Implications of Expected Radiative Forcing

Bruce Parker (bruceparker@alum.mit.edu)

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(http://ccdatacenter.org/documents/ImplicationsofExpectedRadiativeForcing.pdf)

Summary

Analyses of ways to meet the IPCC's temperature target of limiting the temperature increase to less than 2°C have been mostly focused on an emissions budget. However, by looking at the radiative forcings of the various climate elements, the following become apparent:

1. In order to meet the IPCC goals, the net change in radiative forcing between 2020 and 2100 must be close to zero as the equilibrium temperature for 2020 will be about 2°C (i.e., we will need to sequester almost all anthropogenic and natural emissions that occur after 2020 just to meet the 2°C target).
2. The equilibrium temperature increase is about double that of the measured temperature increase, or about 0.4°C per decade.
3. If surface albedo changes are taken into account, the radiative forcing in six years will be about the same as the maximum radiative forcing in RCP 2.6, which occurs about 2040.
4. Even though the oceans will continue to absorb CO2 if net CO2 emissions approach zero, the change in radiative forcing from the reduced atmospheric CO2 will be offset by the additional radiative forcing from reduced aerosol emissions (as the burning of fossil fuels is the main contributor to the aerosols), and the latter will happen at a much greater rate than the former[1].
5. Since many factors will contribute significant additional radiative forcing in the next 40 years (e.g., anthropogenic CO2 emissions; methane emissions[2] - which were expected to decrease in RCP 2.6 but are currently increasing; additional surface albedo changes in the Arctic[3]; greenhouse gases from reservoirs[4]; reduced atmospheric aerosols[5]; the burning of peat[6]; other emission from soils[7]; permafrost thawing[8]; etc.) it will likely cost hundreds of trillions of dollars to limit the warming to 2°C in 2100[9] by just mitigation and carbon sequestration.
6. Some sort of solar radiation management will almost certainly be required to limit the temperature increase to 2°C.

Global Warming and Radiative Forcing

Most climate scientists believe that the climate sensitivity for a doubling of atmospheric CO2 is about 3°C. Given the direct correlation between radiative forcing and atmospheric CO2, the following table shows the equilibrium temperature increase for various amounts of radiative forcing:

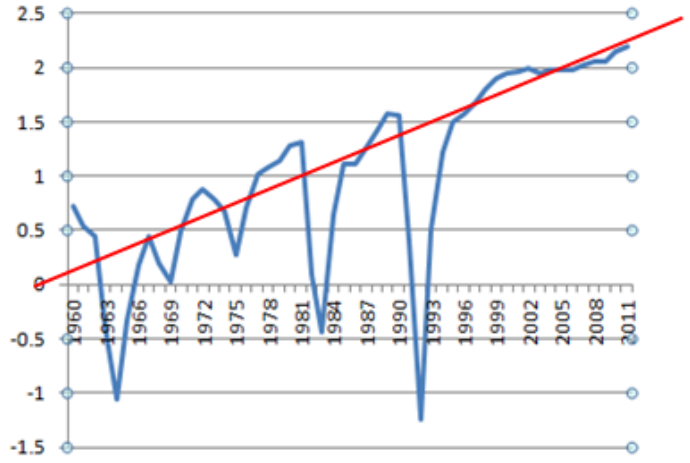
Effective Radiative Forcing (W/m-2)	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8
Equivalent CO2e PPM	375	389	404	419	435	452	469	487	506	525	545	566
Equilibrium Temperature Increase (°C)	1.05	1.20	1.36	1.53	1.70	1.88	2.06	2.26	2.46	2.66	2.88	3.1

Table 1 - Equilibrium temperature increase for various values of radiative forcing

