Global Temperature in 2016

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Abstract. **Global surface temperature in 2016 was the highest in the period of instrumental measurements. Relative to average temperature for 1880-1920, which we take as an appropriate estimate of "pre-industrial" temperature, 2016 was +1.26°C (~2.3°F) warmer than in the base period. The 2016 temperature was partially boosted by a 2015-16 El Niño, which was almost as strong as the 1997-98 "El Niño of the century". We estimate current global temperature excluding short-term variability as +1.07°C relative to 1880-1920, based on linear fit to post-1970 global temperatures.**

Update of the GISS (Goddard Institute for Space Studies) global temperature analysis (GISTEMP)[1,2] (Fig. 1a), finds 2016 to be the warmest year in the instrumental record. (More detail is available at http://data.giss.nasa.gov/gistemp/ and http://www.columbia.edu/~mhs119/Temperature; figures in this summary are available from Makiko Sato on the latter web site.) For the second year in a row the prior record was broken by a substantial margin. 2015 and 2016 annual temperatures were, in part, boosted by the 2015-16 El Niño. Because of the delayed global response to the natural El Niño/La Niña variability,[3] it is likely that the 2017 global temperature will fall below that of 2016, as discussed below.

Here we choose 1880-1920 as baseline, i.e., as the zero-point for temperature anomalies, because it is the earliest period with substantial global coverage of instrumental measurements and because it also has a global mean temperature that should approximate "preindustrial" temperature[4]. The United Nations Framework Convention[5] and Paris Agreement[6] define goals relative to "preindustrial", but do not define that period. Although human-caused increases of greenhouse gases (GHGs) by 1880-1920 were already sufficient to cause a small warming,[7] 1880-1920 was also marked by above-average volcanic aerosols[8], which have a cooling effect. Extreme Little Ice Age conditions may have been ~0.1C cooler than the 1880-1920 mean,[9] but the Little Ice Age seems inappropriate to define preindustrial temperature because the deep ocean did not have time to reach equilibrium with brief surface conditions. Choosing a

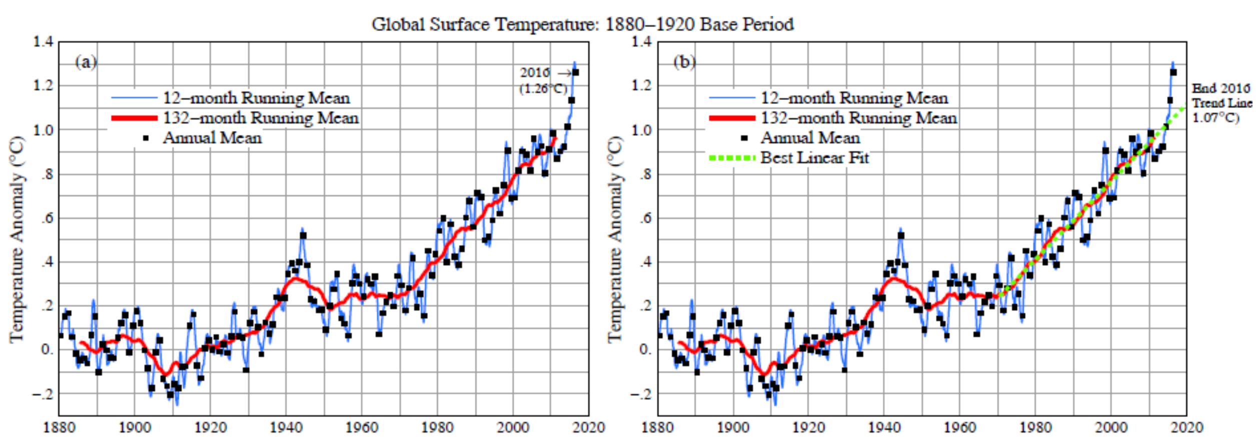

Fig. 1. (a) Global surface temperatures relative to 1880-1920 based on GISTEMP data, which employs GHCN.v3 for meteorological stations, NOAA ERSST.v4 for sea surface temperature, and Antarctic research station data[1]. (b) Post-1970 linear fit to 132-month (11-year) running mean is added to the results shown in (a).

