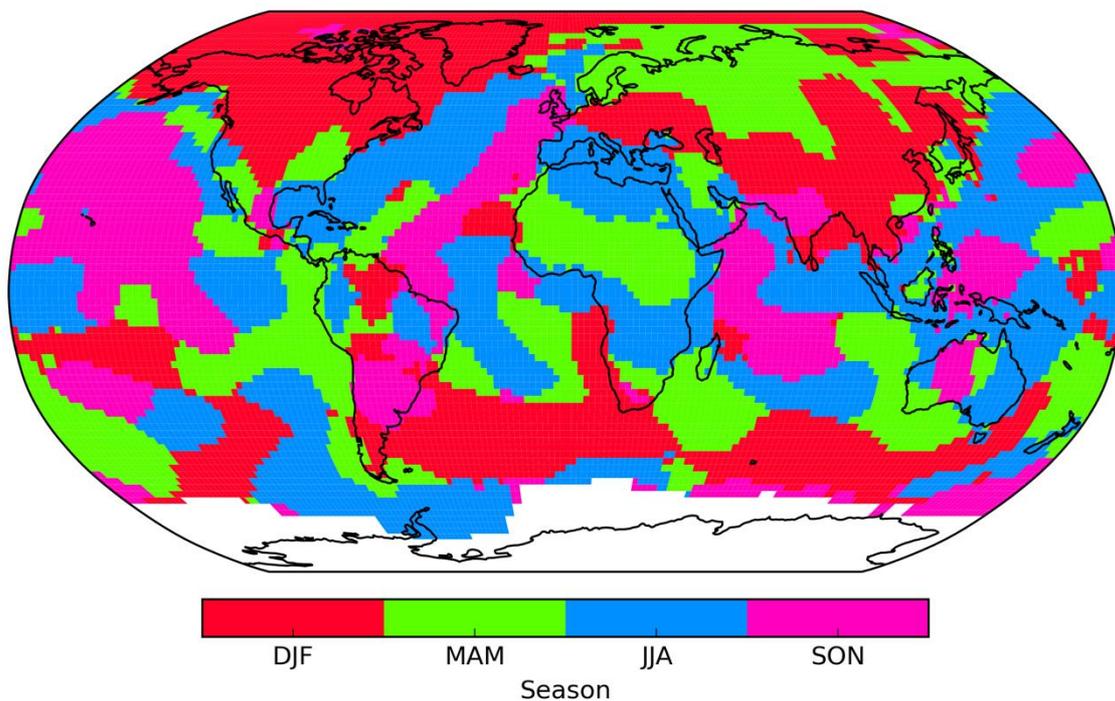


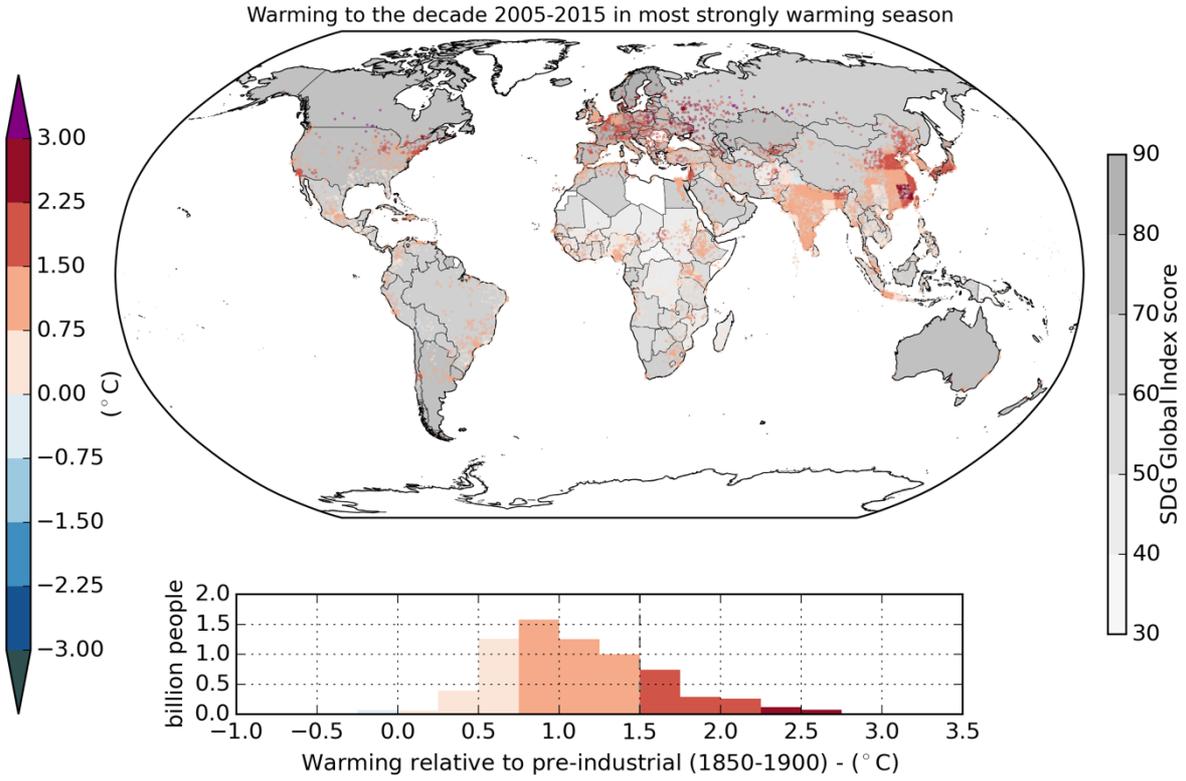
Technical note for Figure 1.1

Externally-forced warming is calculated for the GISTEMP (Hansen et al., 2010) dataset at every location and for each season as in Figure 1.3. The season with the greatest externally-forced warming at every location (averaged over the 2006-2015 period) is selected to give the colour of the dots at that grid box. This field is then regridded to the $1^{\circ}\times 1^{\circ}$ grid of the population density data, taken from Doxsey-Whitfield et al. (2015) for 2010. The density of scatter points in each $1^{\circ}\times 1^{\circ}$ grid box is proportional to the population in the grid-box, up to a maximum of 50, associated with the greatest population grid box. The final version will use bi-linear interpolation of the temperature field. For grid-boxes below the minimum population threshold to guarantee a point is plotted (approximate 650,000), the probability that a dot is plotted reduces with the population in the grid-box. The SDG Global Index Score ranks country performance across 17 sustainable development goals. The goals cross-cut the three dimensions of sustainable development – environmental sustainability, economic growth, and social inclusion. It has a maximum value of 100. Technical Annex 1.A Figure 1 shows the month of maximum warming in each grid-box used in Figure 1.1.