Rate of Increase of Global Warming and Radiative Forcing

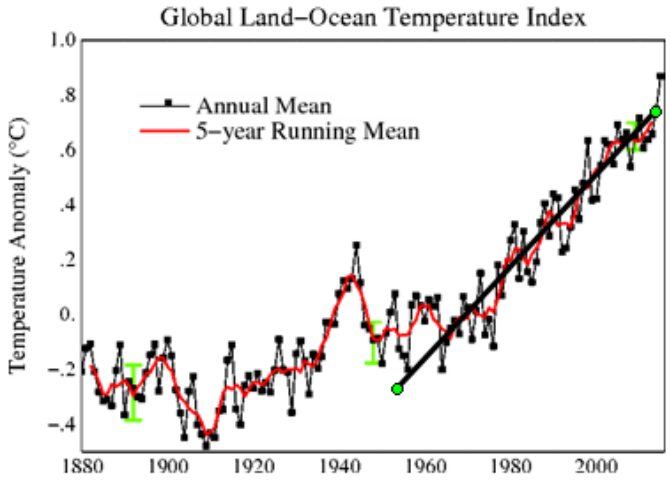
Based on data from NASA (Figure 1), the net radiative forcing has been increasing at a rate of about 0.37 W m-2 per decade since 1960. And at the same time the temperature as increased at about half that rate, about 0.19°C per decade (Figure 2). By looking at these trends over the last 50 years (and extrapolating this to 2060) and assuming a climate sensitivity of 3°C for a doubling of atmospheric CO2 (see Table 2) it appears that the increasing energy imbalance is not causing the global temperature to increase more rapidly, and, as a result, the equilibrium temperature is increasing at almost twice the rate as that of the global temperature (i.e., the global temperature is increasing at about .19°C per decade but we are committing ourselves to a temperature increase of about .37°C per decade).

According to the IPCC, the radiative forcing in 2011 was about 2.3 W m-2. With radiative forcing increasing about 0.43 W m-2 per decade, the radiative forcing will be about 2.5 W m-2 at the end of 2016 and will be about 2.7 W m-2 at the end of 2020. This corresponds to equilibrium temperature increases of about 1.8°C and 2.0°C respectively.



Based on the IPCCs' "Climate Change 2013 The Physical Science Basis" (AR5) - Pages 1408-1409

Figure 1 - Historical net forcing



http://data.giss.nasa.gov/gistemp/graphs_v3/
http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.gif

Figure 2 - Historical temperature increase

	1960	1980	2000	2020	2040	2060		Change 1960-1970		Change 2010-2020
Estimated Radiative Forcing (W m-2)	0.03	0.88	1.73	2.58	3.43	4.29		0.43		0.43
Equilibrium Temperature for RF (°C)	0.02	0.54	1.15	1.86	2.7	3.68		0.25		0.37
Measured Temperature (°C)	0.05	0.44	0.82	1.21	1.59	1.98		0.19		0.19
Calculated Radiative Forcing for Temperature (W m-2)	0.09	0.73	1.29	1.81	2.28	2.71		0.33		0.25
Temperature Imbalance (°C)	-0.03	0.1	0.33	0.65	1.11	1.71		0.06		0.18
Energy Imbalance (W m-2)	-0.06	0.15	0.44	0.77	1.16	1.58		0.1		0.17

Table 2 - Radiative Forcing and Temperature Trends for a linear change in both radiative forcing and temperature increase

Radiative Forcing and Surface Albedo Change

According to Soden and Held (2006) surface albedo contributes about 6% of the total radiative forcing at the global tropopause in models used by the IPCC. If the same percentage applies to surface warming, then the estimated radiative forcing in the above table, for years after 1990, should be adjusted as follows:

	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Arctic Ocean Ice Melt (four weeks ice free in 2060)[10]	0.04	0.08	0.11	0.15	0.19	0.23	0.27	0.30	0.34	0.37	0.41	0.44
NH Snow Cover Extent[11]	0.07	0.10	0.13	0.16	0.19	0.22	0.24	0.26	0.27	0.29	0.30	0.31
Total	0.11	0.18	0.25	0.32	0.38	0.45	0.51	0.56	0.61	0.66	0.71	0.75
Radiative forcing (Linear)	1.31	1.74	2.17	2.60	3.03	3.46	3.89	4.32	4.75	5.18	5.61	6.04
Accounted for in CS	0.08	0.10	0.13	0.16	0.18	0.21	0.23	0.26	0.28	0.31	0.34	0.36
"Extra" RF	0.03	0.07	0.12	0.16	0.20	0.24	0.27	0.30	0.33	0.35	0.37	0.39
"Adjusted" RF	1.33	1.81	2.28	2.76	3.23	3.70	4.16	4.62	5.07	5.53	5.98	6.42

Table 3. Adjustments to radiative forcing to correct for projected surface albedo changes not included in climate sensitivity

Table 4 then gives the adjusted equilibrium temperature, etc., from Table 2 based on the adjustments in Table 3 (and with a different set of years). Based on these adjustments the equilibrium temperature increase for the expected radiative forcing in 2020 is about 2°C.

