

World Scientists' Warning of a Climate Emergency

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Scientists have a moral obligation to clearly warn humanity of any great existential threat and 'tell it like it is'. Based on this obligation and the data presented below, we herein proclaim, with xxxx scientist signatories from around the world, a clear and unequivocal declaration that a climate emergency exists on planet Earth.

Exactly 40 years ago, scientists from 50 nations met at the First World Climate Conference (Geneva, 1979) and agreed that alarming trends for climate change made it “urgently necessary” to act. Since then, similar alarms have been made through the 1992 Rio Summit, the 1997 Kyoto Protocol, the 2015 Paris Agreement, as well as scores of other global assemblies and scientists’ explicit warnings of insufficient progress (Ripple et al. 2017). Yet, greenhouse gas (GHG) emissions are still rising, with increasingly damaging effects on the Earth’s climate. An immense change of scale in endeavors to conserve our biosphere is needed to avoid untold suffering due to the climate crisis (IPCC 2018).

Most public discussions on climate change are based on global surface temperature only, an inadequate measure to capture the breadth of human activities and real dangers stemming from a warming planet (Briggs et al. 2015). Policymakers and the public now urgently need access to a range of indicators that convey the effects of human activities on GHG emissions and the consequent impacts on climate, our environment, and society. Building on prior work (see supplemental file S2), we present a suite of graphical vital signs of climate change over the last 40 years for human activities that can affect GHG emissions/climate change (Figure 1), and actual climatic impacts (Figure 2). We use only relevant datasets that are clear, understandable, systematically collected for at least the last five years, and updated at least annually.

The climate crisis is closely linked to excessive consumption of the western lifestyle. The most affluent countries are mainly responsible for the historical GHG emissions, and have the greatest per capita emissions (Table S1). Here we show general patterns, mostly at the global scale, as there are many climate efforts that involve individual regions and countries. Our vital signs are designed to be useful to the public, to policymakers, and to those working on the Paris climate agreement, as well as solutions for the UN’s Sustainable Development Goals, and the Aichi Biodiversity targets.

Profoundly troubling signs from human activities include sustained increases in both human and ruminant livestock populations, per capita meat production, world gross domestic product, global tree cover loss, fossil fuel consumption, number of air passengers carried, carbon dioxide (CO₂) emissions, and per capita CO₂ emissions since 2000 (Figure 1, supplemental file S2). Encouraging signs include decreases in global fertility (birth) rates (Figure 1b), decelerated forest loss in the Brazilian Amazon (Figure 1g), increases in the consumption of solar and wind power (Figure 1h), institutional fossil fuel divestment of more than six trillion U.S. dollars (Figure 1j), and the proportion of GHG emissions covered by carbon pricing (Figure 1m). However, the decline in fertility rates has substantially slowed during the last 20 years (Figure 1b), and the pace of forest loss in Brazil’s Amazon has now started to increase again (Figure 1g). Consumption of solar and wind energy has

increased 407% per decade, yet in 2017 it was still 32.5 times smaller than fossil fuel consumption (combined gas, coal, oil) (Figure 1h). By 2020, approximately 19.5% of global GHG emissions are expected to be covered by carbon pricing (Figure 1m), but the global emissions-weighted average price per tonne of carbon dioxide is projected to be only ~\$12.93 U.S. (Figure 1n). A much higher carbon fee price is needed (IPCC 2018, Section 2.5.2.1). Fossil fuel subsidies to energy companies have substantially decreased, but they were still greater than 300 billion U.S. dollars per year in 2017 (Figure 1o).

Especially disturbing are concurrent trends in the vital signs of climatic impacts. Three abundant atmospheric GHGs (CO₂, methane, and nitrous oxide) continue to increase (see Figure S1 for ominous 2019 spike in CO₂), as do global surface temperature, ocean heat content, extreme weather and associated damage costs, sea level, ocean acidity, and area burned in the United States (Figure 2, supplemental file S2). Globally, ice is rapidly disappearing, evidenced by declining trends in minimum summer Arctic sea ice, Greenland and Antarctic ice sheets, and glacier thickness worldwide (Figure 2e-h). Climate change is also greatly impacting marine, freshwater, and terrestrial life, from plankton and corals to fishes and forests. These rapid changes highlight the urgent need for action.

Despite 40 years of global climate negotiations, with few exceptions, we have generally conducted business as usual and are largely failing to address this predicament (Figure 1). The climate crisis has arrived and is accelerating faster than many scientists expected (Figure 2, IPCC 2018). It is more severe than anticipated, threatening natural ecosystems and the fate of humanity. Especially worrisome are potential climate tipping points and nature's reinforcing feedbacks (atmospheric, marine, and terrestrial) that could lead to a catastrophic "Hothouse Earth," well beyond the control of humans (Steffen et al. 2018). These climate chain-reactions could cause significant disruptions to ecosystems, society, and economies, potentially making large areas of Earth uninhabitable. To secure a sustainable future, we must change how we live, in ways that improve the vital signs summarized by our graphs. Economic and population growth are among the most important drivers of increases in CO₂ emissions from fossil fuel combustion (Pachauri et al. 2014, Bongaarts and O'Neill 2018); thus, we need bold and drastic transformations regarding economic and population policies. We suggest six critical and interrelated steps (in no particular order) that governments and the rest of humanity can take to lessen the worst effects of climate change. These are important steps, but not the only actions needed or possible – for more steps, see Pachauri et al. (2014) and IPCC (2018).

