How Important are Natural Causes in the Temperature Increases Expected this Century?

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http://ccdatacenter.org/documents/HowImportantareNaturalCausesintheTemperatureIncreasesExpected.pdf

Background

As the signs of global warming and climate change become more apparent (e.g., the successive record-breaking global temperature increases in 2014, 2015, and 2016; "sunny-day flooding" in southern Florida; etc.) we all want to be reassured that climate change can be "solved". And in order to develop appropriate solutions, we need a better understanding of our predicament. Unfortunately, most computer models assume that all (or almost all) of the drivers of global warming are anthropogenic and that other factors will play at most only a minor role in temperature increase this century, especially if the temperature increase can be limited to 2°C. In order to explore the likely temperature change from non-anthropogenic causes we need to know (1) the sensitivity of the climate models to changes in carbon dioxide emissions and the Earth's albedo; and (2) the likely magnitudes of the forcings from factors other than anthropogenic activities. In addition, instead of just looking at the expected temperature increase for 2100, it is also important to estimate the expected temperature increase by mid-century, assuming an aggressive emissions reduction effort, as this will give us an idea of the likely peak temperature increase.

The following table provides an estimate of a possible set of adjustments that might need to be made for temperature increase estimates of 2°C that are based mostly on anthropogenic activities:

	Adjustments for 2060			Adjustments for 2100		
	Change from 2015	Equivalent Emissions (GTC)	Temperature Increase (°C)	Change from 2015	Equivalent Emissions (GTC)	Temperature Increase (°C)
Arctic Sea Ice melt	0.10 W/m-2	25	0.05	0.14 W/m-2	45	0.07
NH Snow line retreat	0.09 W/m-2	23	0.04	0.12 W/m-2	38	0.06
Peat/soils	45 GTC	45	0.08	85 GTC	85	0.14
Reservoirs	30 GTC	30	0.05	60 GTC	60	0.10
Permafrost	30 GTC	30	0.05	120 GTC	120	0.19
Total		153	0.27	0	348	0.56

Notes:

- These estimates assume that there is no sequestration from afforestation, soil management, BECCS, or DAC
- Arctic Sea Ice melt accounts for about 5% of the radiative forcing included in a climate sensitivity of 3. The change in radiative forcing in the table above is for the additional amount expected by the year indicated
- NH Snow line retreat might account for about 4% of the radiative forcing included in a climate sensitivity of 3. The change in radiative forcing in the table above is for the additional amount expected by the year indicated

How sensitive are the climate models to CO2 emissions and albedo changes?

If a climate model provides estimates of just a few important climate change drivers (e.g., CO2 emissions, atmospheric C02, radiative forcing, and temperature increase) the sensitivity of the climate model to CO2 emissions and albedo change can easily be determined. For example, Figures 11-13 in James Hansen's recent discussion paper - "Young People's Burden: Requirement of Negative CO2 Emissions" (October 4, 2016) (http://www.earth-syst-dynam-discuss.net/esd-2016-42/) provide the following data points for the year 2100:

#	Cumulative Emissions (GTC) (Calculated)	Atmospheric C02 (PPM) (Figure 11)	Total Radiative Forcing (W/m-2) (Figure 12)	Temperature Increase (°C) (Figure 13)
1	203	386	1.6	1.00
2	340	416	2.0	1.20
3	838	548	3.5	1.95
4	1829	864	6.5	3.25

By using the above data, the sensitivity to changes in emissions and radiative forcing for net CO2 emissions can be calculated as follows:

	Units	Temperature Increase (°C)	
Sensitivity to:		2060	2100
Increase in Radiative Forcing	1.0 W/m-2	.45	.51
Net increase in CO2 emissions	100 GTC	.18	.16

Source: http://ccdatacenter.org/documents/TemperatureSensitivitytoChangesinRadiativeForcingsandCO2Emissions.pdf

What factors should be taken into account when projecting future temperature increases?