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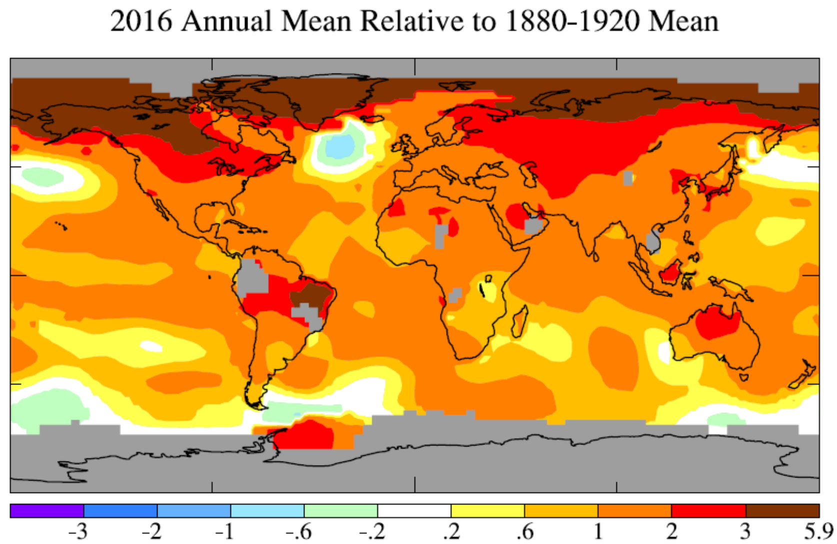

Fig. 2. Temperature anomalies in 2016 relative to 1880-1920 base period.

preindustrial global temperature thus has uncertainty of at least 0.1°C, but 1880-1920 temperature seems about right and that period has the merit of near-global data. An alternative choice of 1720-1800 as base period has similar (within ~0.1°C) global temperature as 1880-1920[10], and their analysis[10] and ours both reach the +1°C level in 2014-2015.

We estimate current underlying temperature, excluding short-term variability via linear fit to the post-1970 temperature (Fig. 1b). The result is +1.07°C at the end of 2016 relative to 1880-1920.

A global map of 2016 surface temperature anomalies relative to 1880-1920 is shown in Fig. 2. Maps for each of the last four years (Fig. 3) are relative to the 1951-1980 base period to allow more complete global coverage. 2013 is the sixth warmest year in the GISS analysis, 2014, 2015, and 2016 are the third, second and first warmest, respectively. The tropical warming in the past few years is apparent, and especially the warming in the Arctic.