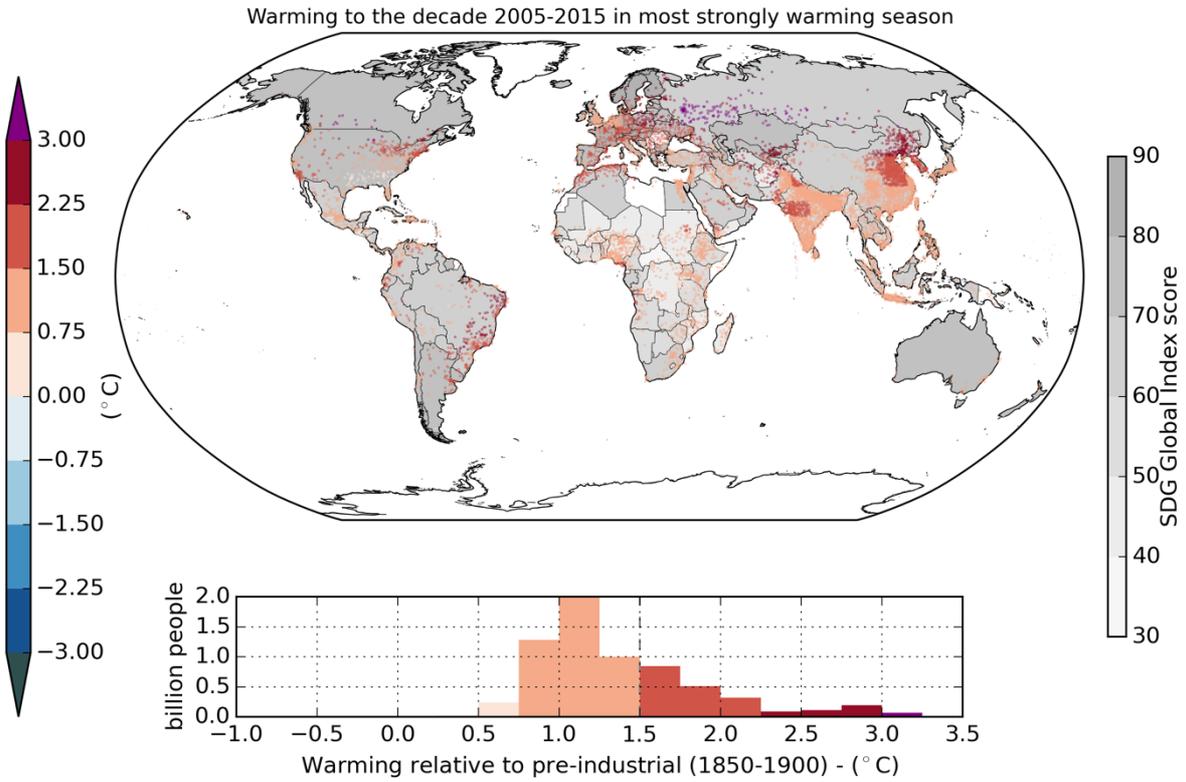


Technical Annex 1.A Figure 1: Season of greatest human-induced warming over 2006-2015 relative to 1850-1900 for the data shown in Figure 1.1.

Versions of Figure 1.1 using the HadCRUT4 and NOAA temperature datasets are shown in Technical Annex 1.A Figure 2 and Technical Annex 1.A Figure 3 respectively.



Technical Annex 1.A Figure 2: As for Figure 1.1 but using the HadCRUT4 temperature dataset.



Technical Annex 1.A Figure 3: As for Figure 1.1 but using the NOAA temperature dataset.

Technical Note for Figure 1.2

Observational data is taken from the Met Office Hadley Centre (<http://www.metoffice.gov.uk/hadobs/hadcrut4/>), National Oceanic and Atmospheric Administration (NOAA) (<https://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp>) and NASA's Goddard Institute for Space Studies (<https://data.giss.nasa.gov/gistemp/>). The GISTEMP and NOAA observational products (which begin in 1880) are expressed relative to 1850-1879 by first expressing all three timeseries relative to a 1850-1900 reference period by constraining all datasets to have the same average over the 1880-1990 period and then adding the offset between the 1880-1990 and 1850-1900 periods in HadCRUT4. All available data is used, through to the end of 2016, in all cases. Data from the Berkeley Earth (<http://berkeleyearth.org/>) combined sea-surface temperature and land air temperature dataset, which was not assessed in AR5, is shown in green.

CMIP5 multi-model means, light blue dashed (full field surface air temperature) and solid (masked and blended as in Cowtan et al. (2015)) are expressed relative to a 1861-1880 base period and then expressed relative to the 1850-1900 reference period using the anomaly between the periods in the HadCRUT4 product. Only r1i1p1 ensemble members are used with only one ensemble member per model.

The pink "Holocene" shading is derived from the "Standard5x5Grid" reconstruction of Marcott et al. (2013) (expressed relative to 1850-1900 using the HadCRUT4 anomaly between this reference period and the 1961-90 base period of the data). The vertical extent of the solid shading is determined by the maximum and minimum temperature anomalies in the dataset in the period before 1850. Marcott et al. (2013) report data with a periodicity of 20 years, so the variability shown by the solid pink shading is not directly comparable to the higher frequency variability seen in the observational products which are reported every month), but this Holocene range can be compared to the emerging signal of human-induced warming. Above and below the maximum and minimum temperature anomalies from Marcott et al. (2013) the pink shading fades out to after a magnitude of warming that is equal to the standard deviation of monthly temperature anomalies in the HadCRUT4 dataset.