	1990	2000	2010	2020	2030	2040	2050	2060		Change 2010-2020
Adjusted Radiative Forcing (W m-2)	1.33	1.81	2.28	2.76	3.23	3.70	4.16	4.62		0.47
Equilibrium Temperature for RF (°C)	0.85	1.21	1.6	2.02	2.48	2.99	3.53	4.11		0.42
Measured Temperature (°C) (increases 0.19°C/decade after 2010)	0.63	0.82	1.01	1.21	1.40	1.59	1.78	1.97		0.19
Calculated Radiative Forcing for Temperature (W m-2)	1.02	1.29	1.56	1.81	2.05	2.27	2.49	2.7		0.25
Temperature Imbalance (°C)	0.22	0.39	0.58	0.81	1.09	1.40	1.75	2.14		0.23
Energy Imbalance (W m-2)	0.32	0.51	0.73	0.95	1.18	1.42	1.67	1.92		0.22

Table 4 - Adjusted Radiative Forcing and Temperature Trends

Brian J. Soden and Isaac M. Held ("An Assessment of Climate Feedbacks in Coupled Ocean–Atmosphere Models", http://journals.ametsoc.org/doi/full/10.1175/JCLI3799 ; the estimated radiative forcing of the models they reviewed was 4.3 W m^{-2} and, "[o]n average, the strongest positive feedback is due to water vapor (1.8 W m^{-2} K^{-1}), followed by clouds (0.68 W m^{-2} K^{-1}), and surface albedo (0.26 W m^{-2} K^{-1})

Radiative Forcings in RCP 2.6

The RCP 2.6 pathway is supposed to demonstrate an emissions pathway that will result in a temperature increase of about 2°C by 2100. The following tables show some of the radiative forcing values from the IPCC's AR5 for both the . Table 6 shows the radiative forcing of some of the "climate factors" both 2011 and 2100, and Table 5 lists the radiative forcing at the end of each decade for RCP 2.6. Note that radiative forcing from all of the greenhouse gases does not change from 2011 to 2100, but just shifts significantly from methane and halocarbons to carbon dioxide. Note also that the IPCC data in "The Physical Science Basis" did not specifically list the aerosol radiative forcings after 2011. Since the majority of the aerosols come from the burning of fossil fuels, it's hard to see how the RCP 2.6 model "makes up" for the

additional forcing that will come as fossil fuel use is reduced significantly (they could be assuming lots of CCS and BECCS and that these would both continue to emit aerosols). In addition, assuming the current growth rate in radiative forcing (0.43 W m-2) continues, the IPCC's 2030 value will be reached by 2023, and the 2040 value (which is just about the maximum value) will be reached in 2026. (Note: is surface albedo changes are taken into account then the IPCC's 2030 value will be reached by 2019, and the 2040 value will be reached in 2022.)

	2011	RCP2.6 (2100)
CO2	1.816	2.220
CH4	0.425	0.270
N20	0.195	0.230
Halocarbons	0.395	0.142
Greenhouse Gases	**2.831**	**2.862**
Statospheric	-0.050	-0.075
Tropospheric	0.400	0.170
Ozone	**0.350**	**0.140**
Strato. H20	0.073	
Land Use	-0.150	
Black Carbon	0.040	
Albedo	**-0.110**	
Contrails	0.050	
Radiation Inter.	-0.450	
Cloud Inter	-0.450	
Aerosols	-0.900	
Total Anthropogenic	**2.294**	
Solar Radiance	0.030	
Total IPCC	**2.324**	**2.600**

Table 5. Radiative Forcing Changes since 1750

RCP 2.6		
Year	Radiative Forcing	Change Per Decade
2010	2.17	
2020	2.53	0.36
2030	2.70	0.17
2040	2.84	0.14
2050	2.85	0.01
2060	2.77	-0.08
2070	2.71	-0.06
2080	2.60	-0.11
2090	2.64	0.04

From Page 1436 "Total anthropogenic plus natural ERF (W m–2) from CMIP5 and CMIP3, including historical" (Adjusted by .2 W m-2 to bring in line with values for 2011 and 2020)

Data based on the IPCCs' "Climate Change 2013: The Physical Science Basis" (AR5)