- 1) **Energy.** The world should quickly implement massive energy efficiency and conservation practices, replace fossil fuels with renewables (Figure 1h) and other cleaner sources of energy if safe for people and the environment (Figure S2), leave remaining stocks of fossil fuels in the ground [see timelines in IPCC (2018)], and carefully pursue negative emissions technology such as carbon extraction from the source and sequestration from the air. Wealthier countries should support poorer nations in transitioning away from fossil fuels. We must swiftly eliminate subsidies to fossil fuel corporations (Figure 1o) and use effective and fair schemes for steadily escalating carbon prices to restrain the use of fossil fuels.
- 2) **Short-lived pollutants.** We need to promptly reduce emissions of short-lived climate pollutants, including methane (Figure 2b), black carbon (soot), and hydrofluorocarbons (HFCs). Doing this could slow climate feedbacks and potentially reduce the short-term warming trend by >50% over the next few decades while saving lives and increasing crop yields due to reduced air pollution (Shindell et al. 2017). The 2016 Kigali amendment to phase down HFCs is welcomed.

- 3) **Nature.** We must protect and restore Earth's ecosystems. Phytoplankton, coral reefs, forests, savannas, grasslands, wetlands, peatlands, mangroves, and sea grasses contribute greatly to sequestration of atmospheric CO₂. Marine and terrestrial plants, animals, and microorganisms play significant roles in carbon and nutrient cycling and storage. We need to work globally and rapidly to curtail forest and biodiversity loss (Figure 1f-1g), protecting the remaining primary forests and intact forest landscapes, especially those with high carbon stores, while accomplishing reforestation and afforestation where ecologically appropriate at enormous scales. Although available land may be limiting in places, up to a third of emissions reductions needed by 2030 for the Paris agreement (< 2°C) could be obtained with these natural climate solutions (Griscom et al. 2017).
- 4) **Food.** Eating mostly plant-based foods while reducing the global consumption of animal products (Figure 1c-1d), especially ruminant meat (Ripple et al. 2014) will help to significantly lower GHGs (including methane in step 2). Moreover, this will free up croplands for growing much needed human plant food instead of livestock feed, while releasing some pasturelands to support natural climate solutions (step 3). Agricultural practices such as minimum tillage and increasing soil carbon are vitally important. We need to drastically reduce food waste, which currently amounts to at least one third of global food production.
- 5) **Economy.** Driven by economic growth, excessive extraction of materials and overexploitation of ecosystems need to be quickly curtailed to maintain long-term sustainability of the biosphere. We need a carbon-free economy that explicitly addresses human dependence on the biosphere and policies that guide economic decisions accordingly. Goals need to shift from GDP growth and the pursuit of affluence towards supporting ecosystem and human wellbeing, prioritizing basic needs, and reducing inequality.
- 6) **Population.** Still increasing by roughly 80 million people per year or >200,000 per day (Figure 1a-1b), we must stabilize and ideally gradually reduce the world population (Bongaarts and O'Neill 2018) within a framework that ensures social integrity. There are proven and effective policies that strengthen human rights, while also lowering fertility rates and thus lessening the impacts of population growth, such as biodiversity losses and GHG emissions over the long term. These policies involve bringing family planning services to all people (and removing cultural and economic barriers to their access) and achieving full gender equity, including secondary education as a global norm for girls and young women.

Mitigating and adapting to climate change entails transformations in the ways we govern, manage, feed, and fulfill material and energy requirements. We are encouraged by a recent global surge of concern. Governmental bodies are making climate emergency declarations. Schoolchildren are striking. Ecocide lawsuits are proceeding in the courts. Grassroots citizen movements are demanding change. As an [Alliance of World Scientists](#), we urge widespread use of vital signs, which will better allow policymakers and the public to understand the magnitude of this crisis, track progress, as well as realign priorities for alleviating climate change. The good news is that such transformative change, with social and economic justice, promises greater human wellbeing in the long-run than business as usual. We believe that prospects will be greatest if policy makers and the rest of humanity promptly respond to our warning and declaration of a climate emergency, and act to sustain life on planet Earth, our only home.

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Supplemental material

Supplementary data are available at [BIOSCI](#) online including supplemental file 1 (full list of all xxxx signatories) and supplemental file 2.

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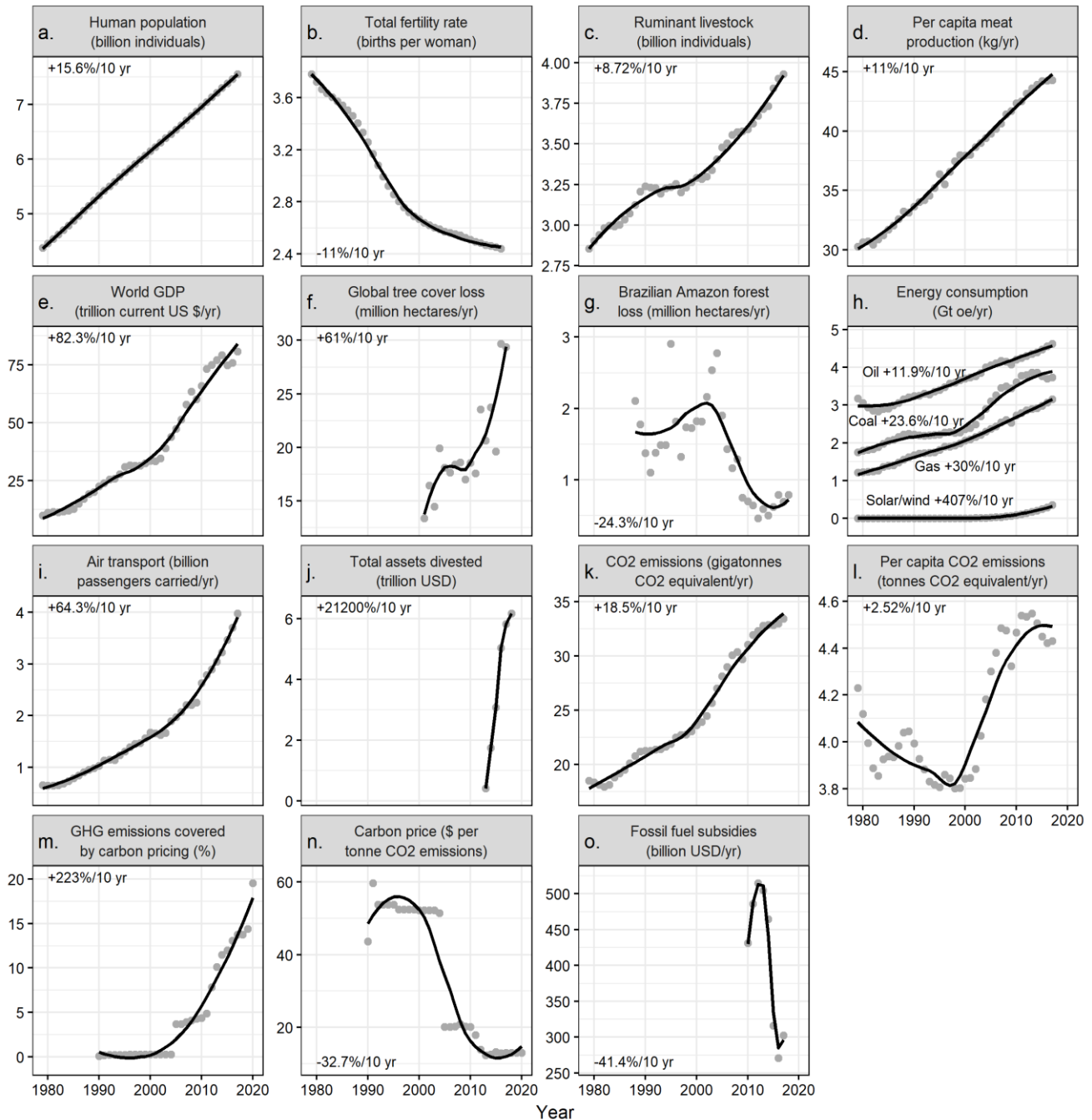


