Annual Greenhouse Gas Index (AGGI)

THE NOAA ANNUAL GREENHOUSE GAS INDEX (AGGI)

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The AGGI is a measure of the climate warming influence of long-lived trace gases and thus that influences how changes since the start of the industrial revolution. The index was established in 1990 and has been updated annually since 1991 using the most recent data. It indicates that the climate system is being perturbed to a much greater extent than it would by natural variations in solar irradiance and volcanic aerosols. The warming influence of long-lived greenhouse gases is well understood by scientists and has been reported by the Intergovernmental Panel on Climate Change (IPCC) and the World Meteorological Organization. The AGGI is designed to track changes that pose the greatest risk to future climate, and it is intended to be a simple but robust index of the long-term climate change that is most influenced by human activities.

Introduction

Increases in the abundance of atmospheric greenhouse gases since the industrial revolution are mainly the result of human activity and are largely responsible for the observed increases in global temperature (IPCC 2014). However, climate-altering trace gas emissions and uptake by sinks are not uniform or proportional to greenhouse gas measurements. We present here an index that is directly proportional to the change in the direct warming influence since 1750 (also known as climate forcing) resulting from these gases. Because it is based on the observed amounts of long-lived greenhouse gases in the atmosphere, this index contains relatively little uncertainty.

The Intergovernmental Panel on Climate Change (IPCC) defines climate forcing as "an externally imposed perturbation in the radiative balance of the Earth-climate system, e.g. through changes in solar radiation, changes in the Earth albedo, or changes in atmospheric gases and aerosol particles." Thus climate forcing is a "change" in the status quo. IPCC has also defined an "index" for greenhouse gas, the year 1750 is set for reference. The perturbation to direct climate forcing (also termed "radiative forcing") that has the largest magnitude and the least uncertainty in the forcing is that caused by changes in the atmospheric global abundance of long-lived well mixed greenhouse gases, in particular carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halogenated compounds (mainly CFCs).

Measured global atmospheric abundances of greenhouse gases are used to calculate changes in radiative forcing beginning in 1750 when global data for atmospheric samples were expected to exist. This is done with annual average total radiative forcing by all the long-lived greenhouse gases since the pre-industrial era (1750) to also used to define the direct climate forcing by the AGGI, which was introduced in 1990 based on measurements through 2004 (Hofmann et al., 2006) and has been updated annually since.

Observations

The NOAA monitoring program provides high-precision measurements of the global abundance and distribution of long-lived greenhouse gases that are used to calculate changes in radiative climate forcing.

Air samples are collected through the NOAA/GML global air sampling network, including a cooperative program for the carbon species which provides samples from ~30 global background air sites, including measurements at 5 degree latitude intervals from ship routes (see Figure 1).

Figure 1. The NOAA Earth System Research Laboratory cooperative global air sampling network where greenhouse gases are measured in continuous or flask-type samples. Red dots represent sampling sites in 2019. Click on image to view full size figure.

Weekly data are used from a subset of these sites to create a smoothed north-south latitude profile from which a global average is calculated. Figure 2 shows the atmospheric abundance of CO_2 has increased by about a factor of 1.46 ppm per year over the past 40 years (1979-2019). The CO_2 increase is accelerating – while it averaged about 1.5 ppm per year in the 1980s and 1.9 ppm per year in the 1990s, the growth rate increased to 2.2 ppm per year during the last decade (2009-2019). The annual CO_2 increase from 1. Jan 2019 to 1. Jan 2020 was 2.14 ± 0.08 ppm (http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html), which is slightly higher than the average of the previous decade, and much higher than the two decades before that.