Table 6. Radiative Forcing by Decade for RCP 2.6

Footnotes

1

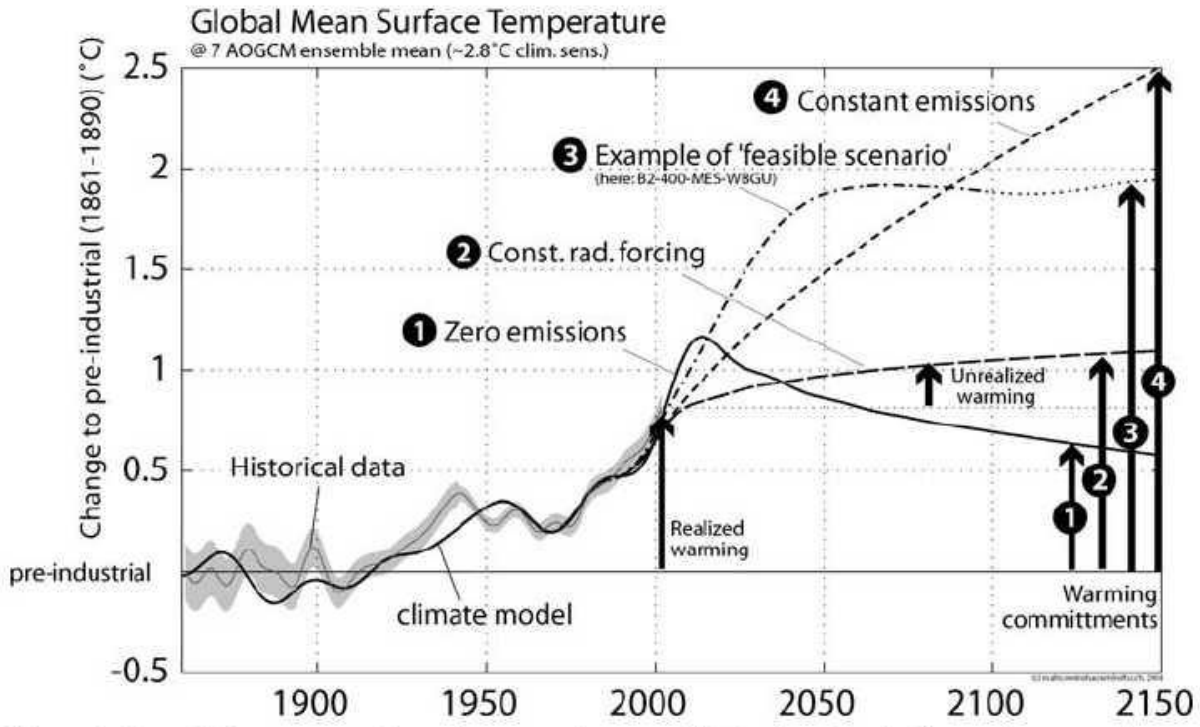


Figure 1. Four different types of warming commitments. (1) The 'geophysical' warming commitment in case that emissions are abruptly reduced to zero after 2005 ('Zero Emissions'); Note that emissions initially rise due to ceased cooling by aerosols. (2) The 'present forcing' warming commitment corresponds to constant radiative forcing at present (2005) levels and comprises the 'realized' and 'unrealized' warming; (3) the 'feasible scenario' warming commitment is the temperature rise that corresponds to the lowest emission scenario judged feasible. Note that the mitigation scenario B2-400-MES-WBGU is shown for illustrative purposes only (dash-dotted line: original scenario up to 2100; dotted part: the extended scenario as described in text). Lastly, (4) the 'constant emissions' warming commitment that corresponds to highest warming levels in the long term. The historical temperature record and its uncertainty (grey shaded area) is taken from Folland et al. (2001).