Figure 1. Change in global human activities from 1979 to the present. These indicators are linked at least in part to climate change. In panel (f), annual tree cover loss may be for any reason (e.g. wildfire, harvest within tree plantations, or conversion of forests to agricultural land). Forest gain is not involved in the calculation of tree cover loss. In panel (h), “Gt oe/yr” is short for gigatonnes of oil equivalent per year; hydroelectricity, nuclear energy, and other energy consumption rates are shown in Figure S2. Rates shown in panels are the percentage changes per decade across the entire range of the time series. Annual data are shown using gray points. Black lines are local regression smooth trend lines. Sources and additional details about each variable are provided in supplemental file S2.

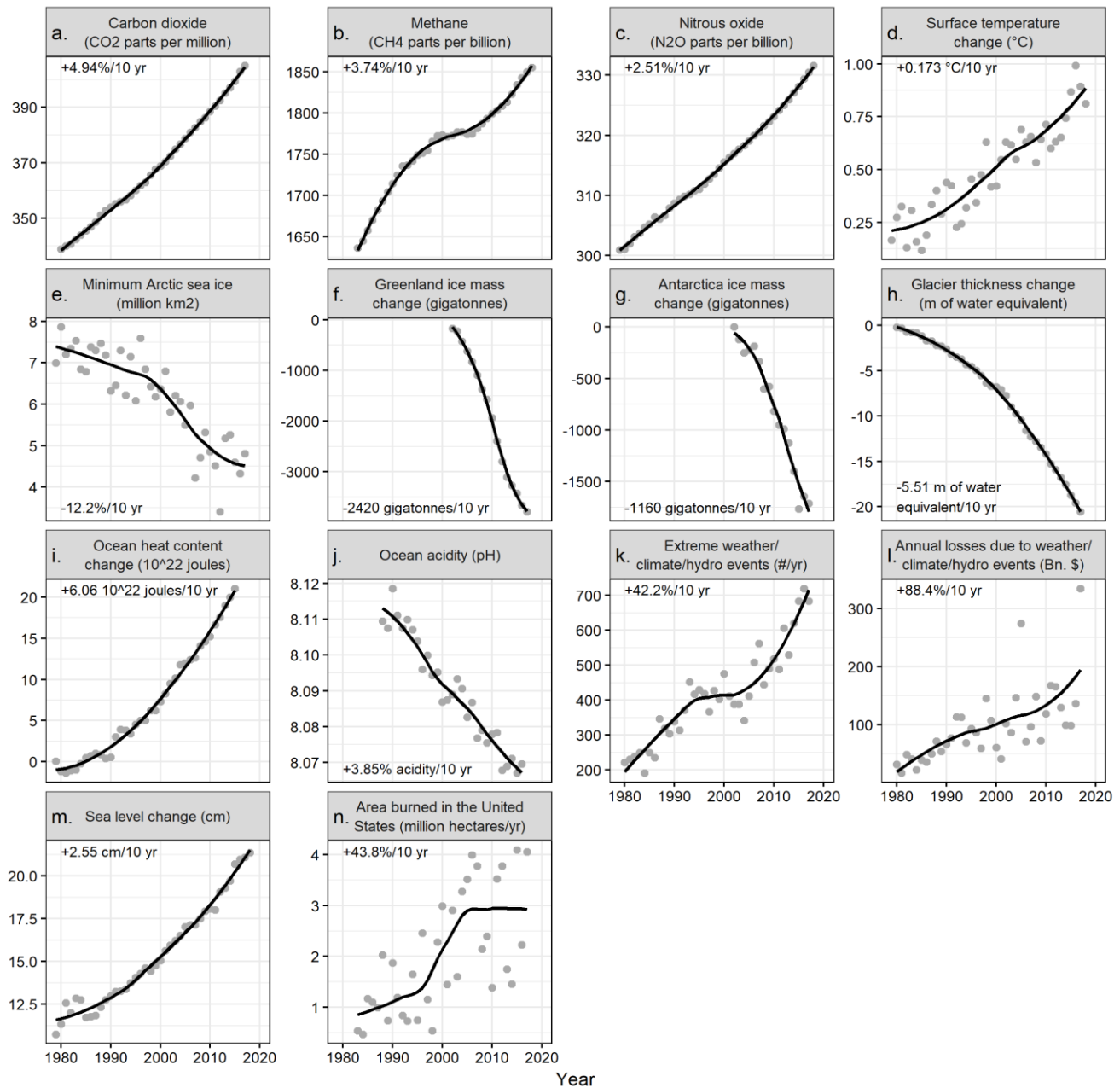


Figure 2. Climatic response time series from 1979 to the present. Rates shown in panels are the decadal change rates for the entire ranges of the time series. These rates are in percentage terms, except for the interval variables (d, f, g, h, i, m), where additive changes are reported instead. For ocean acidity (pH), the percentage rate is based on the change in