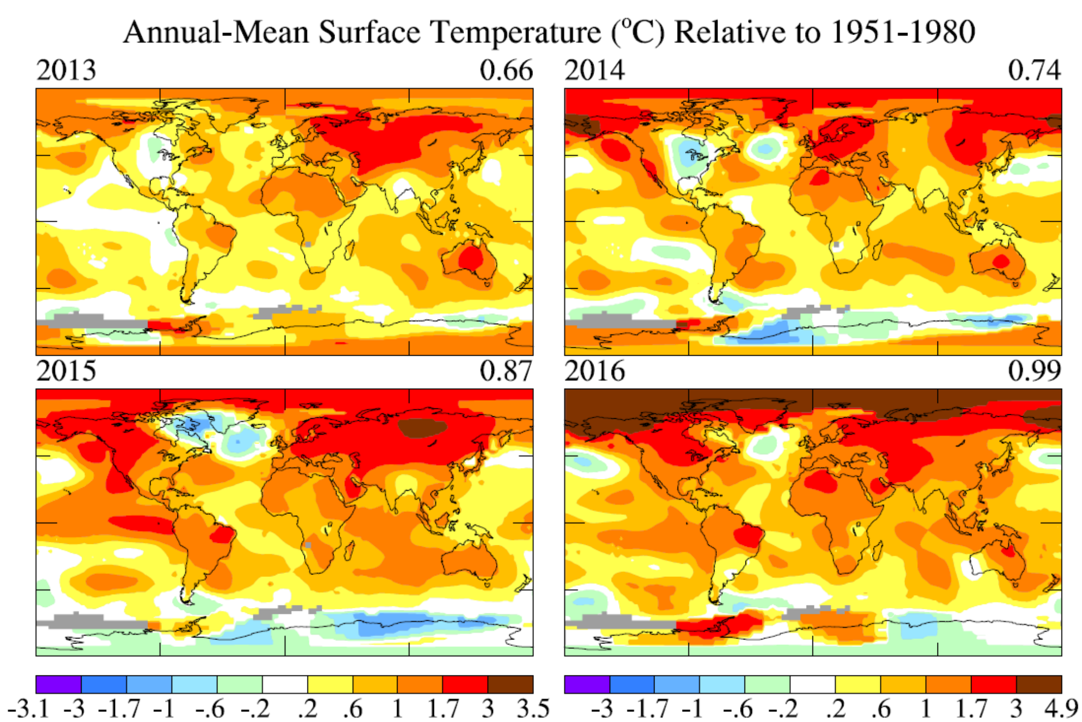

Fig. 3. Temperature anomalies in the last four years.

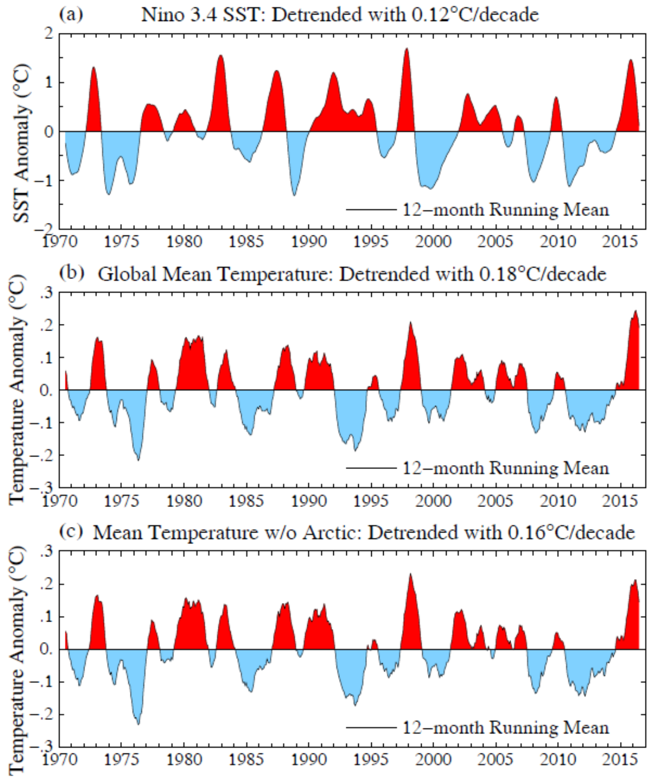

Fig. 4. (a) Temperature anomalies in Niño3.4 region[3], (b) for the global mean, and (c) for the globe excluding the Arctic (latitudes above 66°N). In each case the temperature is detrended by subtracting the temperature based on the linear change over 1970-2016. Data source for (a) http://www.cpc.ncep.noaa.gov/data/indices/ersst4.nino.mth.81-10.ascii

The 2015-16 El Niño was weaker than the 1997-98 El Niño, as measured by the peak SST anomaly in the Niño3.4 region, but the recent El Niño was longer lasting (Fig. 4a). The longevity of tropical warmth may have contributed to the magnitude of global warming, which was larger for the recent El Niño (Fig. 4b). The most extreme warming was in the Arctic (Figs. 2 and 3); when the Arctic is excluded from the global average, global warming relative to the trend line is slightly larger in 1998 than in 2016 (Fig. 4c).

The 12-month running mean temperature peaked at 1.31°C and declined to 1.26°C by the end of 2016 (Fig. 1), with global peak temperature lagging the Niño3.4 temperature peak by 4 months (monthly mean global temperature maximum lags monthly Niño3.4 by 3 months, while the lag is 5 months for 12-month running means). This lag, similar to that for the 1997-98 El Niño, is as expected as maximum correlation