The growth rate of methane (CH_4) has varied considerably with concentration approaching steady state, assuming no trend in CH_4 lifetime. Superimposed on this decline is significant interannual variability in the growth rate (Dlugokencky et al., 1998; 2003) from 1984 to 2019. The atmospheric CH_4 abundance was nearly constant, but since 2007, globally averaged CH_4 has been increasing again. Causes for the increase during 2007-2009 include warmer temperatures in the tropics in 2007 and increased precipitation in the tropics during 2007 and 2008 (Dlugokencky et al., 2009). Isotopic measurements argue for continued increasing microbial emissions after 2006 to explain the observed trends in atmospheric CH_4 (Schwietzke et al., 2016 and Nisbet et al., 2016). Contributions to the recent increase in CH_4 are still uncertain. The growth rate in CH_4 in methane has become even larger, averaging 5.1 ± 2.2 ppb/yr during the last decade (2009-2019) compared to an average annual increase of 2.1 ± 1.1 ppb/yr between 2007 and 2013 (https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/). The annual increase in 2019 was 10.4 ± 0.6 ppb/yr. Although the N_2O growth rate has been relatively constant, the uncertainty in the trend is large because the growth rate is only about 1 ppm that depends on anthropogenic radiative forcing from the sum of observed CFC changes were decreasing in about 2000 and continued to decline through 2019 (Montzka et al., 2021) despite increases in emissions of CFC-11 in recent years (Rigby et al., 2019). The observed decline is a response to global controls on production and CFC production and trade by the fully adjusted and amended Montreal Protocol on Substances that Deplete the Ozone Layer.

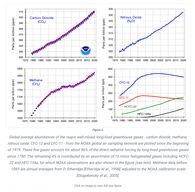

Figure 2

Global average abundances of the major well-mixed, long-lived greenhouse gases - carbon dioxide, methane, nitrous oxide, CFC-11 and CFC-12 – from the NOAA global air sampling network are plotted since the beginning of 1979. These five gases account for about 80% of the total radiative forcing by long-lived greenhouse gases since 1750. The remaining 4% is contributed by an assortment of 11 minor halogenated gases including HCFC-22 and CF4. Data for which NOAA observations are also available in the figure (see text). Values before 1983 are annual averages from D. Etheridge (Etheridge et al., 1992) adjusted to the NOAA calibration scale (Hofmann et al., 2006).

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Radiative Forcing Calculations

To determine the radiative forcing of the greenhouse gases, we have used IPCC (Ramaswamy et al., 2001) recommended expressions to convert greenhouse gas global abundance changes, relative to 1750, to radiative forcing (Hofmann et al., 2006). The IPCC expressions are based on fits to results from more elaborate radiative transfer models and generally include contributions to the radiative forcing of the gases. The uncertainties in the global average abundances of the long-lived greenhouse gases are much smaller (<1%).

Table 1. Expressions for Calculating Radiative Forcing*

Trace Gas	Radiative Forcing, dF (Wm^{-2})	Constant
CO_2	$dF = 5.35 \ln(C/C_0)$	k = 5.35
CH_4	$dF = (0.036^{*}\sqrt{M} - 0.047^{*}\sqrt{N})(M_0 - N_0)$	β = 0.036
N_2O	$dF = (0.12^{*}\sqrt{N} - 0.047^{*}\sqrt{M})(N_0 - N_0)$	α = 0.12
CFC-11	$dF = \alpha^{*}C$	α = 0.25
CFC-12	$dF = \alpha^{*}C$	α = 0.32

*IPCC (2001)

The subscript "0" denotes the year/abundance (1750) global abundance

$M_0 = 0.4745 \times 1.2 \times (1 \times 10^{-6}) \times 5.13 \times 10^{18}$ kilotons$^{(1)}$

C is the CO_2 global measured abundance in ppm, M is the same for CH_4 in ppb,
N is the same for N_2O in ppb, α is the same for CFCs in ppb

$C_0 = 278$ ppm, $M_0 = 722$ ppb, $N_0 = 270$ ppb, $k_0 = 0$

Because we seek an index that is accurate, only direct forcing from these gases has been included. Model-dependent feedbacks, for example, due to water vapor and ozone depletion, are not included. Other spatially heterogeneous, short-lived, climate-altering agents, such as aerosols and tropospheric ozone, have uncertain global magnitudes and also are not included here to maintain accuracy. Figure 3 shows the results for carbon dioxide global mixing ratios for 1750-2019. It also includes an estimate of the total of direct contributions to radiative forcing would be similar to the Consumer Price Index, for example. It would include all the important components to track the components of climate forcing. In contrast to climate model calculations, the results reported here are based mainly on measurements of long-lived well-mixed gases and have small uncertainties.

