Halfway to doubling of CO_2 radiative forcing

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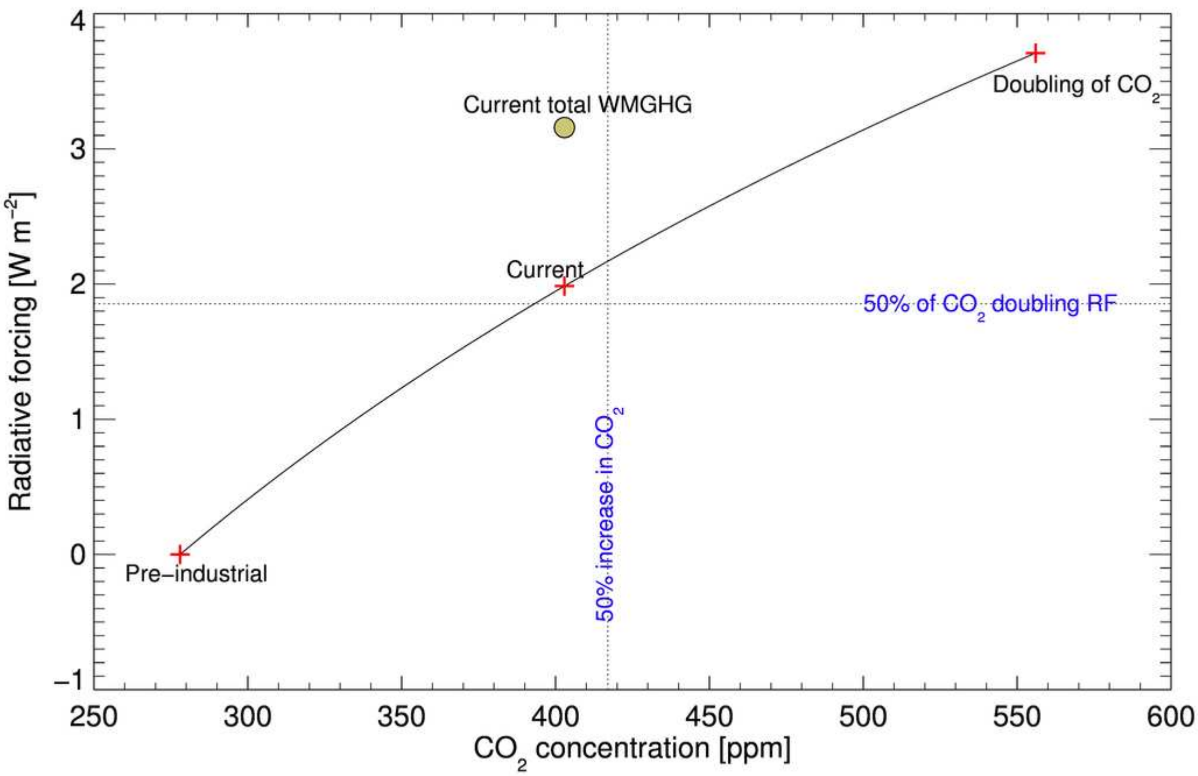
The "double CO_2" experiment has become a standard experiment in climate science, and a convenient way of comparing the sensitivity of different climate models. Double CO_2 was first used by Arrhenius[1] in the 19th century and in the classic paper by Manabe and Wetherald[2], published 50 years ago, which marked the start of the modern era of climate modeling. Doubling CO_2 now has an iconic role in climate research. The equilibrium climate sensitivity (ECS) is defined as the global-mean surface temperature change resulting from a doubling of CO_2[3-5], which is a headline result in Intergovernmental Panel on Climate Change (IPCC) assessments. In its most recent assessment IPCC concluded that the ECS "is likely in the range 1.5 to 4.5°C". We show that we are now halfway to doubling of CO_2 since pre-industrial times in terms of radiative forcing, but not in concentration.

