiga 525-8577, Japan

<sup>4</sup> Social Systems Division, National Institute for Environmental Studies, Tsukuba, Ibaraki 305-8506, Japan

E-mail: [shiogama.hideo@nies.go.jp](mailto:shiogama.hideo@nies.go.jp)

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Supplementary material for this article is available [online](#)

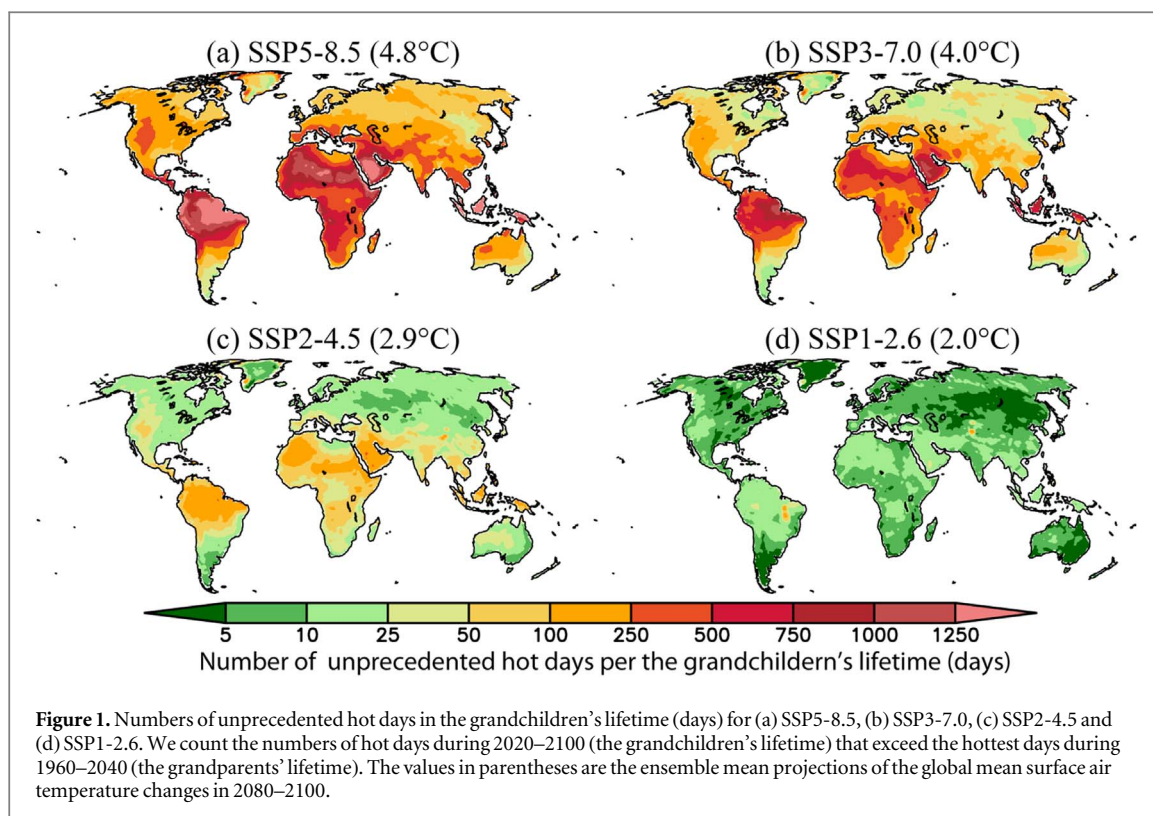
### Abstract

One of the major barriers to climate communication is that climate change is often presented to the public in such a way that impacts seem distant in time. To improve how climate change resonates with people, we propose a simple indicator: how many extreme events (hot days and heavy precipitation days) are grandchildren projected to experience that their grandparents will not experience in their lives? We analyse the Coupled Model Intercomparison Project Phase 6 ensemble. During grandchildren's lifetime (2020–2100) under the shared socioeconomic pathway 5–8.5 (SSP5-8.5), in some tropical regions, they are projected to experience >1000 hot days and >5 heavy precipitation days breaking records set in their grandparents' lifetime until 2040. These numbers of unprecedented hot days and heavy precipitation days under SSP5-8.5 are greater in countries with lower CO<sub>2</sub> emissions and income per capita than in countries with higher CO<sub>2</sub> emissions and income per capita. We show that not only the numbers of unprecedented hot days and heavy precipitation days but also their unevenness across countries can be significantly lowered in the SSP1-2.6 scenario, which is consistent with the 2 °C goal of the Paris Agreement. This new approach would help adults easily understand how their climate change mitigation efforts could decrease the unprecedented extreme events during youths' lifetime and reduce the intergenerational and intragenerational inequalities regarding extreme events.