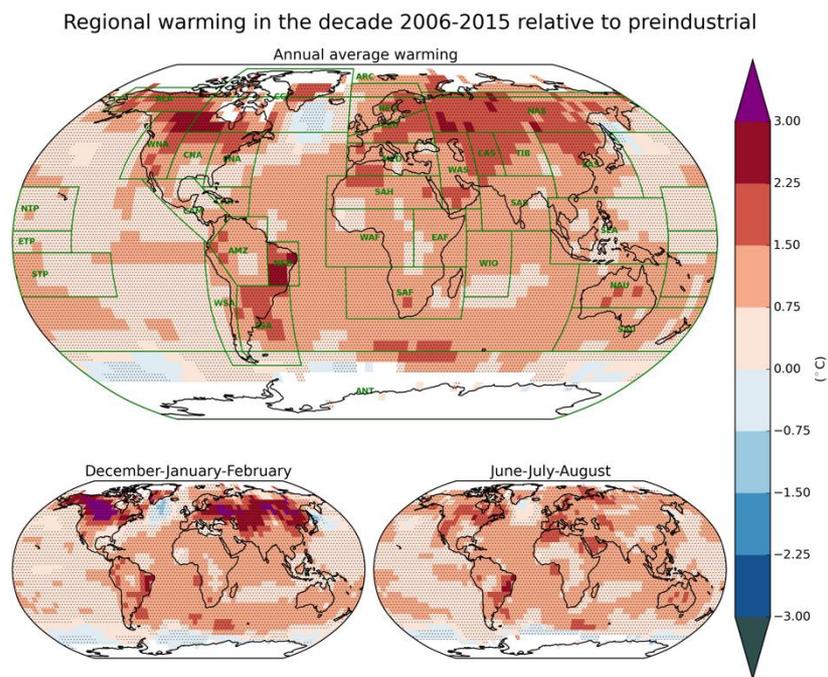
Near term predictions from IPCC-AR5 (Kirtman et al., 2013), for the period 2016-2035 were estimated to be *likely* (>66% probability) between 0.3°C and 0.8°C above the 1986-2006 average, assuming no climatically significant future volcanic eruptions.

Best-estimate human-induced temperature change (thick orange line) and total externally forced warming (thick red line) are estimated using the method of Haustein et al. (2017). Best-estimate historical radiative forcings, extended until the end of 2016, are taken from Myhre et al. (2013), incorporating the significant revision to the methane forcing proposed by Etminan et al. (2016). The 2-box thermal impulse-response model used in Myhre et al. (2013), with modified thermal response time-scales to match the multi-model mean from Geoffroy et al. (2013), is used to derive the shape to the global mean temperature response timeseries to total anthropogenic, and combined volcanic and solar forcing. Both of these timeseries are expressed as anomalies relative to their simulated 1870-1879 averages and then used as independent regressors in a multi-variate linear regression to derive scale factors on the two timeseries that minimise the residual between the combined forced response and the HadCRUT4 observations (expressed as anomalies relative to 1850-1900). The 1870-1879 period is chosen for the anthropogenic and natural forcing response as it covers the mid-period of the reference period, and corresponds to a period of near-zero volcanic forcing. The error bar on the 2016 attributed human-induced warming is derived using the same proportional uncertainty as the $\pm 0.1^\circ\text{C}$ (*likely*) uncertainty in the 0.7°C best-estimate anthropogenic warming trend over 1951-2010 period assessed in Bindoff et al. (2013).