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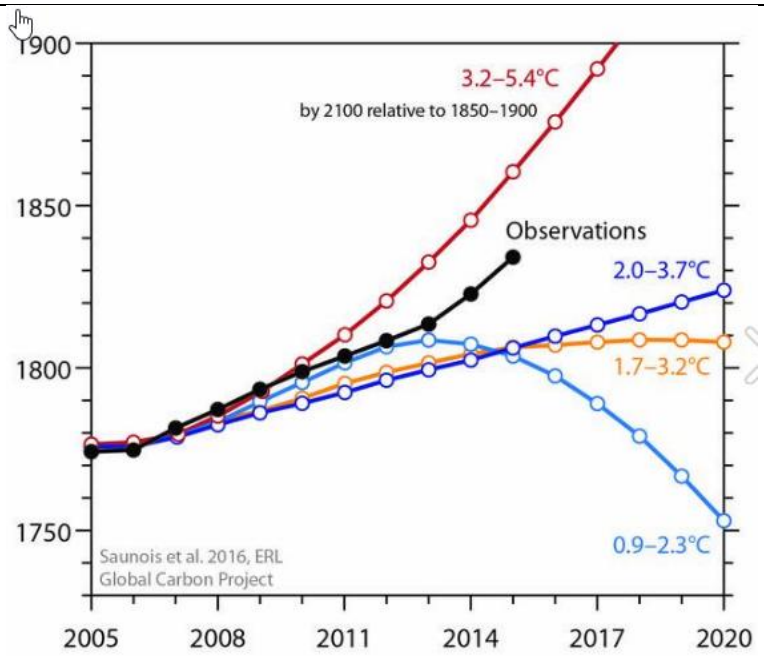
March 2006, Volume 75, Issue 1, pp 111–149
Hare, B. & *Meinshausen, M.*

How Much Warming are We Committed to and How Much can be Avoided

http://www.pik-potsdam.de/~mmalte/simcap/publications/Hare_Meinshausen_2004_WarmingCommitment_PIK-Report.pdf

2	 Methane emissions - observed and what the IPCC RCPs projected https://theconversation.com/methane-from-food-production-might-be-the-next-wildcard-in-climate-change-69894)
3	http://ccdatacenter.org/documents/EstimateofRadiativeForcingfromAlbedoChangeintheIPCCModels.pdf
4	http://www.climatecentral.org/news/greenhouse-gases-reservoirs-fuel-climate-change-20745 *Methane emissions from reservoirs contribute about .7GTC of CO2 equivalent per year, resulting in about 30 GTC through 2060 and 60 GTC through 2100.*
5	Aerosols from the burning of fossil fuels, accounting for about 1 W m-2, mask about .5°C of warming. Most climate models take this into account, but it is probably not included in the climate sensitivity metric. Since the aerosols "wash out" quickly, a rapid reduction of coal burning would likely result in rapid warming of .5°C. (http://www.pik-potsdam.de/~mmalte/simcap/publications/Hare_Meinshausen_2004_WarmingCommitment_PIK-Report.pdf)
6	"Drainage of peat soils results in carbon dioxide (CO2) and nitrous oxide (N2O) emissions of globally 2-3 Gt CO2-eq per year (Joosten & Couwenberg 2009)" http://www.wetlands.org/Portals/0/publications/Report/web_Methane_emissions_from_peat_soils.pdf
7	"The paper then extrapolated these findings for the globe, finding that by the year 2050, the planet could see 55 billion tons of carbon (which converts to 200 billion tons of carbon dioxide, were it all to be released in this form) released from soils. That's if we continue on with a "business as usual" scenario of global greenhouse gas emissions and accompanying warming." https://www.washingtonpost.com/news/energy-environment/wp/2016/11/30/the-ground-beneath-our-feet-is-poised-to-make-global-warming-much-worse-scientists-find/ *(The additional emissions specified in Footnote 6 might not be included in this estimate)*
8	"It [(permafrost melt)] was first proposed in 2005. And the first estimates came out in 2011. Indeed, the problem is so new that it has not yet made its way into major climate projections, Schaefer says." …"None of the climate projections in the last IPCC report account for permafrost," says Schaefer. "So all of them underestimate, or are biased low." … "It's certainly not much of a stretch of the imagination to think that over the coming decades, we could lose a couple of gigatons per year from thawing permafrost," says Holmes…. But by 2100, the "mean" estimate for total emissions from permafrost right now is 120 gigatons, say Schaefer." http://www.washingtonpost.com/news/energy-environment/wp/2015/04/01/the-arctic-climate-threat-that-nobodys-even-talking-about-yet http://ccdatacenter.org/documents/FeedbackFromPermafrost.pdf
9	http://ccdatacenter.org/documents/DoestheIPCCUnderestimatetheAmountofWarmingWeShouldExpect.pdf
10	http://ccdatacenter.org/documents/FeedbackFromArcticSeaIceMelt.pdf
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