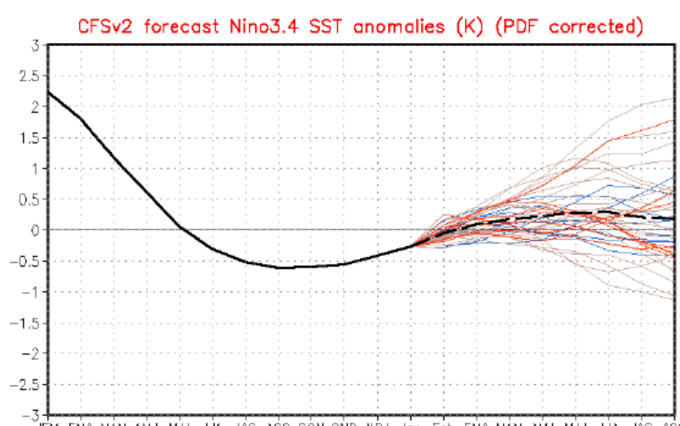

Fig. 5. Observed Niño3.4 temperature and projections with the NOAA NCEP CFS.v2 forecast model (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml#discussion).

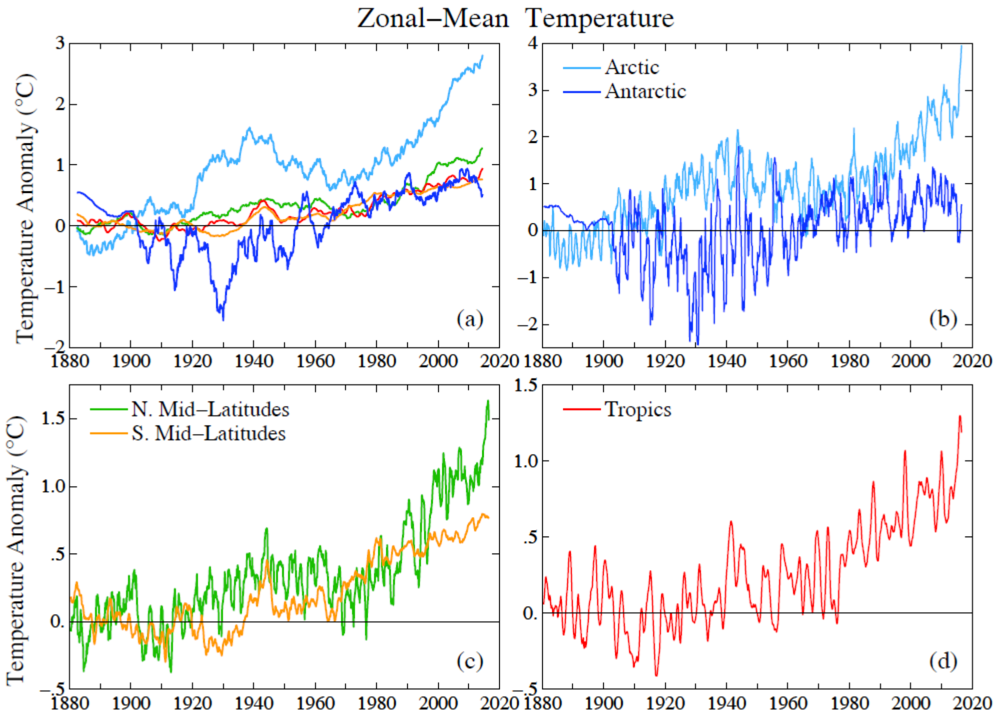

Fig. 6. Zonal-mean temperature for different latitude bands. (a) 132-month (11-year) running means for all five regions, (b-d) 12-month running means. All results are relative to the 1880-1920 base period.

of global and Niño3.4 temperatures has global temperature lagging by 4 months[1,11]. Global temperature in 2017 will almost surely fall from the 2016 value, as it has after other strong El Niños, but the drop may not be as steep as it was in 1999. The 1997-98 El Niño was followed by a strong La Niña (Fig. 4a), but temperature in the Niño3.4 region in 2016 barely reached the −0.5°C level, has since returned to Niño-neutral conditions, and is projected to remain Niño-neutral for the next several months (Fig. 5).

Warming in the Arctic is now about 3°C, and in the tropics about 1°C relative to 1880-1920 (Fig. 6). Middle latitude warming is larger in the Northern Hemisphere than in the Southern Hemisphere, as expected, because of the much larger proportion of land in the Northern Hemisphere. Warming over global land area in the past century is about twice as large as warming over the global ocean (Fig. 7), which is consistent with expectations based on global climate modeling[12].

