Global Temperature in 2019

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James Hansen[a], Makiko Sato[a], Reto Ruedy[b,c], Gavin Schmidt[c], Ken Lo[b,c], Michael Hendrickson[b,c]

***Abstract.* Global surface temperature in 2019 was the 2nd highest in the period of instrumental measurements in the Goddard Institute for Space Studies (GISS) analysis. The rate of global warming has accelerated in the past decade. The 2019 global temperature was +1.2°C (~2.2°F) warmer than in the 1880-1920 base period; global temperature in that base period is a reasonable estimate of 'pre-industrial' temperature. The five warmest years in the GISS record all occur in the past five years, and the 10 warmest years are all in the 21st century. Growth rates of the greenhouse gases driving global warming are increasing, not declining.**

Update of the GISS (Goddard Institute for Space Studies) global temperature analysis (GISTEMP)[1,2,3] (Fig. 1), finds 2019 to be the 2nd 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 shown here are available from Makiko Sato on the latter web site.

We use 1880-1920 as baseline, i.e., as the zero-point for temperature anomalies, in part because it is the earliest period with substantial global coverage of instrumental measurements. Global temperature in 1880-1920 should approximate 'preindustrial' temperature, because the small warming from human-made greenhouse gases in that period tends to be offset by unusually high volcanic activity then[4].

The five warmest years in the GISS record are the past five years, 2015-2019. 2014 is the 6th warmest year, but its temperature is practically indistinguishable from that of 2010. Figure 2 compares the temperature anomalies for each of these years relative to the 1951-1980 base period. We use 1951-1980 as base period for global maps because it allows good global coverage, including data for Antarctica.

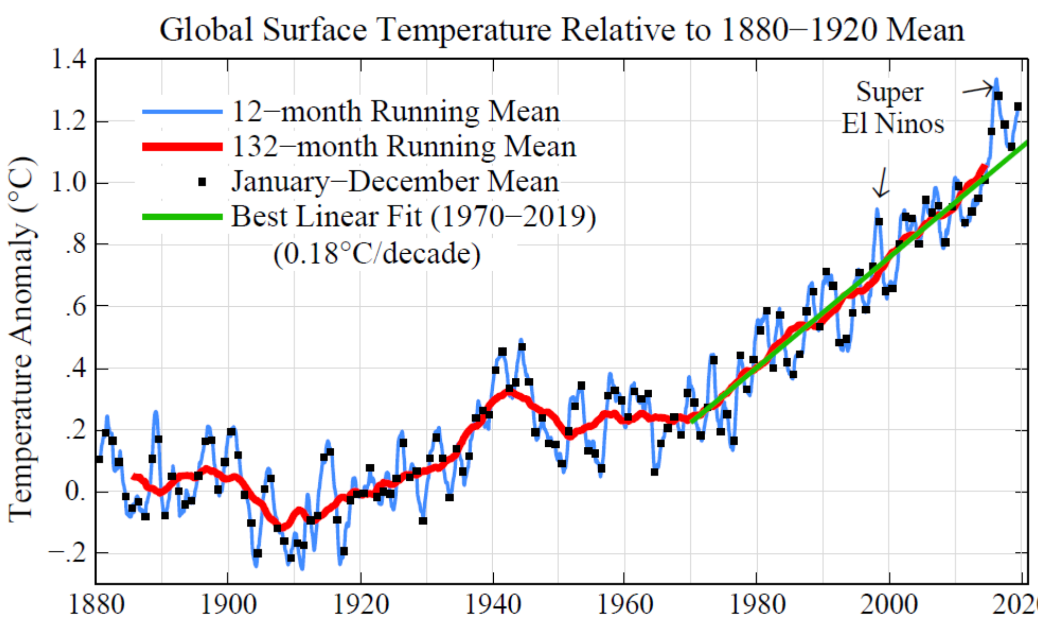

Fig. 1. Global surface temperatures relative to 1880-1920 based on GISTEMP data, which employs GHCN.v4 for meteorological stations, NOAA ERSST.v5 for sea surface temperature, and Antarctic research station data[1].

