Temperature Sensitivity to Changes in Radiative Forcings and CO2 Emissions

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

Summary

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?). And most climate models deal mostly with anthropogenic greenhouse gas emissions. Since natural emissions (e.g., from the drying out peat bogs, etc.) and natural albedo changes (e.g., from the melting of the Arctic Ocean ice in the summer, etc.) could be significant contributors to the future temperature increase, it would be very helpful to know how sensitive the future temperature change is to changes in radiative forcings and CO2 emissions (i.e., how much the temperature will change for a 1 W/m-2 change in radiative forcing or for an additional 100 GTC of carbon dioxide emissions). By examining the output from climate models the temperature sensitivities can be easily determined. Although the temperature sensitivities will likely vary among the climate models, one would expect that the numbers would be close enough that reasonable estimates the future warming from natural causes could be obtained.

By examining 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/), the following temperature and cost sensitivities can be derived (see "Calculations" below for the methodology used for the calculations):

	Units	Temperature Increase Sensitivity (°C)		Negative Emissions to reach 350 PPM in 2100 *(Assumes 100 GTC of forest and soil carbon sequestration)*		
Sensitivity to:		2060	2100	GTC	Min Cost ($B)	Max Cost ($B)
Increase in Radiative Forcing	1.0 W/m-2	.45	.51			
Net increase in CO2 emissions	100 GTC	.18	.16	90	13,500	31,500

By using the above sensitivity factors and a knowledge of what values for CO2 emissions and radiative forcings a model calculated for either 2060 or 2100, a reasonable estimate the additional warming from any source of CO2 emissions or albedo change can be made. For example, it has been estimated that when the summer-time Arctic Ocean is ice free for a month, the albedo will be reduced by 0.3 W/m-2, resulting is a temperature increase of about .14°C. And this could happen any time in the latter half of this century. This does not sound like much, but it is simply one of many factors that will likely increase the temperature this century. And it is the equivalent of about 80 GTC of CO2 emissions, which is about 1/3 of the "post 2015" IPCC CO2 emissions budget where 66% of model runs had a temperature increase of less than 2.0°C.

Calculations

To determine the sensitivities, values were first obtained from the appropriate graphs in James Hansen's recent discussion paper. Quadratic equations were then derived and graphed. In all cases the "sensitivity" graph is essentially linear within the range of interest (i.e., when we try to limit the temperature increase to 2°C) .

<u>Increase in Radiative Forcing</u>

The following figures were used to estimate the temperature sensitivity to radiative forcing:

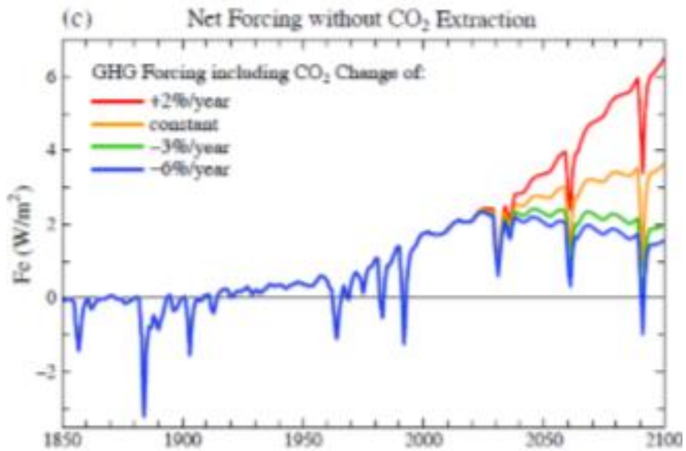


Figure 12C - Radiative forcings for all greenhouse gases, tropospheric aerosols and surface albedo (Page 17)