hydrogen ion activity, a_{H^+} (where lower pH values represent greater acidity). Annual data are shown using gray points. Black lines are local regression smooth trend lines. Sources and additional details about each variable are provided in supplemental file S2.

Supplemental File S2: World Scientists' Warning of a Climate Emergency

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Monthly mean CO₂ at Manua Loa

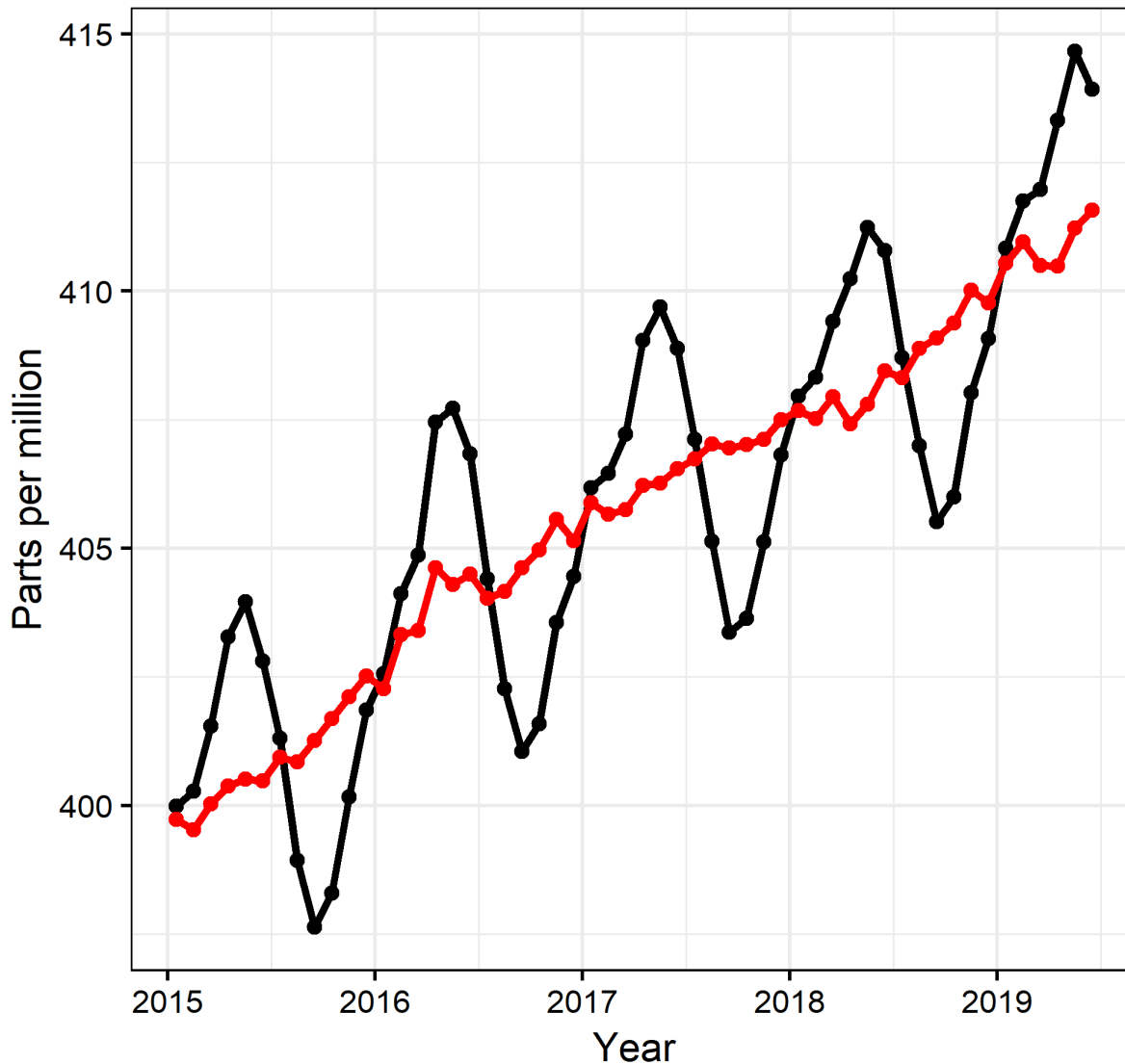


Figure S1. “Monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii. The carbon dioxide data (black curve), measured as the mole fraction in dry air, on Mauna Loa constitute the longest record of direct measurements of CO₂ in the atmosphere. The **black line** represents the monthly mean values, centered on the middle of each month. The **red line** represents the same, after correction for the average seasonal cycle. The latter is determined as a moving average of SEVEN adjacent seasonal cycles centered on the month to be corrected, except for the first and last THREE and one-half years of the record, where the seasonal cycle has been averaged over the first and last SEVEN years, respectively.” Source <https://www.esrl.noaa.gov/gmd/ccgg/trends/>