### Introduction

When children are born, their parents and grandparents hope their lives will be safe and happy. Children have little voice in or power over the shape of their future. Decisions that will affect their lives are largely made by parents and grandparents (Clark *et al* 2020). Our cumulative emissions will determine the degree of climate change impacts that youth will experience in the future (IPCC 2018), but the current mitigation policies of nations are still insufficient to achieve the 1.5 and 2 °C goals of the Paris Agreement (UNFCCC 2015, UNEP 2019).

One of the major barriers to climate communication is that climate change is often presented to the public in such a way that impacts seem distant in time (Stoknes 2014, Weber 2016). Elderly adults, who generally have greater political powers than younger people, may feel that the year 2100 is too far removed for them. However, if their grandchildren are born in 2020 and live for 80 years, the grandchildren would experience the changing climate until 2100. Previous studies have illustrated future increases in the probability of unprecedented hot extremes (Differbaugh *et al* 2018) and timing when the climate moves to a state outside the bounds of historical



variability (Mahlstein *et al* 2011, Mora *et al* 2013, King *et al* 2015). Those analyses of unprecedented events and emergence of significant climate changes are useful for helping adults imagine their children's future.

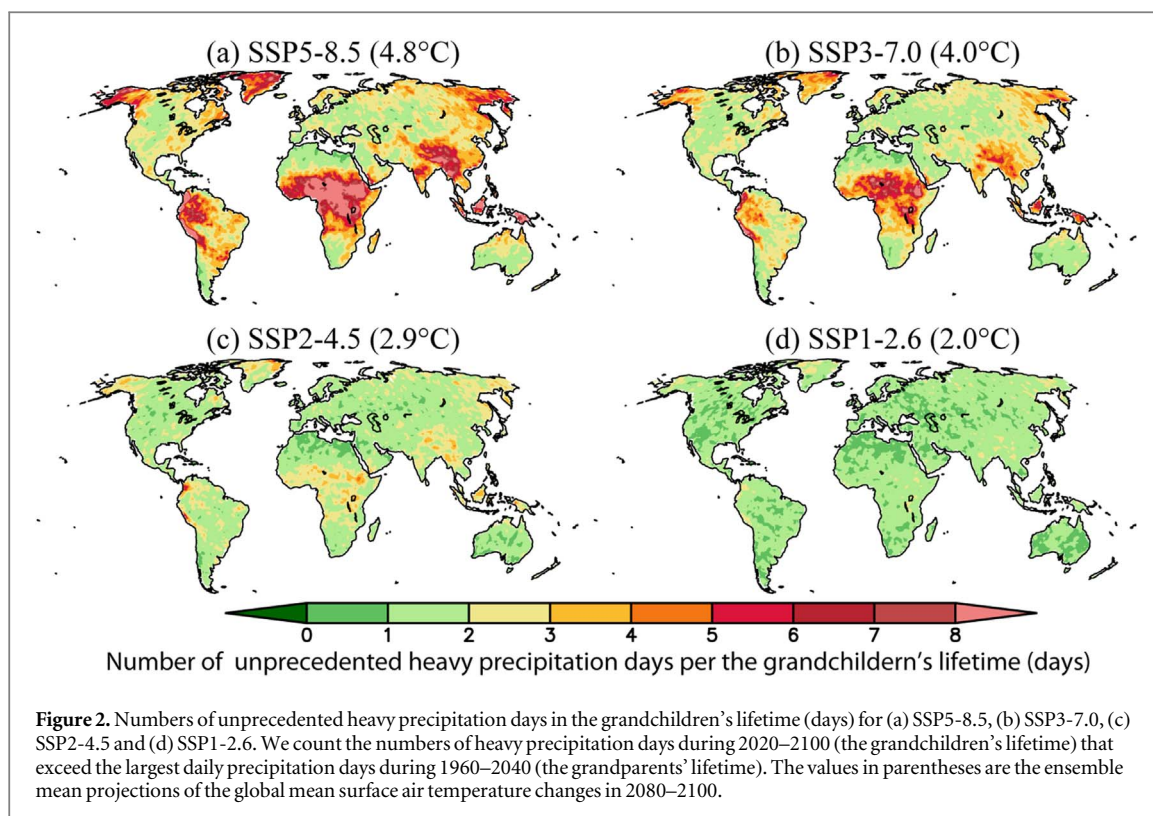
Here, we provide a new framework that would further help grandparents easily understand how their climate change mitigation efforts could decrease 'unprecedented extreme events' (i.e., events breaking the records set in the grandparents' lifetime) during their grandchildren's lifetime and reduce the intergenerational and intragenerational inequalities.