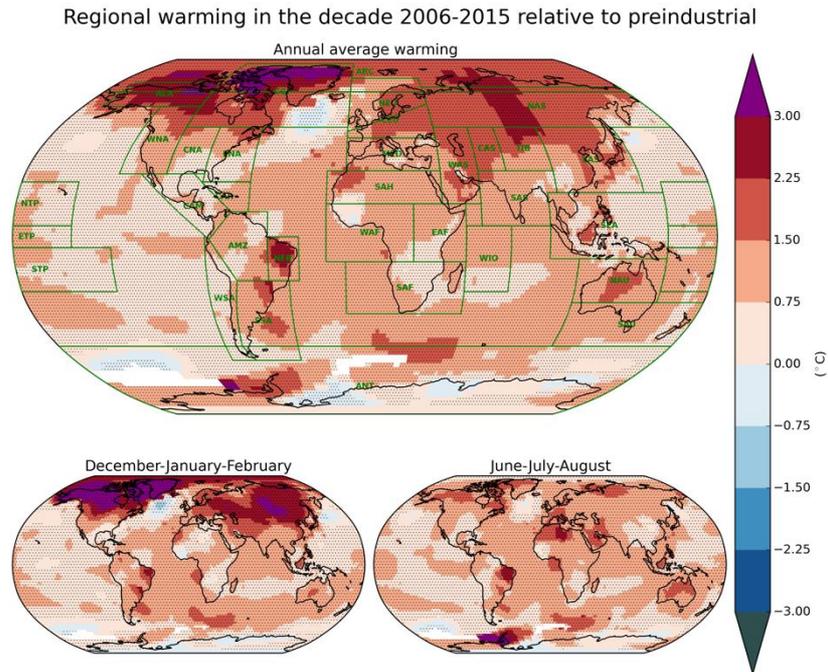
Technical Note for Figure 1.3

Regional attributable human-induced warming shown in Figure 1.3 is derived using a similar method to the calculation of externally-forced warming in Figure 1.2. At every grid box location in the native HadCRUT4 resolution, the timeseries of local temperature anomalies in the HadCRUT4 dataset (expressed relative to the local 1850-1900 average) are regressed onto the global externally-forced warming timeseries shown in Figure 1.1 (assuming a Gaussian error structure) using all available data points. This linear regressed relationship between these two quantities is then used to estimate the human-induced warming relative to 1850-1900 at this location. The maps in Figure 1.3 show the average of local human-induced over the 2006-2015 period. Trends are only plotted only where over 50% of the entire observational record at this location is available. Stippling indicates the linear trend between local warming and global human-induced warming is significant at a 10% level using a one-sided Student-t test. The final versions will use an AR1 residual model to be consistent with practice for calculating uncertainty in linear trends in IPCC-AR5.

Supplementary maps are included below for the NOAA and GISTEMP observational data, which use infilled data to achieve a higher level of coverage than HadCRUT4. The regression of local temperature anomalies onto the global mean human-induced warming (recalculated using the NOAA and GISS global mean observations respectively), allows local human-induced warming to be expressed relative to 1850-1900 despite these records beginning in 1880.



Technical Annex 1.A Figure 4: Human-induced warming for the average of 2006-2015 relative to 1850-1900 calculated for the NOAA observational dataset as for Figure 1.2.



Technical Annex 1.A Figure 5: Human-induced warming for the average of 2006-2015 relative to 1850-1900 calculated for the GISTEMP observational dataset as for Figure 1.2.

Technical note for Figure 1.5

Idealised temperature pathways computed by specifying the level of human-induced warming in 2015, $T_{2015} = 1^{\circ}\text{C}$, with temperatures from 1865 to 2015 given by a single-term polynomial: $T = T_{2015}((t - 1865)/150)^{\gamma}$, with γ set to give a rate of human-induced warming in 2015 of $0.17^{\circ}\text{C}/\text{decade}$. Temperatures from 2016-2115 set by fitting a smooth 4th-order polynomial to prescribed temperatures in 2050 and 2115 and a prescribed gradient in 2115. Gradient is held constant after 2115. Colours are used to illustrate different temperatures pathways, and are consistent in all panels. Upward-pointing triangles indicate years in which 1.5°C is reached from below, and downward-pointing arrows indicate years in which 1.5°C is reached from above.

Radiative forcing F that would give the temperature profiles is computed using a 2-time-constant climate response function (Myhre et al., 2013), with Equilibrium Climate Sensitivity (ECS) of 2.7°C and Transient Climate Response (TCR) of 1.6°C and other parameters as given in Millar et al. (2017). Equivalent CO_2 concentrations given by $C = 278 \times \exp(F/5.4)$ ppm.

Cumulative CO_2 -forcing-equivalent emissions, or the CO_2 emission pathways that would give the CO_2 concentration pathways compatible with the temperature scenario is computed using a simple carbon cycle model (Myhre et al., 2013), modified to account for changing CO_2 airborne fraction over the historical period (Millar et al., 2017).

Indicative cumulative impact variable (sea level rise) is computed from temperature pathways shown in using semi-empirical model of Kopp et al. (2016).

Technical Note for Figure 1.6

All scenarios in Figure 1.6 use a 1000 member ensemble of the FAIR model (Smith et al., 2017) driven with emissions from the RCP historical dataset from 1765 to 2000 (Meinshausen et al., 2011), SSP2 from 2005 to 2020 (Fricko et al., 2017), and a linear interpolation between the two inventories