[a] Earth Institute, Columbia University, New York, NY
[b] SciSpace LLC, New York, NY
[c] NASA Goddard Institute for Space Studies, New York, NY

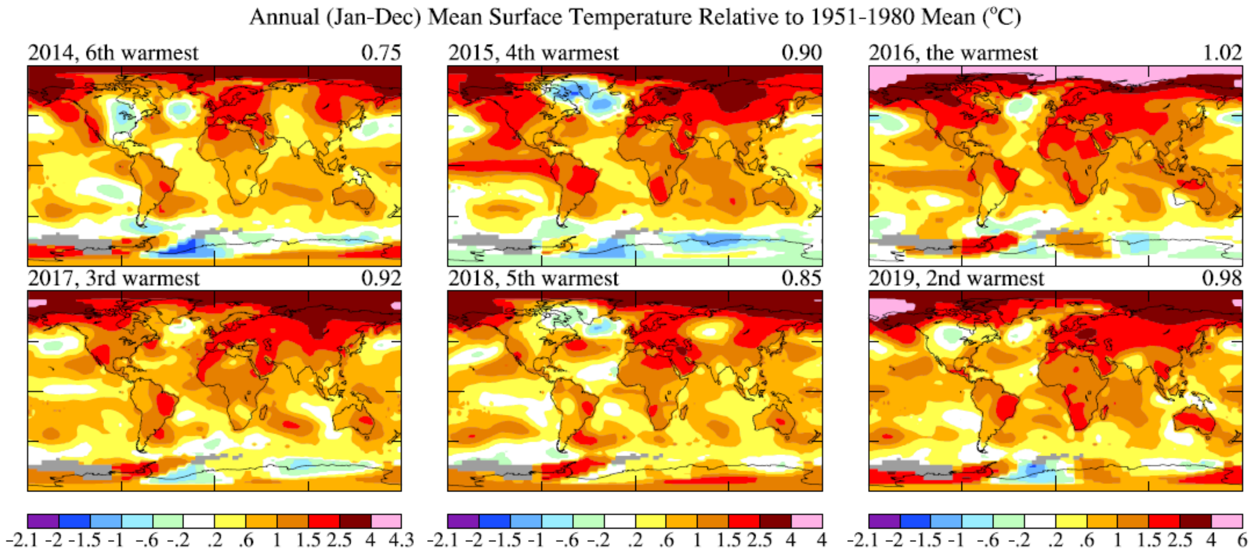

Fig. 2. Temperature anomalies in the past six years relative to the 1951-1980 base period.

Decadal average surface temperature anomalies (Fig. 3) show that since the 1970s each decade has been notably warmer than the prior decade. Average warming over land is twice as large as over ocean, and warming is greatest in the Arctic (Figs. 2 and 3). Average warming over land is now about 3°F (more than 1.5°C). The warming is reaching magnitudes at which it is easier for the public to notice that warming is occurring, even though it is small compared with the magnitude of weather fluctuations.

Cooling or absence of warming southeast of Greenland and in the Southern Ocean surrounding Antarctica is associated with and likely a consequence of injection of freshwater in the upper ocean layers as a result of increasing melt of ice shelves and the ice sheets. If the melting rate continues to increase, the associated regional cooling will increase and may put a damper on (slow the rate of) global warming. That relative cooling effect, if it occurs, would be no cause for celebration, as it would imply an increased heat flux into the ocean, an increased warming rate within the ocean that further increases the melt of ice shelves, and an accelerating rate of sea level rise.[5]

