Supplementary Data for

Rate and velocity of climate change caused by cumulative carbon emissions

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### Table S1. CMIP5 models used in temperature rate of change and velocity analysis

| Institute                                                                 | Model                        |
|--------------------------------------------------------------------------|------------------------------|
| Canadian Centre for Climate Modeling and Analysis                        | CanESM2                      |
| Commonwealth Scientific and Industrial Research Organization, Australia   | CSIRO                        |
| Institute Pierre Simone Laplace                                         | IPSL-CM5A-LR                 |
| Met Office Hadley Centre                                                | HadGEM2-ES                   |
| NASA Goddard Institute for Space Sciences                                | GISS-E2-R                    |
| NASA Goddard Institute for Space Sciences                                | GISS-E2-H                    |
| National Center for Atmospheric Research                                | CCSM4                        |

### Table S2. WorldClim CMIP5 models used for resolution sensitivity analysis

| Institute                                                                 | Model                        |
|--------------------------------------------------------------------------|------------------------------|
| Commonwealth Scientific and Industrial Research Organisation              | ACCESS1-0                    |
| Beijing Climate Center                                                   | BCC-CSM1-1                   |
| National Center for Atmospheric Research                                 | CCSM4                        |
| Centre National de Recherches Meteorologiques                            | CNRM-CM5                     |
| Geophysical Fluid Dynamics Laboratory                                    | GFDL-CM3                     |
| NASA Goddard Institute for Space Sciences                                | GISS-E2-R                    |
| Met Office Hadley Centre                                                | HadGEM2-ES                   |
| Institute for Numerical Mathematics                                     | INMCM4                       |
| Institute Pierre Simone Laplace                                         | IPSL-CM5A-LR                 |
| Atmosphere and Ocean Research Institute (The University of Tokyo)        | MIRCOC5                      |
| Max Planck Institute for Meteorology                                    | MPI-ESM-LR                   |
| Meteorological Research Institute                                       | MRI-CGCM3                    |
| Norwegian Climate Centre                                                | NorESM1-M                    |
Table S3. Mean rate of temperature change (°C per decade) in RCP4.5 and RCP8.5 emissions pathways in years each reach 4,620 Gt CO₂.

| Biome                                              | RCP4.5 | RCP8.5 | Difference | p value |
|----------------------------------------------------|--------|--------|------------|---------|
| Tropical and subtropical moist broadleaf forests  | 0.2185 | 0.41431| 0.19581    | <0.01   |
| Tropical and subtropical dry broadleaf forests    | 0.21349| 0.40213| 0.18864    | <0.01   |
| Tropical and subtropical coniferous forests       | 0.22342| 0.43725| 0.21383    | <0.01   |
| Temperate broadleaf and mixed forests             | 0.24062| 0.46982| 0.2292     | <0.01   |
| Temperate coniferous forests                       | 0.24251| 0.47986| 0.23735    | <0.01   |
| Boreal forests/taiga                               | 0.30237| 0.59744| 0.29508    | <0.01   |
| Tropical and subtropical grasslands, savannas, and shrublands | 0.23891| 0.48382| 0.2449    | <0.01   |
| Temperate grasslands, savannas, and shrublands    | 0.22691| 0.43543| 0.20851    | <0.01   |
| Flooded grasslands and savannas                    | 0.23774| 0.46202| 0.22428    | <0.01   |
| Montane grasslands and shrublands                  | 0.25591| 0.50758| 0.25167    | <0.01   |
| Tundra                                             | 0.30892| 0.60076| 0.29183    | <0.01   |
| Mediterranean                                      | 0.20474| 0.4123 | 0.20756    | <0.01   |
| Deserts and xeric shrublands                       | 0.23726| 0.47584| 0.23858    | <0.01   |
| Mangrove                                           | 0.17792| 0.34078| 0.16286    | <0.01   |
Table S4. Mean climate velocity (km per year) in RCP4.5 and RCP8.5 emissions pathways in years each reach 4,620 Gt CO₂.

| Biome                                                   | RCP4.5 | RCP8.5 | Difference | p value |
|---------------------------------------------------------|--------|--------|------------|---------|
| Tropical and subtropical moist broadleaf forests       | 6.399  | 10.799 | 4.401      | <0.010  |
| Tropical and subtropical dry broadleaf forests         | 4.734  | 7.757  | 3.023      | <0.010  |
| Tropical and subtropical coniferous forests            | 4.044  | 6.297  | 2.253      | <0.010  |
| Temperate broadleaf and mixed forests                  | 3.822  | 7.316  | 3.493      | <0.010  |
| Temperate coniferous forests                           | 3.714  | 7.507  | 3.794      | <0.010  |
| Boreal forests/taiga                                   | 3.729  | 7.515  | 3.786      | <0.010  |
| Tropical and subtropical grasslands, savannas, and shrublands | 3.934  | 7.234  | 3.301      | <0.010  |
| Temperate grasslands, savannas, and shrublands         | 4.369  | 7.593  | 3.224      | <0.010  |
| Flooded grasslands and savannas                        | 4.265  | 6.794  | 2.529      | <0.010  |
| Montane grasslands and shrublands                      | 3.414  | 6.192  | 2.779      | <0.010  |
| Tundra                                                  | 5.509  | 11.618 | 6.109      | <0.010  |
| Mediterranean                                           | 2.407  | 3.963  | 1.556      | <0.010  |
| Deserts and xeric shrublands                           | 3.420  | 5.796  | 2.375      | <0.010  |
| Mangrove                                                | 4.107  | 6.806  | 2.699      | <0.010  |
Supplementary Fig. S1. Temperature differences for each model relative to baseline
Supplementary Fig. S2. Terrestrial biomes as defined by Olson et al. [1]
Supplementary Fig. S3. Plot of decadal warming rates in RCP4.5 and 8.5. Error bars represent two standard deviations.
Supplementary Fig. S4. Plot of the percent of 10-minute grid cells from the WorldClim historical temperature data which no longer exist within the corresponding 1-degree grid box in the WorldClim RCP8.5 2050 climate. The values were first calculated for each of the CMIP5 models for which WorldClim provides data for the 2041-2060 period in RCP8.5 (see table S2). The multi-model mean was then calculated from the individual model values. Pink values indicate that 100% of the 10-minute grid cells do not exist within the original 1-degree grid box in the future climate. For the top panel a 0.25°C window was used to determine if the temperature was equivalent in the future (i.e. future temperatures within +/- 0.125 °C of the baseline temperatures were considered equivalent). For the bottom panel, a 0.50 °C window was used (i.e. future temperatures within +/- 0.25 °C of the baseline temperatures were considered equivalent).
Supplementary References

[1] Olson D M, Dinerstein E, Wikramanayake E D, Burgess N D, Powell G V N, Underwood E C, D'amico J A, Itoua I, Strand H E, Morrison J C, Loucks C J, Allnutt T F, Ricketts T H, Kura Y, Lamoreux J F, Wettengel W W, Hedao P and Kasem K R 2001 Terrestrial Ecoregions of the World: A New Map of Life on Earth *BioScience* **51** 933-8