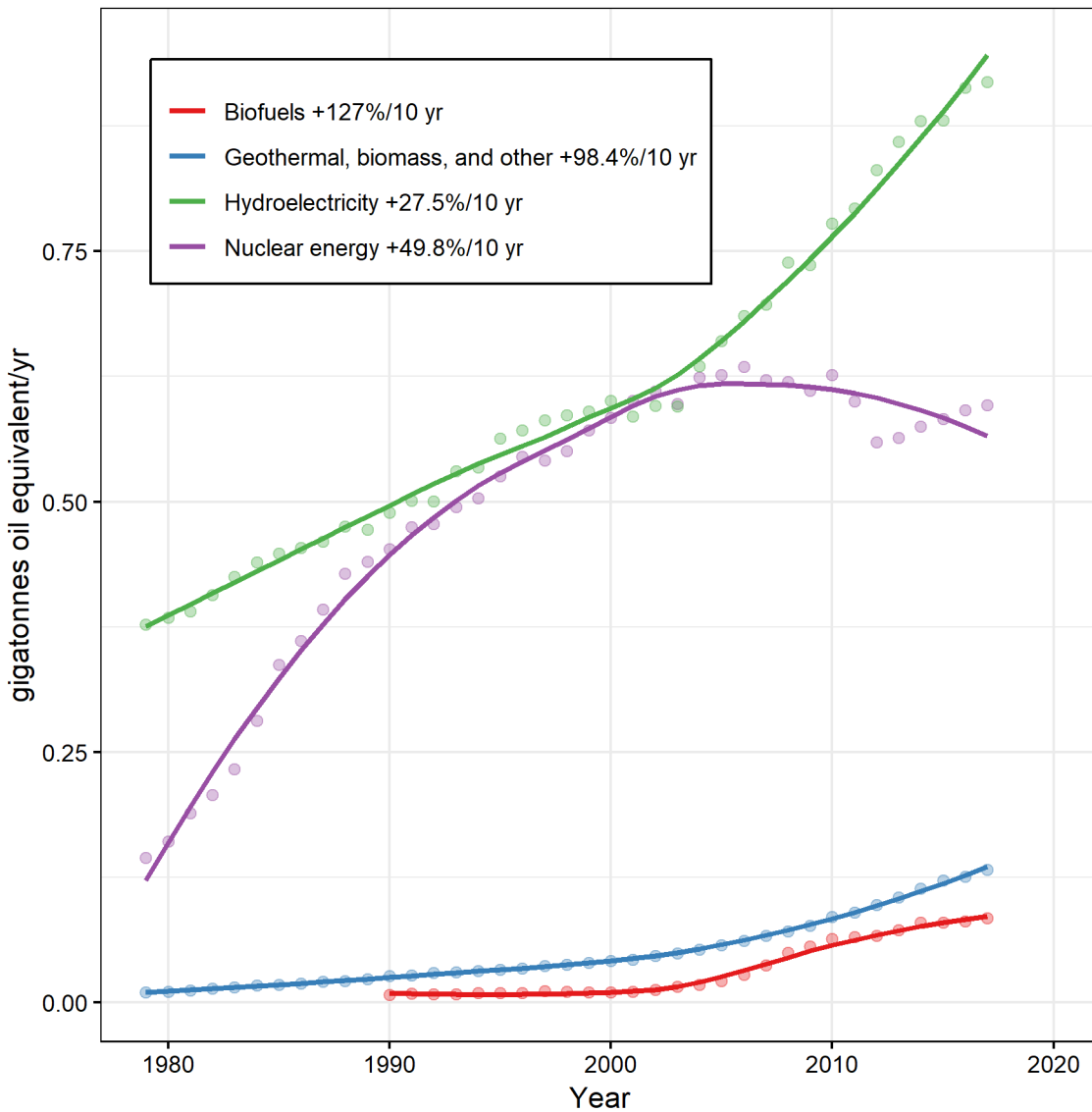


Figure S2. Annual consumption rates for nuclear energy; hydroelectricity; and geothermal, biomass, and other energy sources; and annual production rates for biofuels (British Petroleum Company 2018). Non-fossil fuel energy supply pathways in the future may include hydro and nuclear power in addition to wind, solar, biofuels, and other forms of energy such as geothermal (IPCC 2018). Rates shown in the legend are decadal change rates for the entire ranges of the time series (in percentage terms).

Supplemental Tables

Table S1. Regional summaries for 24 countries and The European Union. Variables shown are “CO₂” (total CO₂ emissions associated with fossil fuel consumption in mega tonnes CO₂), “Population” (human population size in millions), “CO₂/capita” (CO₂ emissions per capita in tonnes per person), “Share” (percentage of all CO₂ emissions associated with fossil fuel consumption compared to the global total), and “GDP/capita” (per capita gross domestic product in US dollars per person). All data are for the year 2017. Additional details on the variables are provided in the supplementary methods.

	CO ₂	Population	CO ₂ /capita	Share	GDP/capita
China	9233	1441	6.4	27.60%	\$8,492
United States	5088	324	15.7	15.20%	\$59,763
The European Union	3532	509	6.9	10.60%	\$33,956
India	2344	1339	1.8	7.00%	\$1,942
Russia	1525	144	10.6	4.60%	\$10,956
Japan	1177	127	9.2	3.50%	\$38,218
South Korea	680	51	13.3	2.00%	\$30,025
Iran	634	81	7.8	1.90%	\$5,594
Saudi Arabia	595	33	18.1	1.80%	\$20,849
Canada	560	37	15.3	1.70%	\$45,135
Indonesia	512	264	1.9	1.50%	\$3,847
Mexico	473	129	3.7	1.40%	\$8,910
Brazil	467	209	2.2	1.40%	\$9,821
South Africa	416	57	7.3	1.20%	\$6,151
Turkey	411	81	5.1	1.20%	\$10,546
Australia	406	24	16.6	1.20%	\$54,126
Thailand	299	69	4.3	0.90%	\$6,595
United Arab Emirates	267	9	28.4	0.80%	\$40,699
Malaysia	256	32	8.1	0.80%	\$9,952
Singapore	227	6	39.7	0.70%	\$56,738
Kazakhstan	219	18	12	0.70%	\$8,948
Egypt	217	98	2.2	0.60%	\$2,413
Vietnam	196	96	2.1	0.60%	\$2,342
Pakistan	189	197	1	0.60%	\$1,548
Argentina	184	44	4.1	0.50%	\$14,398
Top 25	30104	5420	5.6	90.00%	\$13,298
World	33444	7550	4.4	100.00%	\$10,686

Table S2. Summary of human activity indicators. Table columns show the variable name, the most recent year with data, the value of the variable in that year, the rank for that year, and the total number of years with data (since 1979). For example, human population was most recently estimated in 2017 to have a value of 7.55 billion individuals, which ranked as the greatest value among the 39 years of data available since 1979.