for 2000 to 2005. Greenhouse gas forcing uses the relationships (Myhre et al., 1998) with an increase of 25% for methane forcing which approximates the updated relationship from (Etminan et al., 2016). Solar forcing for the historical period is calculated by using total solar irradiance from the SOLARIS HEPPA v3.2 dataset (Matthes et al., 2017) for 1850-2020 and (Myhre et al., 2013) for 1765-1850: the 1850-1873 mean is subtracted from the time series which is then multiplied by 0.25 (annual illumination factor) times 0.7 (planetary co-albedo) to generate the effective radiative forcing (ERF) timeseries. Volcanic forcing is taken by using stratospheric aerosol optical depths from the CMIP6 historical Easy Volcanic Aerosol dataset (Toohey et al., 2016) prepared for the HadGEM3 CMIP6 historical integrations for 1850-2014. The integrated stratospheric aerosol optical depth at 550 nm (τ) is calculated and converted to ERF by the relationship $ERF = -18 \cdot \tau$, based on time slice experiments in the HadGEM3 model*, which agrees well with earlier versions of the Met Office Hadley Centre model as well as CESM1-WACCM (Gregory et al., 2016). The 1850-2014 mean volcanic ERF of -0.107 is subtracted as an offset to define the mean historical volcanic ERF as zero. Owing to rapid adjustments to stratospheric aerosol forcing, which are included in the definition of ERF, this less negative value of $-18 \cdot \tau$ is adopted for volcanic ERF than the $RF = -25 \cdot \tau$ used in AR5. Solar forcing is set to zero in 2020 and volcanic forcing is ramped down linearly from a small positive value in 2014 to zero in 2019, so natural forcings do not directly affect the future temperature evolution.

Equilibrium climate sensitivity (ECS) and transient climate response (TCR) parameters are drawn from a joint lognormal distribution informed by CMIP5 models. Uncertainties in non-CO2 forcing (non-CO2 GHGs, aerosols, etc.) are drawn from the distributions in Myhre et al. (2013) and uncertainties in the carbon cycle response are given a 5 to 95% range of 13% around the best estimate (Millar et al., 2017). All uncertainties except TCR and ECS are assumed to be uncorrelated with each other. The resulting ensemble is constrained by whether individual ensemble members fall within the observed historical temperature change over the 1880 to 2016 period using the Cowtan and Way (2014) in-filled dataset based on HadCRUT4. 291 of the original 1000 ensemble members were retained.

Each scenario is driven with the following assumptions:

1. Zero CO2 emissions, constant non-CO2 forcing (blue): FAIR spun up with all emissions to 2020. Total non-CO2 forcing in 2020 is used as the input to the 2021-2100 run with all CO2 fossil and land use emissions abruptly set to zero.
2. Phase out of CO2 emissions with 1.5C commitment (blue dotted): FAIR spun up with all emissions to 2020. Total non-CO2 forcing in 2020 is used as the input to the 2021-2100 run. Fossil and land-use CO2 emissions are ramped down to zero at a linear rate over 56 years from 2021 to 2076, consistent with a 1.5C temperature rise since pre-industrial at the point of zero CO2 emissions in 2076.
3. Zero GHG emissions, constant aerosol forcing (purple): FAIR spun up with all emissions to 2020. All GHG emissions set abruptly to zero in 2021, with aerosol emissions held fixed at their 2020 levels.
4. Zero CO2 and aerosol emissions, constant non-CO2 GHG forcing (green): FAIR spun up with all emissions to 2020. Total non-CO2 GHG forcing, which also includes the proportion of tropospheric ozone forcing attributable to methane emissions, in 2020 is used as the input to the 2021-2100 run. Fossil and land-use CO2 and aerosol emissions abruptly set to zero in 2021.