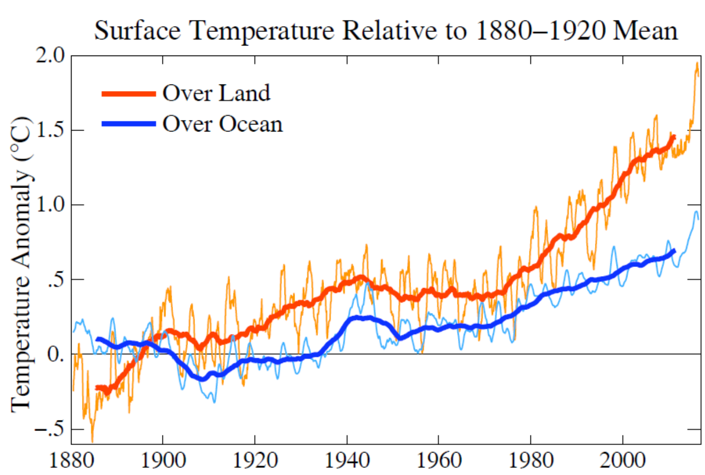

Fig. 7. Global land and global ocean surface temperature anomalies. Light lines are 12-month running means and heavy lines are 132-month (11-year) running means.

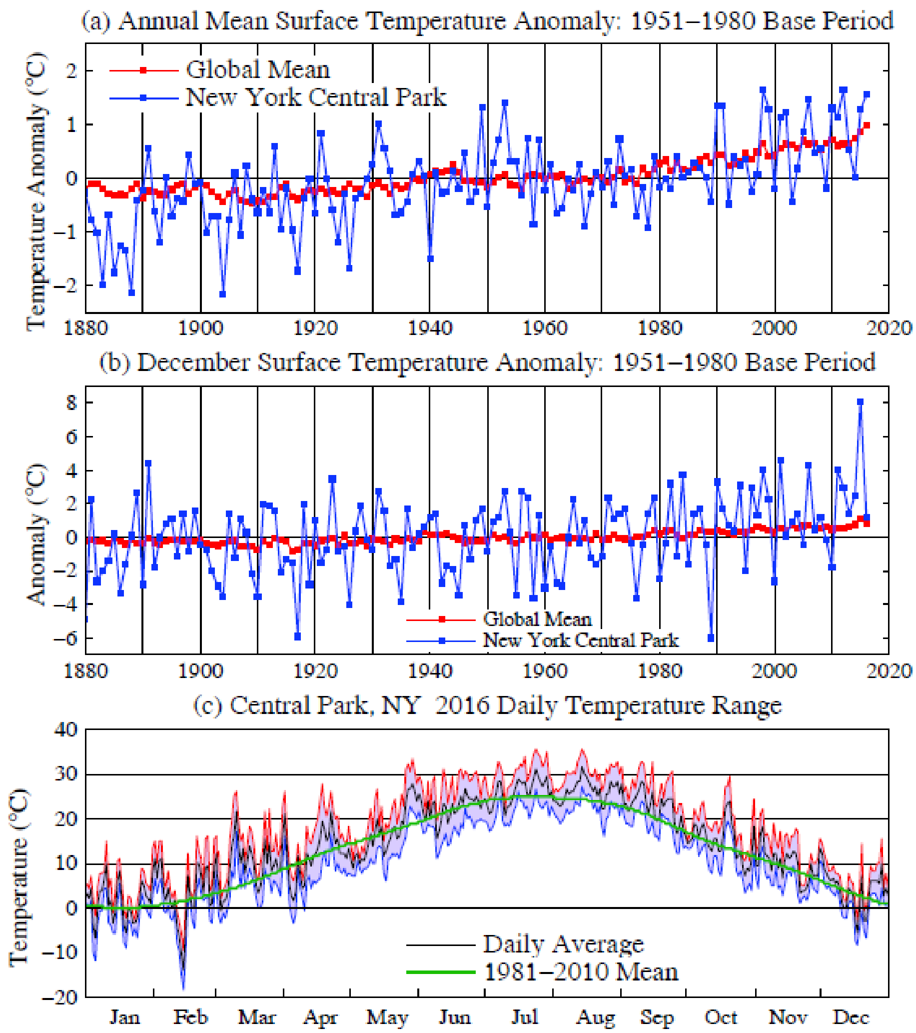

Fig. 8. Daily temperatures in Central Park, New York City, during 2015. Data source: NOAA National Weather Service New York Office http://w2.weather.gov/climate/index.php?wfo=okx

