Expected Temperature Increase Due to Changes in Either the Earth's Albedo or CO2 Emissions

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(http://ccdatacenter.org/documents/AlbedoCO2TempCalcs.pdf)

"Albedo is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space. It is a measure of the reflectivity of the earth's surface. Ice, especially with snow on top of it, has a high albedo: most sunlight hitting the surface bounces back towards space. Water is much more absorbent and less reflective. So, if there is a lot of water, more solar radiation is absorbed by the ocean than when ice dominates. Albedo is not important at high latitudes in winter: there is hardly any incoming sunlight to worry about. It becomes important in spring and summer when the radiation entering through leads can greatly increase the melt rate of the sea ice." [1]

"Earth's overall average albedo is about 0.31. Oceans and forests are quite dark, while deserts are lighter, and clouds, snow, and ice are very bright. Without clouds our planet's albedo would be around 0.15, so clouds roughly double Earth's albedo."[2]

The items in Table 1 show the assumptions, values, and functions use to calculate the expected temperature increase for various changes in the Earth's albedo:

3.4	W/m-2 / .01 albedo change	https://www.skepticalscience.com/print.php?r=111
70	Percent cloud cover in the Arctic	(see footnote 3 below – note that the effective radiative forcing is about 100 times the albedo change when only 30% of the radiation reaches the ground - 3.4 * .30/.01)
278	Historical CO2 concentration(PPM) for calculating the equivalent CO2e PPM	Historical CO2 concentrations are roughly in the range 270-280. This number was selected so that the calculations would match the values in a chart published in Nature Climate Change (see Footnote 5)
403	Atmospheric CO2 concentration(PPM) for calculating the equivalent CO2e PPM	The equivalent CO2e PPM depends on the atmospheric concentration, so the current concentration was adjusted slightly so that the calculations would match the values in a chart published in Nature Climate Change (see Footnote 5)
	$\Delta F = 5.35 \times \ln \frac{C}{C_0}\ \mathrm{W\ m^{-2}}$	Formula for the change in radiative forcing due to change in CO2 concentration[4]. Since we are looking at a change in concentration around 403 PPM, C = 403 + "Equiv CO2e PPM" and C_0 = 278; and since we are also looking for a change in radiative forcing when the atmospheric CO2 is at 403 PPM and since the radiative forcing of 403 PPM is about 1.99 (=5.35 ln(403/278)), we set the value of F = 1.99 + RF, where RF is the change in radiative forcing.
	"Equiv CO2e PPM" =278 * POWER(2.718,(RF+1.99)/5.35) - 403	Solving for "Equiv CO2e PPM" as a function of RF gives this equation in Excel. Note that this equation gives values that are very close those in a chart in a recent Nature Climate Change article[5]
45%	Airborne fraction – the percent of CO2 emissions that remain in the atmosphere	http://www.esrl.noaa.gov/gmd/co2conference/posters_pdf/jones1_poster.pdf
7.80432	Gigatons of CO2 per PPM of atmosphere	http://cdiac.ornl.gov/pns/convert.html (2.13 * 3.664 CO2/C)
17.3429	Gigatons of CO2 emissions per PPM of atmospheric CO2 (airborne fraction = 45%)	=7.80432/.45
3.0	Climate Sensitivity for just CO2	

Table 1 – Calculation Factors/Parameters

Based on the above, the following values can be derived based on specific values for albedo changes[6]:

Yearly Albedo Decrease	Effective Radiative Forcing (W/m-2)	Equiv. CO2e PPM	Equiv. CO2 Em. (GTCO2)	Temp Increase (°C)
0.00020	0.020	1.52	26	0.01
0.00040	0.041	3.07	53	0.02
0.00060	0.061	4.62	80	0.03
0.00080	0.082	6.18	107	0.05
0.00100	0.102	7.74	134	0.06
0.00120	0.122	9.31	161	0.07
0.00140	0.143	10.88	189	0.08
0.00160	0.163	12.47	216	0.09
0.00180	0.184	14.05	244	0.11
0.00200	0.204	15.65	271	0.12
0.00220	0.224	17.24	299	0.13
0.00240	0.245	18.85	327	0.14
0.00260	0.265	20.46	355	0.15
0.00280	0.286	22.08	383	0.17
0.00300	0.306	23.70	411	0.18
0.00320	0.326	25.33	439	0.19
0.00340	0.347	26.97	468	0.20
0.00360	0.367	28.61	496	0.21
0.00380	0.388	30.26	525	0.23
0.00400	0.408	31.92	554	0.24
0.00420	0.428	33.58	582	0.25
0.00440	0.449	35.24	611	0.26
0.00460	0.469	36.92	640	0.28
0.00480	0.490	38.60	669	0.29
0.00500	0.510	40.29	699	0.30

Yearly Albedo Decrease	Effective Radiative Forcing (W/m-2)	Equiv. CO2e PPM	Equiv. CO2 Em. (GTCO2)	Temp Increase (°C)
0.00520	0.530	41.98	728	0.31
0.00540	0.551	43.68	758	0.33
0.00560	0.571	45.39	787	0.34
0.00580	0.592	47.10	817	0.35
0.00600	0.612	48.82	847	0.37
0.00620	0.632	50.54	877	0.38
0.00640	0.653	52.28	907	0.39
0.00660	0.673	54.02	937	0.41
0.00680	0.694	55.76	967	0.42
0.00700	0.714	57.51	997	0.43
0.00720	0.734	59.27	1028	0.44
0.00740	0.755	61.04	1059	0.46
0.00760	0.775	62.81	1089	0.47
0.00780	0.796	64.59	1120	0.48
0.00800	0.816	66.38	1151	0.50
0.00820	0.836	68.17	1182	0.51
0.00840	0.857	69.97	1213	0.52
0.00860	0.877	71.78	1245	0.54
0.00880	0.898	73.59	1276	0.55
0.00900	0.918	75.41	1308	0.57
0.00920	0.938	77.24	1340	0.58
0.00940	0.959	79.07	1371	0.59
0.00960	0.979	80.91	1403	0.61
0.00980	1.000	82.76	1435	0.62
0.01000	1.020	84.62	1468	0.63

Note:

The conversion of radiative forcing (W/m^2) to the “equivalent CO2e PPM” involves an exponential function which uses the radiative forcing (e raised to the power of the radiative forcing, where e is about 2.178), so it takes more atmospheric CO2 to increase the radiative forcing a specific amount as the atmospheric CO2 increases. For example, the table in Footnote 5 shows the radiative forcing and equivalent atmospheric CO2 PPM from a chart in Nature Climate Change. Hence adding radiative forcing and the equivalent atmospheric concentration of CO2 for multiple components which affect the Earth’s atmospheric temperature is problematic.

Based on the above, the following values can be derived based on specific values for annual emissions[6]:

Effective Radiative Forcing (W/m-2)	Annual Emissions (GTCO2)	Total Emissions 2015-2100	CO2 PPM (2015-2100) (GTCO2)	Temp Increase (2015-2100) (°C)
0.065	1	85	4.90	0.04
0.129	2	170	9.80	0.07
0.192	3	255	14.70	0.11
0.254	4	340	19.60	0.15
0.316	5	425	24.51	0.18
0.377	6	510	29.41	0.22
0.437	7	595	34.31	0.26
0.497	8	680	39.21	0.29
0.556	9	765	44.11	0.33
0.614	10	850	49.01	0.36
0.672	11	935	53.91	0.40
0.729	12	1020	58.81	0.44
0.785	13	1105	63.71	0.47
0.841	14	1190	68.62	0.51
0.896	15	1275	73.52	0.55
0.951	16	1360	78.42	0.58
1.005	17	1445	83.32	0.62
1.059	18	1530	88.22	0.66
1.112	19	1615	93.12	0.69
1.165	20	1700	98.02	0.73
1.217	21	1785	102.92	0.77
1.268	22	1870	107.82	0.80
1.320	23	1955	112.73	0.84
1.370	24	2040	117.63	0.88
1.420	25	2125	122.53	0.91
1.470	26	2210	127.43	0.95
1.524	27	2304	132.82	0.99
1.573	28	2389	137.72	1.02
1.621	29	2474	142.62	1.06
1.669	30	2559	147.52	1.09
1.716	31	2644	152.43	1.13
1.763	32	2729	157.33	1.17
1.810	33	2814	162.23	1.20
1.856	34	2899	167.13	1.24
1.902	35	2984	172.03	1.28
1.947	36	3069	176.93	1.31
1.992	37	3154	181.83	1.35