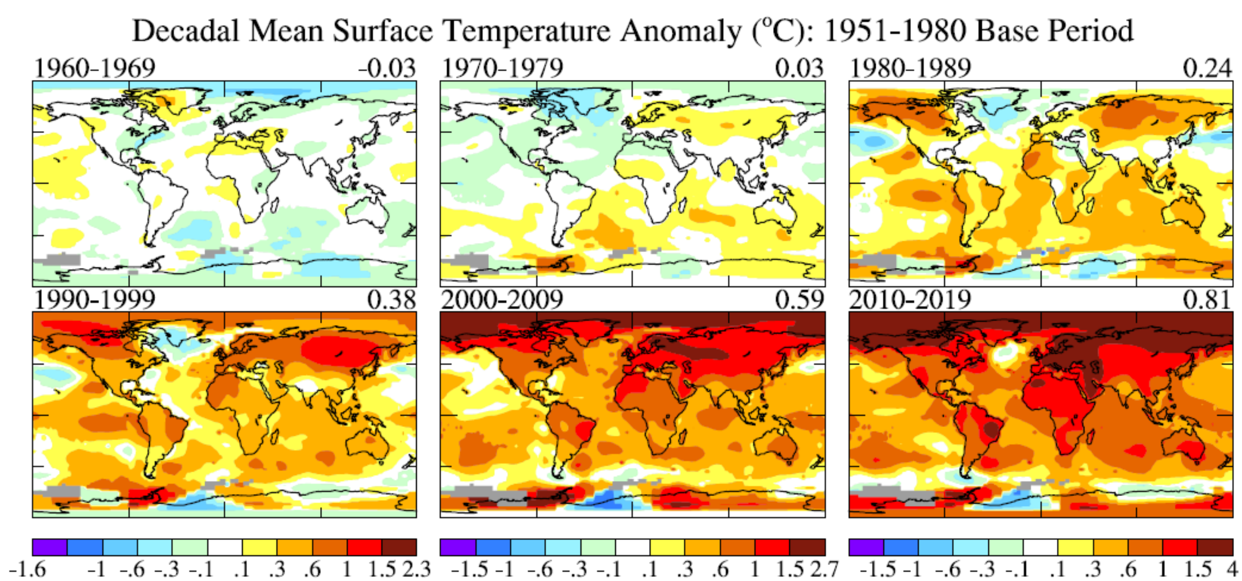

Fig. 3. Temperature anomalies relative to 1880-1920 for global land and global ocean areas.

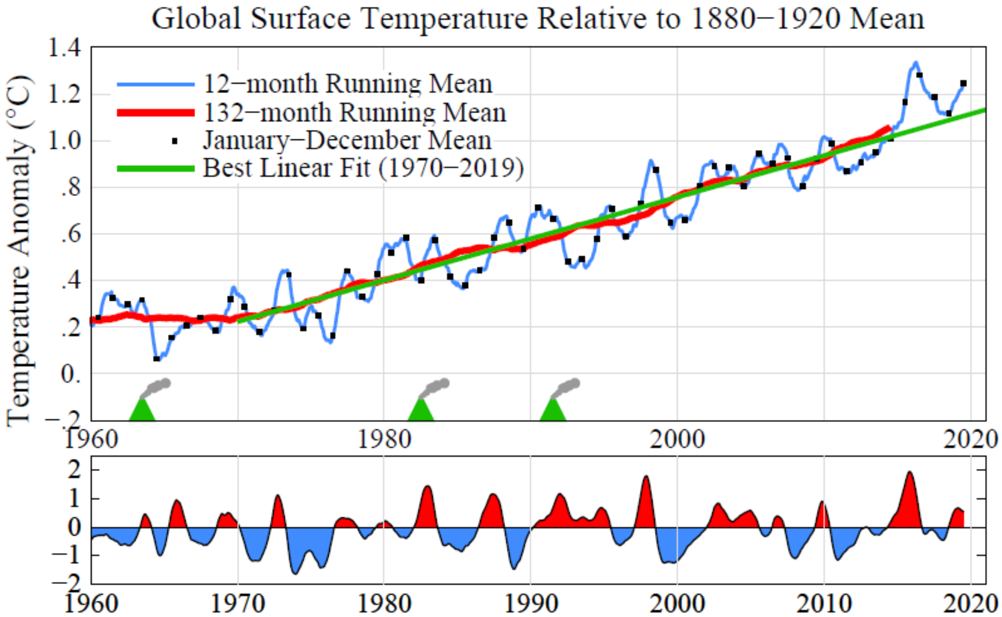

Fig. 4. Global surface temperature since 1960 relative to the 1880-1920 base period. The red-blue diagram is the Niño3.4 index, which is the temperature in a region along the equator in the Pacific Ocean used to characterize the El Niño status. Green triangles mark volcanic eruptions that produced a large amount of stratospheric aerosols.