## Proposed methods and results

We propose a simple indicator: how many extreme events (here, hot days and heavy precipitation days) are grandchildren projected to experience that their grandparents will not experience in their lives? We consider a simple case: grandchildren are born in 2020, when their grandparents are 60 years old, and live until 2100. Grandparents will live until 2040. Using the multi-global climate model (GCM) simulations of daily maximum temperature and daily precipitation, we count the number of hot days/heavy precipitation days during 2020–2100 (the grandchildren's lifetime) that exceed the hottest days/heaviest precipitation days during 1960–2040 (the grandparents' lifetime) in each grid cell (figures 1–2).

We analyse 18 GCM simulations (Supplementary table 1 (available online at [stacks.iop.org/ERC/3/061002/mmedia](https://stacks.iop.org/ERC/3/061002/mmedia))) that contributed to Coupled Model Intercomparison Project Phase 6 (CMIP6) (Eyring *et al* 2016). The spatial resolutions of those GCMs are approximately 80–300 km. For each GCM, we use one realization of historical simulations (1850–2014) and future projections (2015–2100) under 4 shared socioeconomic pathways (SSPs), i.e., SSP5-8.5, SSP3-7.0, SSP2-4.5 and SSP1-2.6 (O'Neill *et al* 2016). We count the numbers of hot days and heavy precipitation days during 2020–2100 (the grandchildren's lifetime) that exceed the hottest days and the largest daily precipitation during 1960–2040 (the grandparents' lifetime) for each GCM, respectively. For example, Supplementary figure 1 shows the hottest days and largest daily precipitation in the grandparents' lives in the historical and SSP3-7.0 runs. For the GCMs that do not use the Gregorian calendar, we scale the numbers of unprecedented hot days/heavy precipitation days by the ratios between the number of whole days according to the Gregorian calendar and the number of whole days according to the GCM's calendar. After that, the numbers of unprecedented events are bilinearly interpolated to a  $1^\circ \times 1^\circ$  grid. The data over the ocean are omitted.

Figures 1–2 illustrate the median values of the GCMs (see Supplementary figures S2–S3 for maps of individual GCMs). It has been reported that extreme temperature and precipitation indices are reasonably well represented in the current-generation GCMs compared to observations and reanalyses (Sillmann *et al* 2013).