The greenhouse effect due to change in CO_2 – quantified using calculations of radiative forcing – follows, to a good approximation, a logarithmic dependence on the ambient concentration in the atmosphere over the last 1000 years[6]. Due to this relationship between radiative forcing and CO_2 concentration, the radiative forcing due to a doubling of CO_2 is approximately independent of background levels. A doubling of CO_2 is estimated by IPCC to cause a radiative forcing of 3.7 W m^{-2}. Recent detailed radiative transfer calculations arrived at a similar estimate[7]. The uncertainties are small for the radiative forcing due to CO_2; uncertainties associated with spectroscopic parameters that underpin forcing calculations are estimated to be less than 1% in a recent study[8], with overall uncertainties assessed to be 10%[6] (with 90% confidence). Forcing estimates of doubling of CO_2 from global climate models have the same best estimate as the IPCC value[6], even though these models include rapid atmospheric adjustments, which modify the forcing calculated using a radiative transfer model.

It is timely to assess where we are now, relative to a doubling. The global-mean CO_2 abundance in 2016 was 403 ppm according to global observations[9] which is less than 50% higher than the pre-industrial CO_2 concentration of 278 ppm. However, due to the logarithmic forcing relationship, a halfway to doubling of CO_2, in terms of radiative forcing, has now been reached. Figure 1a illustrates that this halfway point happened at 393 ppm, which was reached in 2012. A halfway to doubling in the CO_2 concentration is 417 ppm and will be reached before 2025 with current CO_2 growth rates. Hence, at CO_2 concentrations between of 393 and 417 ppm we are more than a halfway to CO_2 doubling in radiative forcing, but not in concentration (Figure 1a).

Climate change over the industrial era is caused by several anthropogenic climate drivers in addition to CO_2, including other atmospheric gases and aerosols and changes to the land surface[6]. Increases in concentrations of well-mixed greenhouse gases (WMGHGs) other than CO_2 (notably CH_4, N_2O and halocarbons) contribute to a stronger greenhouse effect. The combined radiative forcing from all WMGHGs is 3.1 W m^{-2} in 2015 (Figure 1b) and hence in CO_2-equivalent forcing terms, is 84% of the way to a doubling. This value includes a recent estimate of methane's radiative forcing which incorporated its absorption of solar radiation; this update resulted in an increase in the 1750-2011 CH_4 forcing from 0.48 (the value in IPCC fifth assessment[6]) to 0.61 W m^{-2} [7]. This increase is, in radiative forcing terms, close to the increase in CO_2 concentration over the 5 year period from 2010 to 2015. Consequently, we estimate that total WMGHG radiative forcing will be equivalent to doubling of CO_2, with present growth rates, by around 2030 Figure 1b). This is almost 5 years earlier than is estimated without the update to the CH_4 forcing. Aerosols generally cool the Earth and have historically countered much of this additional WMGHG forcing. The total anthropogenic forcing is expected to be close to the CO_2-only forcing, but aerosols add uncertainty[6]. Nevertheless, in terms of radiative forcing we are more than half way to a doubling of CO_2.

a


Current total WMGHG
Doubling of CO_2
Current
50% of CO_2 doubling RF
50% increase in CO_2
Pre−industrial
Radiative forcing [W m^{-2}]
CO_2 concentration [ppm]
4
3
2
1
0
−1
250
300
350
400
450
500
550
600