Reminder of the large magnitude of local temperature variability, relative to global mean warming, is always in order. We use data for New York City to illustrate (Fig. 8). Local annual mean temperature now has high likelihood of being warmer than mean climatology (Fig. 8a), but few people are concerned with annual mean temperature. Monthly temperature anomalies (Fig. 8b) are more noticeable to the public, but in this case the long-term average warming of about 1°C is much smaller than the interannual variability of monthly mean temperature. Although the past six Decembers have all been warmer than the 1951-1980 average, the interannual variability is so large that some months colder than the climatological mean must be anticipated. Daily temperature anomalies are even larger (Fig. 8c). One day in February 2016 the temperature reached a low of −1°F (−18°C), which was 28°F (16°C) colder than climatology.

References

[1] Hansen, J., R. Ruedy, M. Sato, and K. Lo, 2010: Global surface temperature change. *Rev. Geophys.*, **48**, RG4004, doi:10.1029/2010RG000345.

[2] The current GISS analysis employs NOAA ERSST.v4 for sea surface temperature, GHCN.v.3.3.0 for meteorological stations, and Antarctic research station data, as described in reference 1.

[3] Philander, S.G., *Our Affair with El Niño: How We Transformed an Enchanting Peruvian Current into a Global Climate Hazard*, Princeton Univ. Press, Princeton, NJ, 288 pp., 2006.

[4] The United Nations 1992 Framework Convention on Climate Change (UNFCCC, 1992) stated its objective as '…stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. The 15th Conference of the Parties (Copenhagen Accord, 2009) concluded that this objective required a goal to '…reduce global emissions so as to hold the increase of global temperature below 2°C…'. The 21st Conference of the Parties (Paris Agreement, 2015) strengthened this objective 'to holding the increase of global average temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase to 1.5°C above preindustrial levels…'.

[5] United Nations: Framework Convention on Climate Change (UNFCCC), United Nations, New York, NY, available at: http: //unfccc.int/essential_background/items/6036.php (last access: 3 March 2016), 1992.

[6] Paris Agreement 2015, UNFCCC secretariat, available at "Paris Agreement, FCCC/CP/2015/L.9/Rev.1" *(PDF),* 12 December 2015.

[7] Myhre, G., Shindell, D., Breon, F., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J. F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., and Zhang, H: Anthropogenic and natural climate forcing, in: Climate Change 2013: The Physical Science Basis, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, United Kingdom, 2013.

[8] Sato, M., Hansen, J. E., McCormick, M. P., and Pollack, J. B.: Stratospheric aerosol optical depths, 1850-1990, J. Geophys. Res., 98, 22987-22994, doi:10.1029/93JD02553, 1993.

[9] Abram, N. J., McGregor, H. V., Tierney, J. E., Evans, M. N., McKay, N. P., Kaufman, D. S., and PAGES 2k Consortium: Early onset of industrial-era warming across the oceans and continents, Nature, doi:10.1038/nature19082, 2016.

[10] Hawkins, E., Ortega, P., Suckling, E., Schurer, A., Hegerl, G., Jones, P., Joshi, M., Osborn, T.J., Masson-Delmotte, V., Mignot, J., Thorne, P., and van Oldenborgh, G.J.: Estimating changes in global temperature since the pre-industrial period, Bull. Amer. Meteorol. Soc., in press, 2017.

[11] Foster, G., Annan, J.D., Jones, P.D., Mann, M.E., Mullan, B., Renwick, J., Salinger, J., Schmidt, G.A., and Trenberth, K.E.: Comment on "Influence of the Southern Oscillation on Tropospheric Temperature" by J.D. McLean, C.R. de Freitas, and R.M. Carter, J. Geophys. Res., 115, D09110, doi:10.1029/2009JD012960, 2010.

[12] Collins, M., Knutti, R., Arblaster, J., Dufresne, J. L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W. J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A., and Wehner, M.: Long-term climate change: Projections, commitments and irreversibility, in: Climate Change 2013: The Physical Basis, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, United Kingdom, 2013.