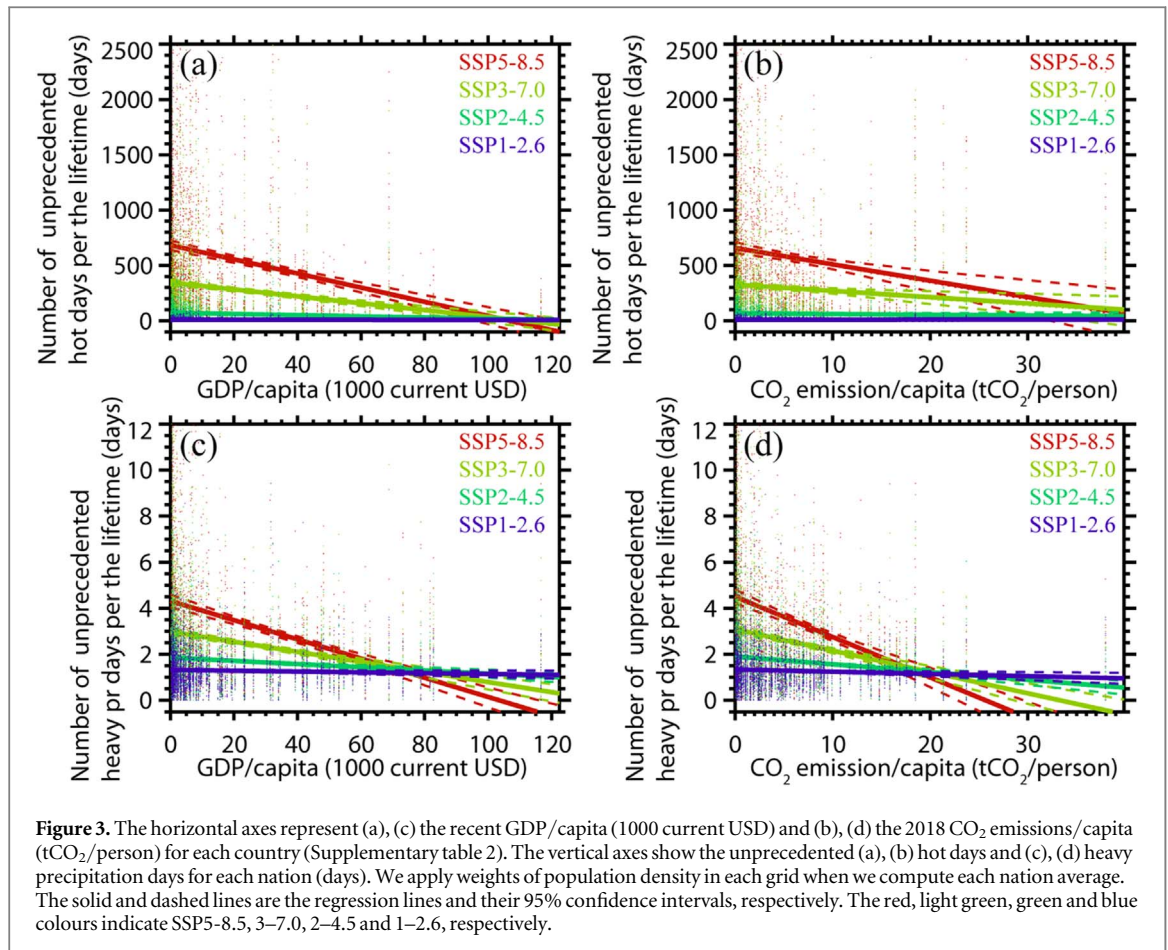


The values in parentheses in figures 1 and 2 indicate the ensemble mean projections of the global mean annual average surface air temperature changes from the 1851–1900 averages to 2080–2100 for each SSP.

In the SSP5-8.5 simulations, in which the mean GCM projection shows a 4.8 °C global warming in 2080–2100 relative to 1851–1900, the grandchildren in northern Africa and tropical South America are projected to experience >1000 unprecedented hot days (figure 1). Although the numbers of unprecedented hot days are smaller in the middle and high latitudes than in tropical countries due to larger natural variability in the middle and high latitudes (supplementary figure S4) (Mahlstein *et al* 2011, Shiogama *et al* 2019), for example, grandchildren in the Mediterranean have >250 unprecedented hot days in their lifetime. If the 2 °C goal is achieved (i.e., SSP1-2.6), increases in unprecedented hot days are largely reduced.

The increases in unprecedented heavy precipitation days are smaller than those in hot days (figure 2). Although the maps for individual models are patchy (Supplementary figure S3) due to smaller signal to noise ratios than that in temperature (Supplementary figure S2), the ensemble averaging make the maps of figure 2 more spatially coherent. In the SSP5-8.5 simulations, more than 5 days of unprecedented heavy precipitation occur in, for example, central Africa, northwest South America, southeast Asia, China, India, Alaska, Greenland and the east Siberia because the internal variability of extreme precipitation is small in those regions (Supplementary figure S4). These spatial patterns resemble the maps of heavy precipitation frequency changes of Fischer and Knutti (2015). If we can limit global warming to a 2 °C level, increases in unprecedented heavy precipitation days are efficiently suppressed (figure 2(d)).