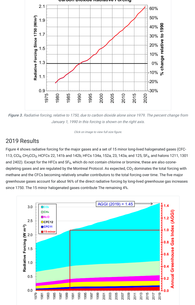

Figure 3. Radiative forcing relative to 1750 due to carbon dioxide alone since 1979. The percent change from January 1, 1990 in this forcing is given on the other axis.

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2019 Results

Figure 4 shows radiative forcing for the major gases and a set of 15 minor long-lived halogenated gases (CFC-113, CCl_4, CH_3CCl_3, HCFC-22, HFC-134a and HFC-152a, 1,1dfea, 23, 125a, and 143a, and halons 1211, 1301 and 2402). Except for the HFCs and SF_6, which do not contain chlorine or bromine, these are the ozone depleting gases and are regulated by the Montreal Protocol. As expected, CO_2 dominates the total forcing with methane and the halogens (mainly smaller contributors to the total forcing over time). The four major greenhouse gases account for about 96% of the direct radiative forcing by long-lived greenhouse gas increases since 1750. The 15 minor halogenated gases contribute the remaining 4%.

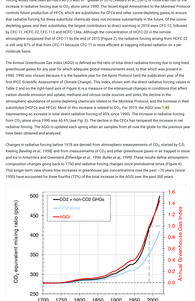

Figure 4. Radiative forcing relative to 1750 of all the long-lived greenhouse gases. The NOAA Annual Greenhouse Gas Index (AGGI) which is indexed to 1 for the year 1990, is shown on the right axis.

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Of the five long-lived greenhouse gases (CO_2 and N_2O are the only ones that continue to increase at regular rates over decades, halocarbons from the Montreal Protocol and methane exhibit complex behavior) changes from 1990 to 2006. While the radiative forcing of the long-lived, well-mixed greenhouse gases increased 45% from 1990 to 2019 (by ~0.48 watts m^{-2}), this increase accounted for about 85% of the increase from 1990 to 2006. As the ozone depleting gases not been regulated by the Montreal Protocol and its amendments, it is estimated that climate forcing would be much larger than it is today if these gases had been released to the atmosphere. The 15 minor halocarbons contribute a small but significant amount to the total forcing by long-lived greenhouse gases. Their combined radiative forcing increased from 0.05 watts m^{-2} in 1990 to 0.06 watts m^{-2} in 2019. The ozone depleting gases not been regulated by the Montreal Protocol and its amendments, it is estimated that climate forcing would be much larger than it is today if these gases had been released to the atmosphere. The 15 minor halocarbons contribute a small but significant amount to the total forcing by long-lived greenhouse gases. Their combined radiative forcing increased from 0.05 watts m^{-2} in 1990 to 0.06 watts m^{-2} in 2019. The increase in radiative forcing from CO_2 alone since 1990 was 60.6% (see Fig. 3). The decline in the CFCs has tempered the increase in net radiative forcing. The AGGI is calculated each spring when air samples from all over the globe for the previous year have been obtained and analyzed.

Changes in radiative forcing before 1979 are derived from atmospheric measurements of CO_2 (started by C.D. Keeling (Keeling et al., 1976)) and from measurements of CO_2 and other greenhouse gases in air trapped in snow and ice in Antarctica and Greenland (Etheridge et al., 1996; Butler et al., 1999). These results define atmospheric concentrations during the pre-1979 and radiative forcing changes since the beginning of the industrial revolution. This longer-term view shows how increases in greenhouse gas concentrations over the past ~75 years (since 1945) have accounted for more than two-thirds (67%) of the total increase in the AGGI over the past 250 years.

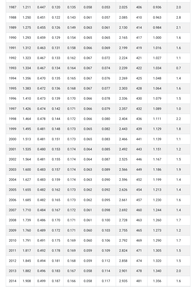

*Figure 5. The 1979 changes in the CO_2-equivalent mixing ratio and AGGI based on the ongoing measurements of all greenhouse gases reported here, measurements of CO_2 going back to the 1950s from C.D. Keeling (Keeling et al., 1976), and estimates of greenhouse gases from air trapped in ice and snow above glaciers (Etheridge et al., 1995; Battle et al., 1996; Butler et al., 1999; Rubinstein et al., 1996; Rubinstein et al., 1996; Rubinstein et al., 1996