	Global Warming Factor	Description
CO2 Emissions		
1	CO2	Anthropogenic CO2 emissions from the burning of fossil fuels, production of cement, etc.
2	Peat/soils	"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 http://ccdatacenter.org/documents/GlobalWarmingFeedbacks.pdf)
3	Reservoirs	" Globally, reservoirs are responsible for about 1.3 percent of the world's man-made greenhouse gas emissions each year" (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.*
4	Permafrost	"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)
5	Other	
Sequestration		
6	Afforestation	" Smith et al. (2016) estimate that reforestation and afforestation together have carbon storage potential of about 1.1 GtC/year. However, as forests mature, their uptake of atmospheric carbon

		decreases (termed "sink saturation"), thereby limiting CO2 drawdown. Taking 50 years as the average time for tropical, temperate and boreal trees to experience sink saturation yields 55 GtC as the potential storage in forests this century." ("Young People's Burden: Requirement of Negative CO2 Emissions" (October 4, 2016) http://www.earth-syst-dynam-discuss.net/esd-2016-42/, Page 19)
7	Soil	"Smith (2016) shows that soil carbon sequestration and soil amendment with biochar compare favorably with other negative emission technologies ... We conclude that 100 GtC is an appropriate estimate for potential carbon extraction via an ambitious concerted global-scale effort to improve agricultural and forestry practices with carbon drawdown as a prime objective" *(leaving 45 GTC for soil sequestration)* ("Young People's Burden: Requirement of Negative CO2 Emissions" (October 4, 2016) http://www.earth-syst-dynam-discuss.net/esd-2016-42/, Pages 19-20)
8	BECCS/DAC/CCS	"The popular concept of bioenergy with carbon capture and storage (BECCS) requires large areas, high fertilizer and water use, and may compete with other vital land use such as agriculture 675 (Smith, 2016). Costs estimates are ~$150-350/tC for crop-based BECCS (Smith et al 2016). Direct air capture has less area and water needs than BECCS and no fertilizer requirement, but it has high energy use, has not been demonstrated at scale, and cost estimates exceed those of BECCS (Socolow et al 2011; Smith et al 2016). Keith et al (2006) have argued that, with strong research and development support and industrial-scale pilot projects sustained over decades, it 680 may be possible to achieve costs ~$200/tC, thus comparable to BECCS costs; however other assessments are higher, reaching $1400-3700/tC (NRC 2015). Carbon capture and storage (CCS) from a stream of nearly 100 percent CO2 at fossil fuel burning sites is more efficient and thus less expensive than direct air capture, but CCS at power plants is properly included in our scenarios as one of the mechanisms competing to achieve phase-down of fossil fuel emissions, along with energy efficiency, renewable energies, and nuclear power." ("Young People's Burden: Requirement of Negative CO2 Emissions" (October 4, 2016) http://www.earth-syst-dynam-discuss.net/esd-2016-42/, Page 20)
9	Other	
Radiative Forcing		
10	Greenhouse gases	This would include the radiative forcings of CO2, CH2, NO2, and all other greenhouse gases
11	Aerosols	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. 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)
12	Surface Albedo Change	That portion of the albedo change due to land use changes (does not include changes in the Arctic region)
13	Arctic Sea Ice melt	Melting of Arctic sea ice accounts for about 5% of the 3°C climate sensitivity. Since a radiative forcing of about 2.7 W/m-2 results in a temperature increase of about 2°C, the Arctic sea ice contribution would be about 0.135 W/m-2. This is equivalent to a September sea ice extent of about 3.7 million km-2, whereas climate scientists are projecting that the Arctic ocean will become ice free in September by 2060. A reasonable estimate is that the radiative forcing due to Arctic sea ice melt is twice that of what is currently expected, or an additional 0.1 W/m-2 in 2060 and 0.14 W/m-2 in 2100 for a 2°C temperature increase. (The expected radiative forcing for the albedo change due to sea ice melt is .26 W/m-2 in 2060 and .39 W/m-2 in 2100, but the temperature increase will likely be greater than 2°C by then.) (http://ccdatacenter.org/documents/ClimateSensitivityandArcticSeaIceMelt.pdf)
14	Northern Hemisphere Snow line	As the Arctic region warms the spring-time snow is melting sooner (it is currently declining by about 2.7% per decade, faster than the models predict). The resulting albedo change is similar to, but smaller than, that of the melting of the Arctic sea ice. Since the melting of Arctic sea ice

	retreat	accounts for about 5% of the 3°C climate sensitivity, perhaps the expected decline in snow cover contributes about 4% of the 3°C climate sensitivity. (http://ccdatacenter.org/documents/FeedbackFromNHSnowCover.pdf)
15	Tundra Greening	As the Arctic region warms the tundra vegetation will become darker, absorbing more sunlight
16	Other	