We also investigate uneven distributions of unprecedented hot days/heavy precipitation days regarding the gross domestic product (GDP)/capita and CO<sub>2</sub> emissions/capita (Shiogama *et al* 2019) (figure 3). When we calculate country averaged values of unprecedented events, we use a 0.25° × 0.25° resolution domain data of each country and unprecedented event numbers in a nearest grid from each domain grid. We apply the weights of the 2020 gridded population data (Center for International Earth Science Information Network 2018) to compute population-adjusted averaged values for each country. We use the most recent values of GDP/capita during 2010–2018 (current US\$/person) (World Bank, <https://data.worldbank.org/indicator/NY.GDP.PCAP.CD>, accessed 3 March 2020) and the 2018 CO<sub>2</sub> emissions/capita (tCO<sub>2</sub>/person) (Global Carbon Project, <http://www.globalcarbonatlas.org/en/CO2-emissions>, accessed 3 March 2020) for each country (Supplementary table 2). We do not include countries for which the values of GDP/capita and/or the 2018 CO<sub>2</sub> emissions/capita had not been reported by March 3, 2020, when we downloaded those data from the websites of the World Bank and the Global Carbon Project. Because future scenarios of CO<sub>2</sub> emissions/capita for individual countries are not available, we use the current data of CO<sub>2</sub> emissions/capita, GDP/capita and population. To estimate the confidence intervals of the regression lines in figure 3, we apply the following bootstrap method (Shiogama *et al* 2019):