Variable	Year	Value	Rank	Total years
Human population (billion individuals)	2017	7.55	1	39
Total fertility rate (births per woman)	2016	2.44	38	38
Ruminant livestock (billion individuals)	2017	3.93	1	39
Per capita meat production (kg/yr)	2017	44.3	1	39
World GDP (trillion current US \$/yr)	2017	80.7	1	39
Global tree cover loss (million hectares/yr)	2017	29.4	2	17
Brazilian Amazon forest loss (million hectares/yr)	2018	0.79	22	31
Coal consumption (gigatonnes oil equivalent/yr)	2017	3.73	6	39
Oil consumption (gigatonnes oil equivalent/yr)	2017	4.62	1	39
Natural gas consumption (gigatonnes oil equivalent/yr)	2017	3.16	1	39
Solar/wind (gigatonnes oil equivalent/yr)	2017	0.354	1	39
Air transport (billion passengers carried/yr)	2017	3.98	1	39
Total assets divested (trillion USD)	2018	6.17	1	6
CO2 emissions (gigatonnes CO2 equivalent/yr)	2017	33.4	1	39
Per capita CO2 emissions (tonnes CO2 equivalent/yr)	2017	4.43	9	39
GHG emissions covered by carbon pricing (%)	2020	19.5	1	31
Carbon price (\$ per tonne CO2 emissions)	2020	12.9	28	31
Fossil fuel subsidies (billion USD/yr)	2017	302	7	8

Table S3. Summary of climatic response indicators. Table columns show the variable name, the most recent year with data, the value of the variable in that year, the rank for that year, and the total number of years with data (since 1979). For example, atmospheric carbon dioxide concentration was most recently estimated in 2017 to have a value of 405 parts per million, which ranked as the greatest value among the 38 years of data available since 1979.

Variable	Year	Value	Rank	Total years
Carbon dioxide (CO2 parts per million)	2017	405	1	38
Methane (CH4 parts per billion)	2018	1860	1	36
Nitrous oxide (N2O parts per billion)	2018	332	1	40
Surface temperature change (°C)	2018	0.812	4	40
Minimum Arctic sea ice (million km ²)	2017	4.81	33	39
Greenland ice mass change (gigatonnes)	2017	-3790	16	16
Antarctica ice mass change (gigatonnes)	2017	-1710	15	16
Glacier thickness change (m of water equivalent)	2017	-20.6	38	38
Ocean heat content change (10 ²² joules)	2015	21.1	1	37
Ocean acidity (pH)	2016	8.07	26	29
Extreme weather/climate/hydro events (#/yr)	2017	683	3	38
Annual losses due to weather/climate/hydro events (Bn. \$)	2017	335	1	38
Sea level change (cm)	2018	21.4	1	40
Area burned in the United States (million hectares/yr)	2017	4.06	2	35

Other graphical indicators

Global Climate Observing System (GCOS)- uses seven climate indicators including surface temperature, ocean heat, atmospheric CO₂, ocean acidification, sea level, glaciers, and arctic and Antarctic sea ice extent. <https://gcos.wmo.int/en/home>

NASA vital signs of the planet- uses five climate indicators including global temperature, arctic ice minimum, ice sheets, sea level, and CO₂. <https://climate.nasa.gov/>

2 Degrees Institute- uses six climate indicators including global temperature record, CO₂ levels, methane (CH₄) levels, nitrous oxide (N₂O) levels, oxygen (O₂) levels, and global sea levels. <https://www.2degreesinstitute.org/>

IPCC 1.5C Report- uses the global warming index. https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

Methods

We compiled a set of global time series related to human actions that affect the environment (e.g. fossil fuel consumption) and environmental and climatic responses (e.g. temperature change). Descriptions and sources for each variable are given in the next section. Although the data used are from sources believed to be reliable, no formal accuracy assessment for these datasets has been made by us and users should proceed with caution. We only considered indicator variables that are updated at least every year. We converted each variable to annual format by averaging together observations within each calendar year if necessary. For each variable, we removed years prior to 1980. We then computed smooth trend lines using locally estimated scatterplot smoothing. We fit the trend lines in R using the ‘loess’ function with default settings (degree 2, span 0.75) (R Core Team 2018).

We used the trend lines to calculate the rate of change of each variable. For ratio variables (i.e. those with a ‘true’ zero, like atmospheric CO₂ concentration), we computed percentage change, and for interval variables (which can be shifted up or down arbitrarily, like sea level) we computed additive change. For ratio variables, we used the following formula for 10-year percentage change:

$$r_{ratio} = 100\% \times \left[\left(\frac{y_{end}}{y_{start}} \right)^{\frac{10}{t_{end} - t_{start}}} - 1 \right]$$

Where y_{start} and y_{end} are the start and end values of the time series and t_{start} and t_{end} are the start and end years. This is the 10-year percentage change with a decadal compounding interval. For example, a variable that increased at a rate of 15% per decade over its entire time span would have a value of 15% according to this formula. For ocean acidity (pH), we calculated percentage change in terms of hydrogen ion activity (a_{H^+}) (lower pH values represent greater acidity). For interval variables, we used the formula

$$r_{interval} = 10 \times \frac{y_{end} - y_{start}}{t_{end} - t_{start}}$$

Indicators of human activities that can affect GHG emissions or climate change (Figure 1)

Below, we list sources and provide brief descriptions of indicators in our analysis. Full methods for each indicator are available at the provided sources.