b

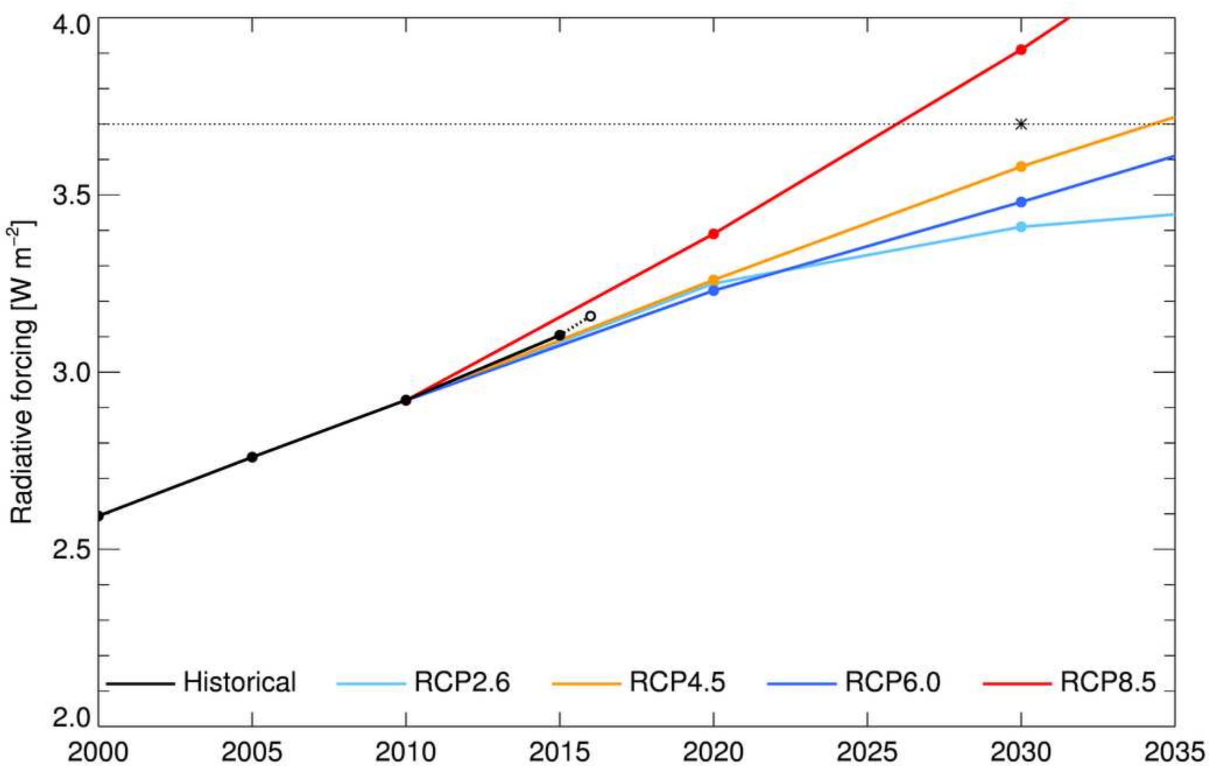

Radiative forcing [W m^{-2}]
4.0
3.5
3.0
2.5
2.0
2000
2005
2010
2015
2020
2025
2030
2035
Historical
RCP2.6
RCP4.5
RCP6.0
RCP8.5

Figure 1: Radiative forcing due to CO_2 and all well-mixed greenhouse gases (WMGHG). **a**, The CO_2 radiative forcing shown as a function of its global-mean abundance calculated using the IPCC forcing expressions[6]. Dotted lines are for a 50% increase in concentration (vertical) and radiative forcing (horizontal). **b,** Radiative forcing for all WMGHGs using the IPCC forcing expressions[6], except for CH_4 where a stronger forcing, based on recent detailed calculations, is used[7]. Historical values are based on observed concentrations. Radiative forcing for CO_2, N_2O and halocarbons for the 2000-2010 period and future scenarios are from IPCC[10]. CH_4 concentrations are from IPCC[10]. For year 2015 the global annual mean concentrations of CO_2, CH_4 and N_2O are from NOAA[9], and for halocarbons the relative increase since 2010 are from the Arctic Zeppelin observatory. Preliminary data for 2016 is included[9], which may be subject to small changes. Growth in WMGHG radiative forcing in the 2010-2016 period is 0.04 W m^{-2} yr^{-1}; the asterix shows the date at which the total WMGHG forcing equals a CO_2 doubling by extrapolating this trend.

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