Climate Models

Sophisticated climate models have to deal with many uncertainties (e.g., how much will the Earth's population grow? how much will GDP grow? what will the energy mix be in 50 years? how quickly does the Earth's temperature change as greenhouse gases area added to the atmosphere? what albedo changes in the Arctic region were expected? etc.). In order to determine, without re-running the model, how the expected temperature increase for a model would change if values for some of the global warming factors changed, it would be really helpful if the analysis of the results of a simulations for specific climate scenario included the following:

Model: ___________
Ending Year: _______ (e.g.,2100)
Temperature Increase ___°C

	Global Warming Factor	Scenario Value	Description
Emissions			
1	CO2		
2	Peat/soils		
3	Reservoirs		
4	Permafrost		
5	Other		
Sequestration			
6	Afforestation		
7	Soil		
8	BECCS/ DAC/CCS		
9	Other		
Radiative Forcing			
10	Greenhouse gases		
11	Aerosols		
12	Surface Albedo Change		
13	Arctic Sea Ice melt		
14	NH Snow line retreat		
15	Tundra Greening		
16	Other		

What are the likely magnitudes of the climate forcings in 2100?

	Global Warming Factor	2100 Change	Temp Change	Notes
Emissions		GTC		
1	CO2			Depends on emissions
2	Peat/soils	85	0.14	if not included
3	Reservoirs	60	0.10	if not included
4A	Permafrost	120	0.19	
4B	Permafrost		0.28	- 0.4-0.6°F in2100 (NAS)
5	Other			
Sequestration		GTC		
6	Afforestation	-55	-0.09	Hansen - max realistic
7	Soil	-45	-0.07	Hansen - max realistic
8	BECCS/CCS			
9	Other			
Radiative Forcing		W/m-2		
10	Greenhouse gases			
11	Aerosols	-1.00	0.51	Change from -1.25 (already included in most models)
12	Surface Albedo Change			
13	Arctic Sea Ice melt	0.14	0.13	0.14 already included in climate sensitivity of 3
14	NH Snow line retreat	0.12	0.11	Slightly less than that of Arctic sea ice melt
15	Tundra Greening			
16	Other			

What are the likely magnitudes of the climate forcings in 2060?

The 45-year time was selected because, once emissions are significantly reduced, the atmospheric CO2 will drop as the oceans continue to absorb CO2. 2060 was picked as year by which CO2 emissions approach zero and before significant CO2 is removed from the atmosphere, thus providing an estimate of the minimum "peak temperature" that can be expected. Since it is was not possible to determine if either of the two examples shown below included feedbacks from "natural emissions", these were added to the model's temperature increase to get the expected temperature increase for 2060.

	Global Warming Factor	2060 Value	Temp Change	Notes
Emissions		GTC		
1	CO2			
2	Peat/soils	45	0.08	if not included
3	Reservoirs	30	0.05	if not included
4A	Permafrost	30	0.05	
4B	Permafrost		0.07	- 0.4-0.6°F in2100 (NAS)
5	Other			
Sequestration		GTC		
6	Afforestation	-13.75	-0.02	Hansen - max realistic (1/4 of 2100 value)
7	Soil	-11.25	-0.02	Hansen - max realistic (1/4 of 2100 value)
8	BECCS/ DAC/CCS			
9	Other			
Radiative Forcing		W/m-2		
10	Greenhouse gases			
11	Aerosols	-.25	0.46	Change from -1.25
12	Surface Albedo Change			

13	Arctic Sea Ice melt	0.16	0.07	0.10 already included in climate sensitivity of 3
14	NH Snow line retreat	0.14	0.06	Slightly less than that of Arctic sea ice melt
15	Tundra Greening			
16	Other			

According to Climate Central (https://docs.google.com/spreadsheets/d/1odltJu_rxabdVXv_pACMBNIRiFSkc_HqJn-V8z0av2w/edit#gid=731498129), the remaining carbon budget for a 66% chance of limiting warming to 2°C is about 220 GTC. Most analysis of the budget assumes that all future emissions are anthropogenic. However, the emissions-equivalent from all of the natural feedbacks is about 280 GTC by 2060. And since aggressive afforestation/soil build-up program will only sequester about 25 GTC by then, we have, for all practical purposes, already exceeded the budget.