Human population (Figure 1a)

We used the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) as our source of human population data (FAOSTAT 2019). For human population estimates, the source data used by FAOSTAT are from national population censuses.

Total fertility rate (Figure 1b)

We obtained this variable from the World Bank (The World Bank 2019). The full variable name is “Fertility rate, total (births per woman)” and the World Bank variables ID is SP.DYN.TFRT.IN. This variable was derived using data from multiple sources, including the United Nations Population Division. The full list of original sources is available at The World Bank (2019). Total fertility rate is defined as “the number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with age-specific fertility rates of the specified year” (The World Bank 2019).

Ruminant livestock population (Figure 1c)

We used the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) as our source of ruminant livestock population data (FAOSTAT 2019). We considered ruminants to be members of the following groups: cattle, buffaloes, sheep, and goats. For livestock estimates, the primary data sources are national statistics obtained using questionnaires or collected from countries’ websites or reports. When national livestock statistics were unavailable, they were estimated by FAOSTAT using imputation (FAOSTAT 2019).

Per capita meat production (Figure 1d)

We used total meat production data from FAOSTAT along with FAOSTAT human population size estimates (Figure 1a) to estimate per capita meat production (FAOSTAT 2019). These data “are given in terms of dressed carcass weight, excluding offal and slaughter fats” (FAOSTAT 2019).

Gross domestic product (Figure 1e)

We obtained this variable from the World Bank (The World Bank 2019). The full variable name is “GDP (current US\$)” and the World Bank variable ID is NY.GDP.MKTP.CD. This variable was derived from multiple sources, including World Bank national accounts. The full list of sources is available at The World Bank (2019). Gross domestic product is “the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products” (The World Bank 2019).

Global tree cover loss (Figure 1f)

We obtained data on annual global tree cover loss from Global Forest Watch (Hansen et al. 2013). These data express loss globally in million hectares (Mha) and were derived from remotely-sensed forest change maps. It should be noted that loss is general and not linked to a specific type of deforestation. So, it includes wildlife, conversion to agriculture, disease, etc. Additionally, tree cover loss does not take tree cover gain into account. Thus, net forest loss may be lower than the reported numbers.

Brazilian Amazon forest loss (Figure 1g)

We obtained annual Brazilian Amazon forest loss estimates from Butler (2017). Brazil contains about 60% of the Amazon rainforest. The sources used by Butler (2017) were the Brazilian National Institute of Space Research (INPE) and the United Nations Food and Agriculture Organization (FAO).

Energy consumption (Figure 1h)

We used the British Petroleum Company's 2018 Statistical Review of World Energy as our source of data on energy consumption (British Petroleum Company 2018). For energy consumption, we used the following time series: coal, oil, natural gas, solar, and wind. We grouped solar and wind together into a single category. Coal consumption data are only for commercial solid fuels. In each case, the units of energy consumption are gigatonnes oil equivalent (Gt oe). Other sources of energy such as hydropower, nuclear, geothermal, and biofuels are shown in Figure S2. Although not used in this report, global energy consumption data are also available from the International Energy Agency (IEA 2018).

Air transport (Figure 1i)

We obtained this variable from the World Bank (The World Bank 2019). The full variable name is "Air transport, passengers carried." The corresponding World Bank variable ID is IS.AIR.PSGR. This variable was derived from multiple sources, including the International Civil Aviation Organization. The full lists of sources is available at The World Bank (2019). Air transport includes both domestic and international travelers.

Divestment (Figure 1j)

Divestment data were obtained from Arabella Advisors (2018). According to the report, "Asset sizes represent the total assets (or assets under management for financial institutions) of institutions that have committed to divest. As such, asset sizes do not represent the total sum divested from fossil fuel companies" (Arabella Advisors 2018).

CO₂ emissions (Figure 1k)

We used the British Petroleum Company's 2018 Statistical Review of World Energy as our source of data on CO₂ emissions (British Petroleum Company 2018). These CO₂ emissions data "reflect only [...] consumption of oil, gas and coal for combustion related activities" (British Petroleum Company 2018). They do not account for carbon sequestration, other CO₂ emissions, or other greenhouse gas emissions.

Per capita CO₂ emissions (Figure 1l)

We converted total CO₂ emissions (Figure 1k) to per capita CO₂ emissions using FAOSTAT human population size estimates (Figure 1a).

Greenhouse gas emissions covered by carbon pricing (Figure 1m)

The data on percentage of greenhouse gas emissions covered by carbon pricing schemes are taken directly from World Bank and Ecofys (2018). When multiple schemes covered the same emissions, the emissions were associated with the earliest of the schemes. The data were accessed using the Carbon Pricing Dashboard. They were last updated on November 1, 2018.

Carbon price and share of greenhouse gas emissions covered by carbon pricing (Figure 1n)

These data were derived from World Bank and Ecofys (2018). To estimate the global carbon price, we used the average of the individual scheme prices weighted by the percentage of greenhouse gas emissions covered by each scheme. When multiple schemes covered the same emissions, the emissions were associated with the earliest of the schemes. The data were accessed using the Carbon Pricing Dashboard. They were last updated on November 1, 2018.

Fossil fuel subsidies (Figure 1o)

We obtained data on fossil fuel subsidies from the International Energy Agency. For 2010-2014, we obtained these data from International Energy Agency (2019a), and for 2015-2017, we used International Energy Agency (2019b). Because the 2010-2014 data are in 2016 USD, while the 2015-2017 data are in 2017 USD, we converted the earlier dataset to 2017 USD using a 2.13% inflation rate for 2017 (<http://www.in2013dollars.com/2016-dollars-in-2017>; original source is the Bureau of Labor Statistics consumer price index).