Interannual variability of global temperature is highly correlated with the tropical Southern Oscillation, the El Niño/La Niña cycle (Fig. 4). The rate of warming had been almost constant for several decades, at about 0.18°C/decade, if short-term variability is removed by 132-month (11-year) running mean (Fig. 4). However, data for the past several years suggest that the warming rate may be accelerating.

Global warming is linked to increasing long-lived atmospheric greenhouse gases,[6] especially CO_2 and CH_4, and in turn these are linked to a substantial degree with fossil fuel use. Thus we also update here fossil fuel CO_2 emissions, CO_2 and CH_4 growth rates, and the resulting growth rate of greenhouse gas climate forcing. The latest data on global energy use and fossil fuel emissions (Fig. 5) are through December 2018. Greenhouse gases are up-to-date within a few months, and are estimated to the end of 2019, as is the resulting climate forcing. Energy use and CO_2 emissions are continuing to rise (Fig. 5).

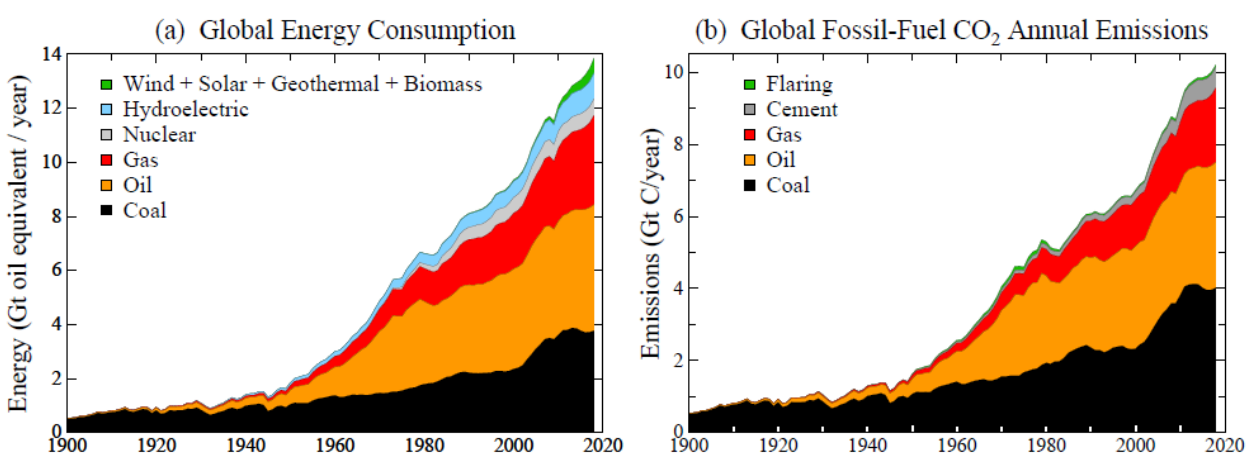

Fig. 5. Global energy consumption and fossil fuel emissions through December 2018. Energy is based on Boden et al.[7] to 1965 and BP[8] subsequently. CO_2 is based on Boden through 2014 and subsequently BP.