Estimate for 2060 based on Hansen's models

Model: 2 - no net increase in CO2 emissions, then a 3% decline starting in 2020
Ending Year: 2060
Temperature Increase 1.35°C
Total Temperature Change with new values: 2.44°C

	Global Warming Factor	Scenario Value	Variation Value	Difference	Temperature Change
Emissions					
1	CO2	340	480+	140	0.22
2	Peat/soils	0	45	45	0.08
3	Reservoirs	0	30	30	0.05
4	Permafrost	0	30	30	0.05
5	Other				
Sequestration					
6	Afforestation				
7	Soil				
8	BECCS/ DAC/CCS				
9	Other				
Radiative Forcing					
10	Greenhouse gases				
11	Aerosols	-1.25	-.25		0.45
12	Surface Albedo Change	-.25	-.25		
13	Arctic Sea Ice melt	0	-0.16	-0.16	0.07
14	NH Snow line retreat	0	-0.14	-0.14	0.06
15	Other				

+ Emissions increase 1%/year to 2030 then decline 2%/year
Scenario Values of 0 are assumptions, as specific values were not provided

	Temperature Increase (°C)	Equivalent Emissions (GTC)	
	1.35		Temperature increase through 2060 for CO2 emissions of 340 GTC
11	0.45		Reduction of Aerosols when burning of fossil fuels eliminated
1	0.22		From additional CO2 emissions of 140 GTC
	2.02		Increase without considering natural feedbacks
13	0.07	40	Arctic Sea Ice melt
14	0.06	35	NH Snow line retreat

2	0.08	45	Peat/soils
3	0.05	30	Reservoirs
	2.28	150	Increase without considering permafrost or sequestration
4	0.05	30	Permafrost
	2.33	180	Increase without considering sequestration

Temperature Increase for 2060 based on B. Hare and M. Meinshausen

The B. Hare and M. Meinshausen study (Figure 1) was included because it shows (1) the expected temperature increase if CO2 emissions are eliminated, (2) the expected temperature decrease that results as the oceans continue to absorb CO2 from the atmosphere, and (3) an expected temperature increase of 1.1°C 50 years after the start of a 'feasible scenario' (about 500 GTC of CO2 emissions without any mitigation). It is not clear if the 'feasible scenario' includes any global warming feedbacks, so none were assumed.

Model: 2 B2-400-MES-WGBU (500 GTC of emissions)
Ending Year: 2060
Temperature Increase 2.2°C (= 1.1°C (2015) + 1.1°C (increase after 50 years))
Total Temperature Change with new values: 2.5°C (an additional .3°C from feedbacks)

	Global Warming Factor	Scenario Value	Variation Value	Difference	Temperature Change
Emissions					
1	CO2	500	500	0	
2	Peat/soils	0	45	45	0.08
3	Reservoirs	0	30	30	0.05
4	Permafrost	0	30	30	0.05
5	Other				
Sequestration					
6	Afforestation				
7	Soil				
8	BECCS/ DAC/CCS				
9	Other				
Radiative Forcing					
10	Greenhouse gases				
11	Aerosols				
12	Surface Albedo Change				
13	Arctic Sea Ice melt	0	-0.16	-0.16	0.07
14	NH Snow line retreat	0	-0.14	-0.14	0.06
15	Other				

+ Emissions increase 1%/year to 2030 then decline 2%/year
Scenario Values of 0 are assumptions, as specific values were not provided