5. Zero emissions (orange): FAIR spun up with all emissions to 2020. All emissions set abruptly to zero in 2021.

References

- Bindoff, N. L., Stott, P. A., AchutaRao, K. M., Allen, M. R., Gillett, N., Gutzler, D., et al. (2013). "Detection and Attribution of Climate Change: from Global to Regional," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press), 426–488.
- Cowtan, K., Hausfather, Z., Hawkins, E., Jacobs, P., Mann, M. E., Miller, S. K., et al. (2015). Robust comparison of climate models with observations using blended land air and ocean sea surface temperatures. *Geophysical Research Letters* 42, 6526–6534. doi:10.1002/2015GL064888.
- Cowtan, K., and Way, R. G. (2014). Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends. *Quarterly Journal of the Royal Meteorological Society* 140, 1935–1944. doi:10.1002/qj.2297.
- Doxsey-Whitfield, E., MacManus, K., Adamo, S. B., Pistolesi, L., Squires, J., Borkovska, O., et al. (2015). Taking Advantage of the Improved Availability of Census Data: A First Look at the Gridded Population of the World, Version 4. *Papers in Applied Geography* 1, 226–234. doi:10.1080/23754931.2015.1014272.
- Etminan, M., Myhre, G., Highwood, E. J., and Shine, K. P. (2016). Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing. *Geophysical Research Letters* 43, 12,614–12,623. doi:10.1002/2016GL071930.
- Fricko, O., Havlik, P., Rogelj, J., Klimont, Z., Gusti, M., Johnson, N., et al. (2017). The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. *Global Environmental Change* 42, 251–267. doi:10.1016/j.gloenvcha.2016.06.004.
- Geoffroy, O., Saint-Martin, D., Olivié, D. J. L., Voldoire, A., Bellon, G., and Tytéca, S. (2013). Transient climate response in a two-layer energy-balance model. Part I: Analytical solution and parameter calibration using CMIP5 AOGCM experiments. *Journal of Climate* 26, 1841–1857. doi:10.1175/JCLI-D-12-00195.1.
- Gregory, J. M., Andrews, T., Good, P., Mauritsen, T., and Forster, P. M. (2016). Small global-mean cooling due to volcanic radiative forcing. *Climate Dynamics* 47, 3979–3991. doi:10.1007/s00382-016-3055-1.
- Hansen, J., Ruedy, R., Sato, M., and Lo, K. (2010). Global surface temperature change. *Reviews of Geophysics* 48, RG4004. doi:10.1029/2010RG000345.
- Haustein, K., Allen, M. R., Forster, P. M., Otto, F. E. L., Mitchell, D. M., Matthews, H. D., et al. (2017). A robust real-time Global Warming Index. *Scientific Reports* in press.
- Kirtman, B., Adedoyin, A., and Bindoff, N. (2013). "Near-term Climate Change: Projections and Predictability," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press), 953–1028. doi:10.1017/CBO9781107415324.023.
- Kopp, R. E., Kemp, A. C., Bittermann, K., Horton, B. P., Donnelly, J. P., Gehrels, W. R., et al. (2016). Temperature-driven global sea-level variability in the Common Era. *Proceedings of the National Academy of Sciences* 113, 1–8. doi:10.1073/pnas.1517056113.
- Marcott, S. A., Shakun, J. D., Clark, P. U., and Mix, A. C. (2013). A reconstruction of regional and global temperature for the past 11,300 years. *Science* 339, 1198–201. doi:10.1126/science.1228026.
- Matthes, K., Funke, B., Andersson, M. E., Barnard, L., Beer, J., Charbonneau, P., et al. (2017). Solar forcing for CMIP6 (v3.2). *Geoscientific Model Development* 10, 2247–2302. doi:10.5194/gmd-

10-2247-2017.

- Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J., et al. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change* 109, 213–241. doi:10.1007/s10584-011-0156-z.
- Millar, R. J., Nicholls, Z. R., Friedlingstein, P., and Allen, M. R. (2017). A modified impulse-response representation of the global near-surface air temperature and atmospheric concentration response to carbon dioxide emissions. *Atmospheric Chemistry and Physics* 17, 7213–7228. doi:10.5194/acp-17-7213-2017.
- Myhre, G., Highwood, E. J., Shine, K. P., and Stordal, F. (1998). New estimates of radiative forcing due to well mixed greenhouse gases. *Geophysical Research Letters* 25, 2715–2718. doi:10.1029/98GL01908.
- Myhre, G., Shindell, D., Bréon, F., Collins, W., Fuglestvedt, J., Huang, J., et al. (2013). “Anthropogenic and natural radiative forcing,” in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press), 658–740. doi:0.1017/CBO9781107415324.018.
- Smith, C. J., Forster, P. M., Allen, M., Leach, N., Millar, R. J., Passerello, G. A., et al. (2017). FAIR v1.1: A simple emissions-based impulse response and carbon cycle model. *Geoscientific Model Development Discussions*, 1–45. doi:10.5194/gmd-2017-266.
- Toohey, M., Stevens, B., Schmidt, H., and Timmreck, C. (2016). Easy Volcanic Aerosol (EVA v1.0): an idealized forcing generator for climate simulations. *Geoscientific Model Development* 9, 4049–4070. doi:10.5194/gmd-9-4049-2016.