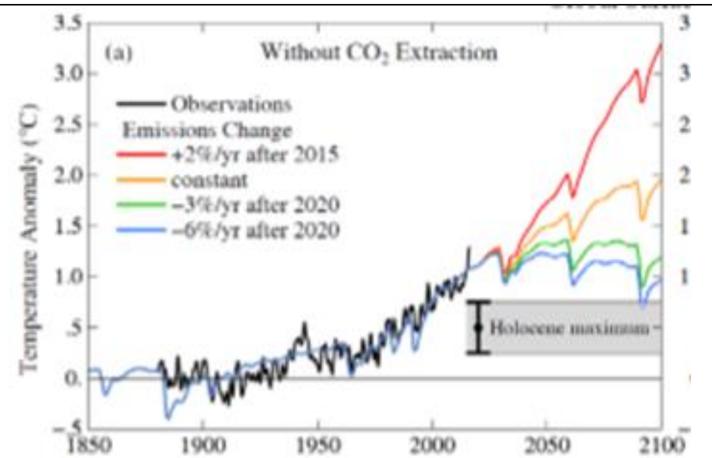


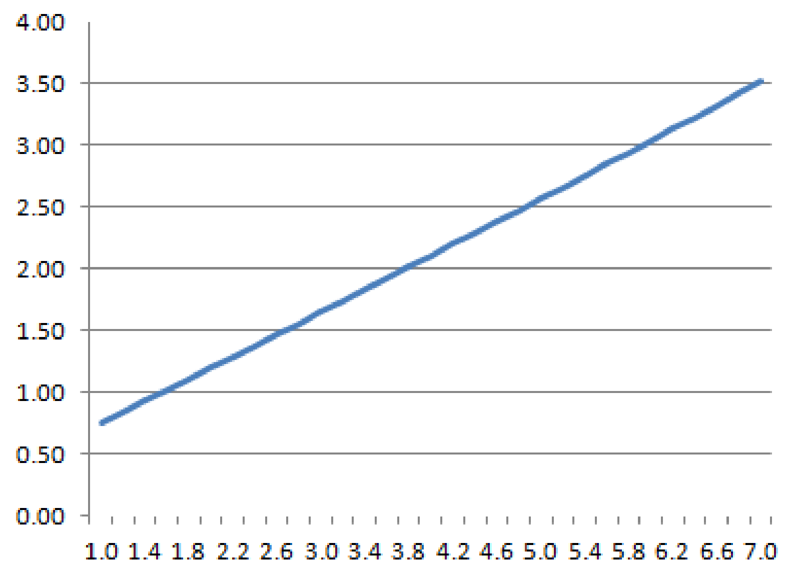
Figure 13 - Global Surface Temperature Anomaly (Page 18)

Calculations for 2060

Radiative Forcing from Figure 12	Temperature From Figure 13
2.00	1.20
2.35	1.35
3.00	1.65
4.10	2.15

Quadratic equation coefficients

A	B	C
0.003428	0.432793	0.318348



Temperature increase for change in radiative forcing (2060)

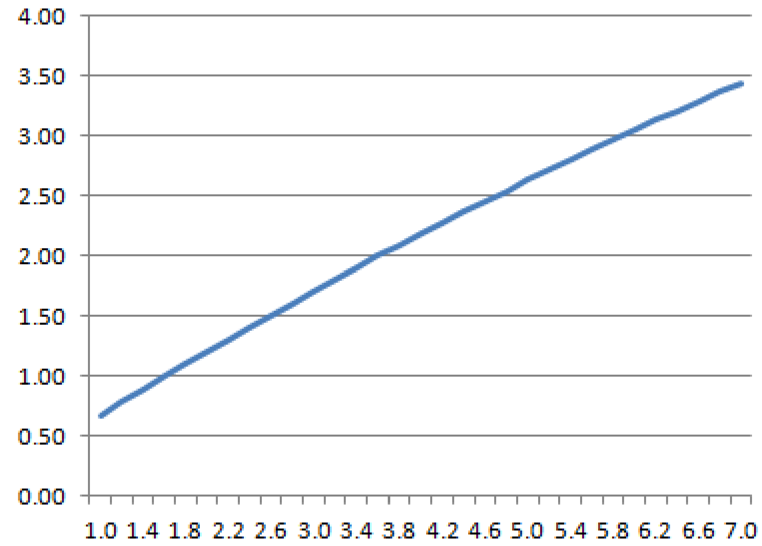
The graph is essentially linear, with a temperature change of .45°C per Watt/m-2