Fossil fuel consumption subsidies are global totals in billion US dollars. They cover oil, electricity, natural gas, and coal. Subsidy values are estimated using the price-gap approach, which involves comparing "average end-user prices paid by consumers with reference prices that correspond to the full cost of supply" (International Energy Agency 2019b). The subsidy amount is equal to the product of this price gap and the amount consumed (International Energy Agency 2019b).

Indicators of actual climatic impacts (Figure 2)

Atmospheric CO₂ (Figure 2a)

We obtained globally averaged estimates of atmospheric CO₂ concentration from NOAA's Global Greenhouse Gas Reference Network (NOAA 2019a). Specifically, we used the variable "Globally averaged marine surface annual mean data". It is based on data collected by The Global Monitoring Division of NOAA/Earth System Research Laboratory using a global network of sampling sites. Global means were estimated by first smoothing observations from each site across time and then estimating the relationship between atmospheric CO₂ and latitude.

Atmospheric methane (Figure 2b)

We obtained data on atmospheric methane (CH₄) from the 2 Degrees Institute (2° Institute 2019). Methane concentration data are globally averaged estimates based on marine surface sites.

Atmospheric nitrous oxide (Figure 2c)

We obtained data on nitrous oxide (N₂O) concentration from the 2 Degrees Institute (2° Institute 2019). N₂O monthly means originally come from the NOAA/ESRL halocarbons program. Global values were estimated using cosine weighting by latitude.

Surface temperature change (Figure 2d)

We obtained data global mean surface temperature anomaly from the 2 Degrees Institute (2° Institute 2019). Temperature anomaly/change data is global and combines land-surface air and sea-surface water temperature estimates. The baseline period used for setting zero is the 1951-1980 mean.

Minimum Arctic sea ice (Figures 2e)

We obtained minimum Arctic sea ice estimates from NASA (2019). They are derived from satellite observations. For each year, the data show the average Arctic sea ice extent for the month of September, which is when the annual minimum occurs.

According to NASA (2019), "Arctic sea ice reaches its minimum each September. September Arctic sea ice is now declining at a rate of 12.8 percent per decade, relative to the 1981 to 2010 average. The graph above shows the average monthly Arctic sea ice extent each September since 1979, derived from satellite observations. The 2012 extent is the lowest in the satellite record."

Greenland ice mass (Figure 2f)

We obtained total land ice mass change measurements for Greenland from NASA (2019). These data show the changes in ice sheet mass (in Gt) since April 2002. They come from NASA's GRACE satellites. According to NASA (2019), the Greenland ice sheet has "seen an acceleration of ice mass loss since 2009".

Antarctica ice mass (Figure 2g)

We obtained total land ice mass change measurements for Antarctica from NASA (2019). These data show the changes in ice sheet mass (in Gt) since April 2002. They come from NASA's GRACE satellites. According to NASA (2019), the Antarctica ice sheet has "seen an acceleration of ice mass loss since 2009".

Cumulative glacier thickness change (Figure 2h)

We obtained cumulative glacier mass balance data from the World Glacier Monitoring Service (WGMS 2019). These data were derived from a database with information about changes in mass, volume, etc. of individual glaciers over time.

The units of these data are meters of water equivalent. According to the World Glacier Monitoring Service, "A value of -1.0 [meter of water equivalent] per year is representing a mass loss of 1,000 kg per square meter of ice cover or an annual glacier-wide ice thickness loss of about 1.1 m per year, as the density of ice is only 0.9 times the density of water" (WGMS 2019).

Ocean heat content (Figure 2i)

We obtained pentadal ocean heat content time series data from NOAA's National Centers for Environmental Information (NCEI) (NOAA 2019b). These data are in units of 10^{22} joules and cover the depth range 0-2000 m. The reference period is 1955-2006 (Levitus et al. 2012).

Ocean acidity (Figure 2j)

As a proxy for global ocean acidity, we used a time series of seawater pH from the Hawaii Ocean Time-series surface CO₂ system data product (HOT 2019). This data product was adapted from Dore et al. (2009). The data were collected at Station ALOHA (22°45'N, 158°00'W). We used the variable "pHmeas_insitu," which is described as the "mean measured seawater pH, adjusted to in situ temperature, on the total scale" (HOT 2019). To report percentage change for this variable, we first converted pH to hydrogen ion activity (a_{H^+}) using the formula $a_{H^+}=10^{-\text{pH}}$.

Extreme weather events (number) (Figure 2k)

These data come from Munich Re's NatCatSERVICE (Munich Re 2019). Extreme weather events are meteorological, hydrological, or climatological events that "have caused at least one fatality and/or produced normalized losses \geq US\$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country)." The entire database contained 17,320 events, but we excluded geophysical events, leaving a total of 15,788 events. These span three categories: meteorological events (tropical cyclones, extratropical storms, etc.), hydrological events (floods, mass movements), and climatological events (droughts, forest fires, etc.).

Extreme weather events (economic losses) (Figure 2l)

These data come from Munich Re's NatCatSERVICE (Munich Re 2019) as described above. Economic losses (in 2017 USD) were "Inflation adjusted via country-specific consumer price index and consideration of exchange rate fluctuations between local currency and US\$" (Munich Re 2019).

Sea level change (Figure 2m)

We obtained data on global mean sea level from the 2 Degrees Institute (2° Institute 2019). The reference year corresponds to a value of zero in 1900. Sea levels from 1993 to the present were estimated using satellite altimetry. Data prior to 1993 are based on tide gauge records from locations around the world that were adjusted using more recent (higher accuracy) information.

Total area burned by wildfires in the United States (Figure 2n)

These data come from the National Interagency Coordination Center at The National Interagency Fire Center (National Interagency Coordination Center 2017) and include Alaska and Hawaii. They are derived from information published in Situation Reports. Because sources of the figures are unknown prior to 1983, we omitted data before 1983. The total for 2004 does not include state lands within North Carolina.

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