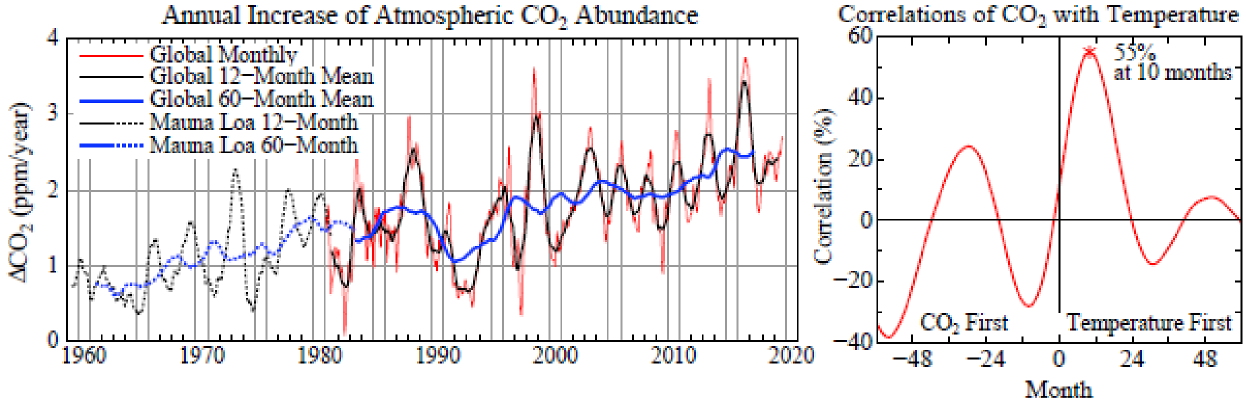

Fig. 6. (a) Global CO_2 annual growth based on NOAA data (http://www.esrl.noaa.gov/gmd/ccgg/trends/). Red curve is monthly global mean relative to the same month of prior year; black curve is 12-month running mean of red curve. (b) CO_2 growth rate is highly correlated with global temperature, with the CO_2 change lagging global temperature change by 10 months;

Annual growth of atmospheric CO_2 has increased from less than 1 ppm (parts per million) per year when Keeling began his measurement in the late 1950s to about 2.5 ppm per year averaged over the past several years (Fig. 6). The CO_2 growth rate has a strong correlation with the global temperature anomaly with CO_2 lagging the temperature by 10 months. This suggests that the CO_2 growth rate may increase in 2020, but this is uncertain because the recent tropical and global warming was weak (Fig. 4).

The annual growth of atmospheric CH_4, after falling to near zero in the early 21st century, has increased to about 10 ppb (Fig. 7). Mechanisms that may have contributed to this resurgence of methane growth include leakage during increased use of hydrofracturing in fossil fuel mining, increased emissions from warming wetlands, increased emissions from melting tundra and methane hydrates, but contributions from these processes have not been adequately quantified.

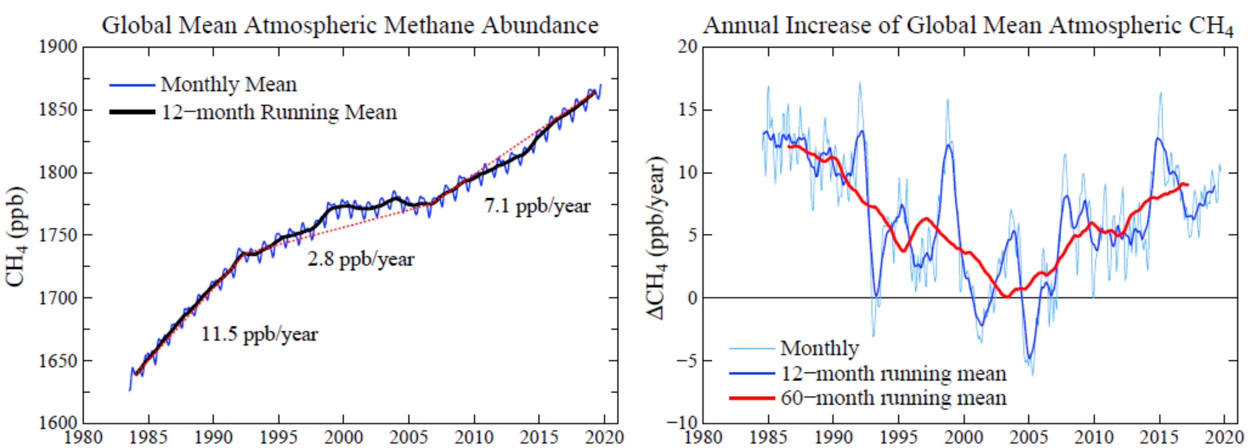

Fig. 7. Global CH_4 from Dlugokencky[9] (2016), NOAA/ESRL (http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/). End months for three indicated slopes are January 1984, May 1992, August 2006, and September 2019. Data extend through September 2019.