Calculations for 2100

Radiative Forcing from Figure 12	Temperature From Figure 13
1.6	1.00
2.0	1.20
3.5	1.95
6.5	3.25

Quadratic equation coefficients

A	B	C
-0.0137	0.570972	0.117889



Temperature increase for change in radiative forcing (2100)

The graph is essentially linear between 1.5 W/m-2 and 3 W/m-2 (the range of interest when we try to limit the temperature increase to 2°C) , with a temperature change of .51°C per Watt/m-2

Net increase in GHG emissions

The emissions for the four scenarios that Hansen used were based on CO2 emissions increasing at a specific rate until a specific year and then either decreasing or staying constant. The following table specifies that cumulative emissions for the four scenarios:

	Yearly Increase (Percent)	Peak Year	Reduction Rate/year (Percent)	Emissions 2016-2060	Emissions 2016-2100
1	0	2020	-6	191	203
2	0	2020	-3	274	340
3	0	2020	0	444	838
4	2	2068	0	723	1835

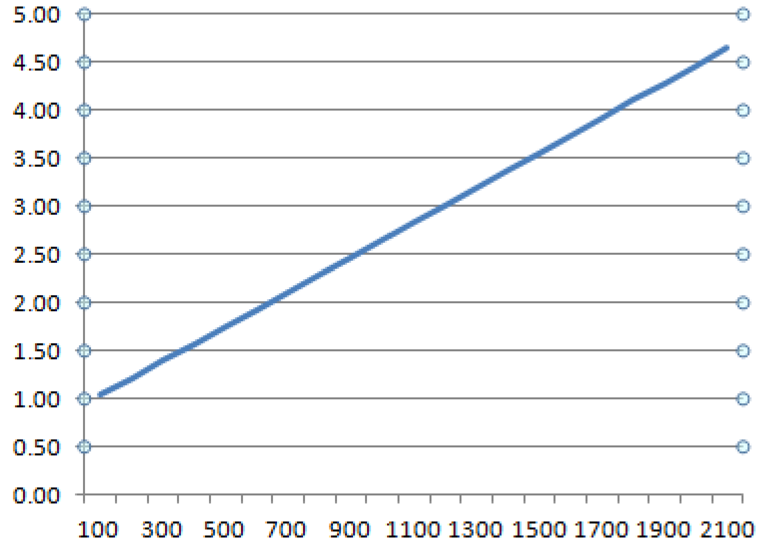
Table 1 - Cumulative CO2 Emissions for four Hansen scenarios

Calculations for 2060

Emissions From Table 1	Temperature From Figure 13
191	1.20
274	1.35
444	1.65
723	2.15

Quadratic equation coefficients

A	B	C
1.87E-08	0.001767	0.862872



Temperature increase for change in CO2 emissions (2060)

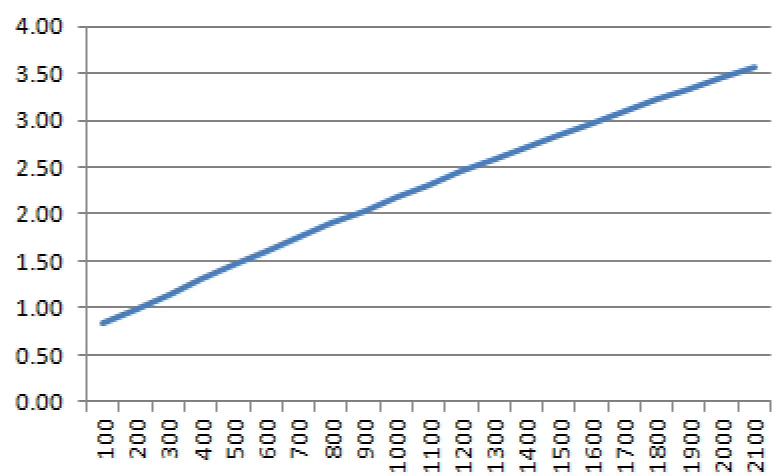
The graph is essentially linear, with a temperature change of .18°C per 100 GTC of CO_2 emissions