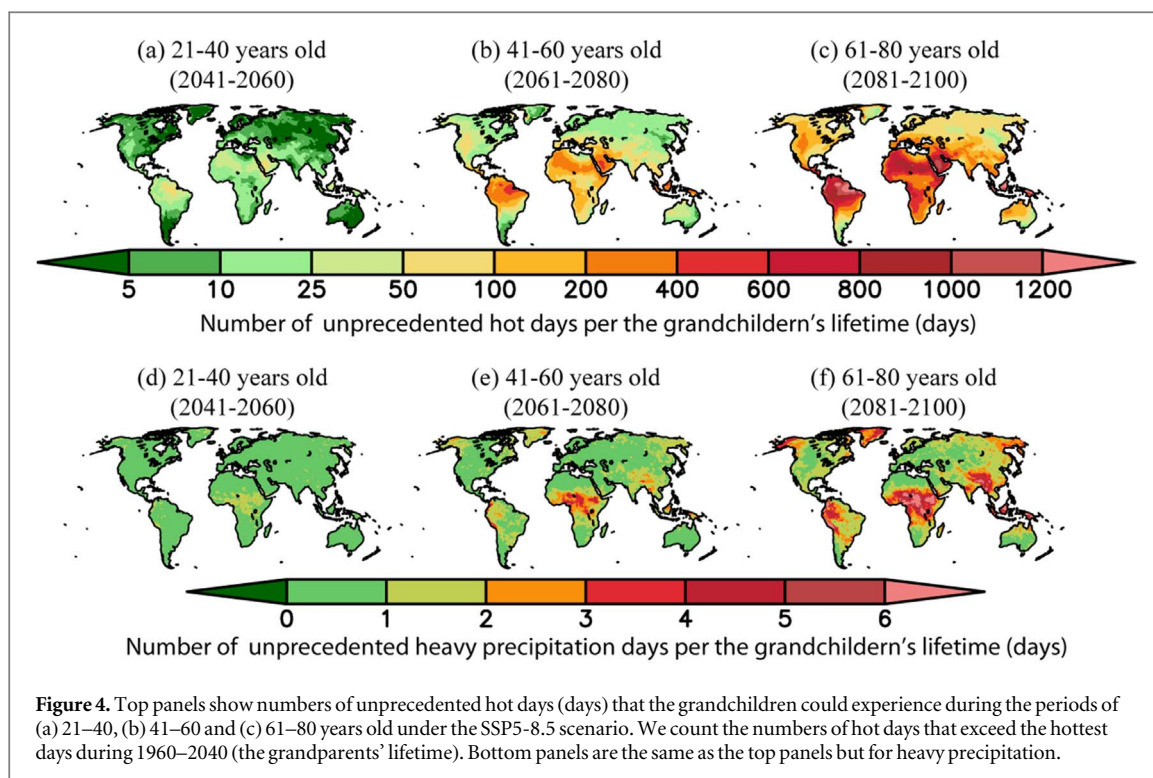


- (1) Let  $n = (\text{the number of countries}) \times (\text{the number of GCMs})$ .
- (2) We take  $\{U_1, U_2, \dots, U_n\}$  to represent all the possible combinations of the countries and GCMs.
- (3) We generate a random sample  $\{V_1, V_2, \dots, V_n\}$  from  $\{U_1, U_2, \dots, U_n\}$  with replacement.
- (4) We estimate the regression line between GDP/capita (or emission/capita) and the number of unprecedented extreme events using  $\{V_1, V_2, \dots, V_n\}$ .
- (5) We repeat steps (3) and (4) 1000 times.
- (6) The 2.5% and 97.5% percentiles of the distributions of the regression lines indicate the 95% confidence intervals.

In SSP5-8.5, there are significant inequalities: countries with lower income and/or smaller CO<sub>2</sub> emissions per capita have larger differences in the extreme hot days/heavy precipitation days between generations (figure 3) (c.f., Mahlstein *et al* 2011, Harrington *et al* 2016). Greater mitigation efforts would reduce increases in the inequalities of generational differences in extremely hot days/heavy precipitation days between countries (c. f., King and Harrington 2018, Döll *et al* 2018, Shioyama *et al* 2019).

## Summary and discussions

To help adults imagine their grandchildren's future under climate change, we provide a new approach showing how many extreme events grandchildren will experience that their grandparents will not experience in their lives. During their lifetime (2020–2100 under the SSP5-8.5 scenario), grandchildren in northern Africa and tropical South America are projected to experience >1000 hot days that break the records set in the grandparents' lifetime (1960–2040). More than 5 days of unprecedented heavy precipitation are projected to occur in the lifetime of grandchildren in central Africa, southeast Asia, China and India under the SSP5-8.5 scenario. Climate change mitigation efforts of adults can largely reduce these numbers of unprecedented extreme events in the grandchildren's lifetime.



**Figure 4.** Top panels show numbers of unprecedented hot days (days) that the grandchildren could experience during the periods of (a) 21–40, (b) 41–60 and (c) 61–80 years old under the SSP5–8.5 scenario. We count the numbers of hot days that exceed the hottest days during 1960–2040 (the grandparents' lifetime). Bottom panels are the same as the top panels but for heavy precipitation.

We also show significant inequalities of the modelled unprecedented hot days and heavy precipitation days in the grandchildren's lifetime across countries regarding GDP/capita and/or CO<sub>2</sub> emissions/capita. Grandchildren in countries with lower income/capita and smaller responsibilities for climate change are projected to experience greater numbers of unprecedented hot days and heavy precipitation days than in countries with higher income/capita and greater responsibilities for climate change. Mitigation efforts can lower these intragenerational (intercountry) unevenness of intergenerational inequalities.

We can also investigate the numbers of unprecedented extreme events that the grandchildren experience during the periods of 21–40, 41–60 and 61–80 years old (figure 4). Under the SSP5–8.5 scenario, the most of unprecedented extreme events occur in the middle and old ages of the grandchildren's lives.

Our simple approach would be easy for the public to understand and could extend for several types of hazards (e.g., extreme floods) and impact assessments (e.g., excess mortality due to heat stress). As this study shows, to improve how climate change resonates with people, there is still room for improvement in the use of climate change information.

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## Data availability statement

The data that support the findings of this study will be openly available following an embargo at the following URL/DOI: <https://doi.org/10.6084/m9.figshare.13635239>. Data will be available from 31 July 2021.

## Author contributions

HS performed the research and wrote the paper with input from the other authors.

## ORCID iDs

Hideo Shiogama  <https://orcid.org/0000-0001-5476-2148>  
 Shinichiro Fujimori  <https://orcid.org/0000-0001-7897-1796>  
 Tomoko Hasegawa  <https://orcid.org/0000-0003-2456-5789>  
 Kiyoshi Takahashi  <https://orcid.org/0000-0002-0163-545X>  
 Yasuko Kameyama  <https://orcid.org/0000-0001-5143-2688>  
 Seita Emori  <https://orcid.org/0000-0002-9949-5167>

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