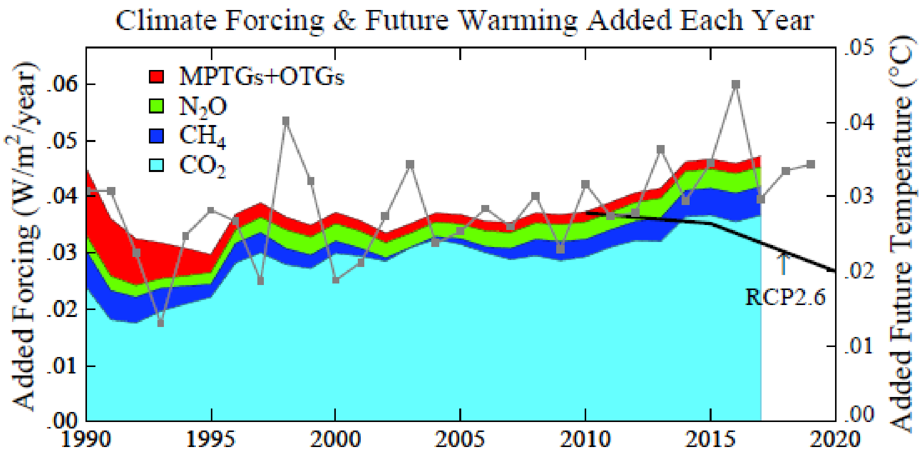

Fig. 8. Greenhouse gas climate forcing annual growth rate. Colored areas are 5-year running means. Gray dots connected by grey lines are annual changes of the total forcing by all gases. Greenhouse gas amounts are from NOAA/ESRL Global Monitoring Division. O_3 changes are not fully included, as they are not well measured, but O_3 tropospheric changes are partially included via the effective CH_4 forcing. MPTGs are Montreal Protocol Trace Gases and OTGs are Other Trace Gases. The added future warming (right scale) is the equilibrium warming for the added forcing, assuming a climate sensitivity of 0.75°C per W/m^2.

As a result of the increasing growth rates of the greenhouse gases, the annual growth of the greenhouse gas climate forcing is tending to increase. Large interannual fluctuation in the CO_2 growth causes interannual fluctuation in annual growth of the total greenhouse gas climate forcing, but the smoothed growth rate has increased steadily over the past decade.

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] Lenssen, N.J.L., G.A. Schmidt, J.E. Hansen, M.J. Menne, A. Persin, R. Ruedy, and D. Zyss, 2019: Improvements in the GISTEMP uncertainty model, *J. Geophys. Res. Atmos.*, **124**, no. 12, 6307-6326, 10.1029/2018JD029522.

[3] The current GISS analysis employs NOAA ERSST.v5 for sea surface temperature, GHCN.v4 for meteorological stations, and Antarctic research station data, as described in references 1 and 2.

[4] Hansen, J., M. Sato, P. Kharecha, K. von Schuckmann, D.J. Beerling, J. Cao, S. Marcott, V. Masson-Delmotte, M.J. Prather, E.J. Rohling, J. Shakun, P. Smith, A. Lacis, G. Russell, and R. Ruedy, 2017: Young people's burden: Requirement of negative CO_2 emissions. *Earth Syst. Dynam.*, **8**, 577-616, doi:10.5194/esd-8-577-2017.

[5] Hansen, J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, I. Velicogna, B. Tormey, B. Donovan, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. Legrande, M. Bauer, and K.-W. Lo, 2016: Ice melt, sea level rise and superstorms:/ evidence from paleoclimate data, climate modeling, and modern observations that 2 C global warming could be dangerous *Atmos. Chem. Phys.*, **16**, 3761-3812

[6] IPCC – Intergovernmental Panel on Climate Change: Climate Change 2013, edited by: Stocker, T., Qin, D., Q., Plattner, G. K., Tignor, M. M. B., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, 1535 pp., 2013.

[7] Boden, T. A., Andres, R. J., and Marland, G. *Global, Regional, and National Fossil-Fuel CO2 Emissions (1751 - 2014) (V. 2017)*. United States: N. p., 2017. Web. doi:10.3334/CDIAC/00001_V2017.

[8] BP: 2019 BP Statistical Review of World Energy, available at: http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, l

[9] Dlugokencky, E. J.: Global CH_4 data, NOAA/ESRL, available at: http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/, last access: 10 January 2020.