Calculations for 2100

Emissions From Table 1	Temperature From Figure 13
203	1.00
340	1.20
838	1.95
1829	3.25

Quadratic equation coefficients

A	B	C
-1.1E-07	0.00162	0.670214



Temperature increase for change in CO2 emissions (2100)

The graph is essentially linear between 100GTC and 300 GTC (the range of interest when we try to limit the temperature increase to 2°C) , with a temperature change of .16°C per 100 GTC of CO_2 emissions

Calculations for Negative Emissions

(Assumes 100 GTC of forest and soil carbon sequestration)

PPM to Extract based on Figure 13	72	112	328	768
GTC To Extract (PPM * 2.12)	153	237	695	1628
Forest sequestration	55	55	55	55
Soil sequestration	45	45	45	45
Required Negative Emissions	53	137	595	1528

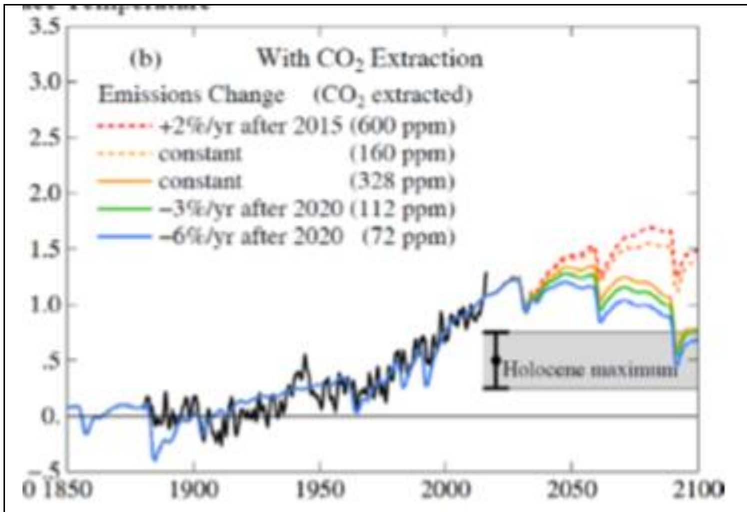


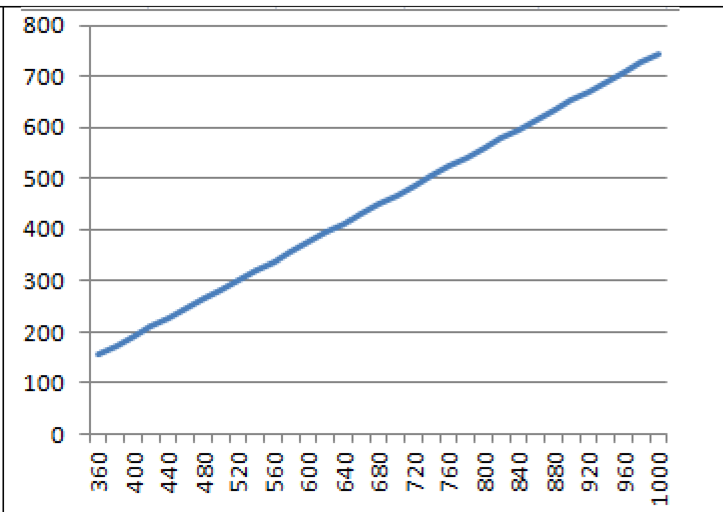
Figure 13

"The scenarios that reduce CO2 to 350 ppm succeed in getting temperature back close to the Holocene maximum by 2100 (Fig. 13b), but they require extractions of atmospheric CO2 that range from 72 ppm in the scenario with 6%/year emission reductions to 768 ppm in the scenario with +2%/year emission growth." (Page 18)

Calculations for 2100

Emissions From Table 1	Required negative emission based on Table 13
203	53
340	137
838	595
1829	1528

A	B	C
1.4637E-05	0.902436	-171.52



Negative emissions to reach 350 PPM vs CO2 emissions

The graph is essentially linear, with Required negative emissions of 90 GTC per 100 GTC of CO2 emissions