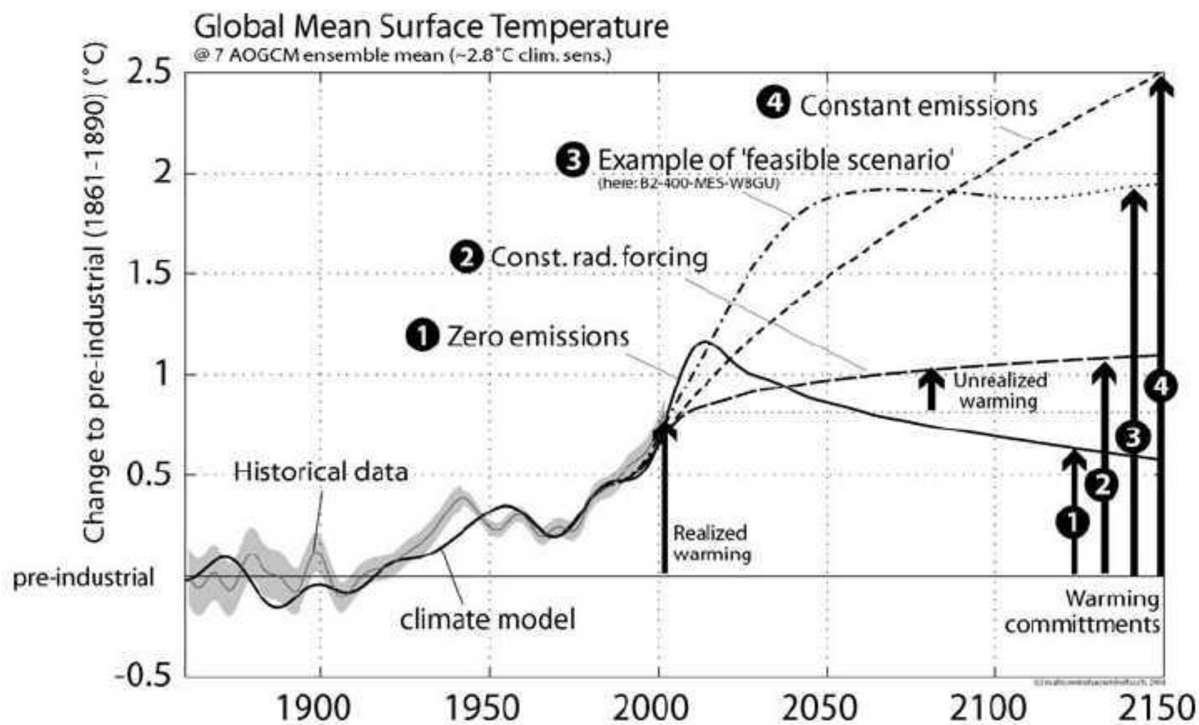

Figure 1. Four different types of warming commitments. (1) The 'geophysical' warming commitment in case that emissions are abruptly reduced to zero after 2005 ('Zero Emissions'); Note that emissions initially rise due to ceased cooling by aerosols. (2) The 'present forcing' warming commitment corresponds 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).

Climatic Change
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

Figure 1

Estimate for 2060 based on current rate of temperature increase plus aerosol masking

The global temperature has been increasing steadily at about .18°C per decade. With the current temperature increase of about 1.1°C, if this trend continues for 50 years, the expected temperature increase would be about 2.°C. If fossil fuel emissions are significantly reduced, the increase from the aerosol reduction would add another 0.5°C (see "11. Aerosols" on Page 3 above), resulting in a temperature increase of about 2.5°C if no sequestration efforts are taken.

Appendix A - Climate Forcings

See http://ccdatacenter.org/documents/GlobalWarmingFeedbacks.pdf for more information on natural feedbacks

11. Aerosols

The models that Hansen used do not appear to have taken into account the likely reduction of aerosols that will happen as the burning of fossil fuels is reduced. When this reduction is taken into account the expected temperature increase from his scenario 2 much more closely resembles that of RCP 2.6. The RCP models appear to take this into account, so no aerosol adjustment will be needed.

While greenhouse warming [from CO2] would abate, the cessation of coal burning (if we were truly to go cold-turkey on all fossil fuel burning) would mean a disappearance of the reflective sulphate pollutants ("aerosols") produced from the dirty burning of coal. These pollutants have a regional cooling effect that has offset a substantial fraction of greenhouse warming, particularly in the Northern Hemisphere. That cooling would soon disappear, adding about 0.5°C to the net warming.

http://www.huffingtonpost.com/michael-e-mann/how-close-are-we-to-dangerous-planetary-warming_b_8841534.html

Note: The above was reported on several blogs but I was not able to track down the original source. However, the IPCC reported that the total radiative forcings due to aerosols and precursors was about -0.82 W/m^2 (see Figure 2 below), so if two thirds of that is due coal, then the aerosols from coal reduce the radiative forcing by about 0.55 W/m^2; so the aerosols from coal could easily be masking 0.5CC.

See http://ccdatacenter.org/documents/BurningCoalCoolsPlanet.pdf *for additional details*