Effective Radiative Forcing (W/m-2)	Annual Emissions (GTCO2)	Total Emissions 2015-2100	CO2 PPM (2015-2100) (GTCO2)	Temp Increase (2015-2100) (°C)
2.037	38	3239	186.73	1.39
2.081	39	3324	191.63	1.42
2.125	40	3409	196.54	1.46
2.169	41	3494	201.44	1.50
2.212	42	3579	206.34	1.53
2.255	43	3664	211.24	1.57
2.297	44	3749	216.14	1.61
2.339	45	3834	221.04	1.64
2.381	46	3919	225.94	1.68
2.423	47	4004	230.84	1.71
2.464	48	4089	235.74	1.75
2.505	49	4174	240.65	1.79
2.546	50	4259	245.55	1.82
2.586	51	4344	250.45	1.86
2.626	52	4429	255.35	1.90
2.665	53	4514	260.25	1.93
2.705	54	4599	265.15	1.97
2.744	55	4684	270.05	2.01
2.783	56	4769	274.95	2.04
2.821	57	4854	279.85	2.08
2.860	58	4939	284.76	2.12
2.898	59	5024	289.66	2.15
2.935	60	5109	294.56	2.19
2.973	61	5194	299.46	2.23
3.010	62	5279	304.36	2.26
3.047	63	5364	309.26	2.30
3.084	64	5449	314.16	2.34
3.120	65	5534	319.06	2.37
3.156	66	5619	323.96	2.41
3.192	67	5704	328.87	2.44
3.228	68	5789	333.77	2.48
3.263	69	5874	338.67	2.52
3.299	70	5959	343.57	2.55
3.334	71	6044	348.47	2.59
3.368	72	6129	353.37	2.63
3.403	73	6214	358.27	2.66
3.437	74	6299	363.17	2.70

(Additional values can be found at http://ccdatacenter.org/documents/AlbedoCO2TempCalcs.xlxs)

Based on the above the following values can be derived for changes in radiative forcing:

Change Since Preindustrial		
Effective Radiative Forcing (W/m-2)	Equiv. CO2e PPM	Temp Increase (°C)
2.0	404	1.4
2.1	412	1.4
2.2	419	1.5
2.3	427	1.6
2.4	435	1.7
2.5	444	1.8
2.6	452	1.9
2.7	460	2.0
2.8	469	2.1
2.9	478	2.2

Change Since Preindustrial		
Effective Radiative Forcing (W/m-2)	Equiv. CO2e PPM	Temp Increase (°C)
3.0	487	2.3
3.1	496	2.4
3.2	506	2.5
3.3	515	2.6
3.4	525	2.7
3.5	535	2.8
3.6	545	2.9
3.7	555	3.0
3.8	566	3.1
3.9	576	3.2

Change Since Preindustrial		
Effective Radiative Forcing (W/m-2)	Equiv. CO2e PPM	Temp Increase (°C)
4.0	587	3.3
4.1	598	3.5
4.2	609	3.6
4.3	621	3.7
4.4	633	3.8
4.5	645	4.0
4.6	657	4.1
4.7	669	4.2
4.8	682	4.4
4.9	695	4.5

Footnotes

<table>
<tr><td>1</td><td colspan="2">http://www.esr.org/outreach/glossary/albedo.html</td></tr>
<tr><td>2</td><td colspan="2">http://www.windows2universe.org/earth/climate/sun_radiation_at_earth.html</td></tr>
<tr><td>3</td><td>http://www.atmos.washington.edu/~rmeast/ArcticClouds1web.pdf

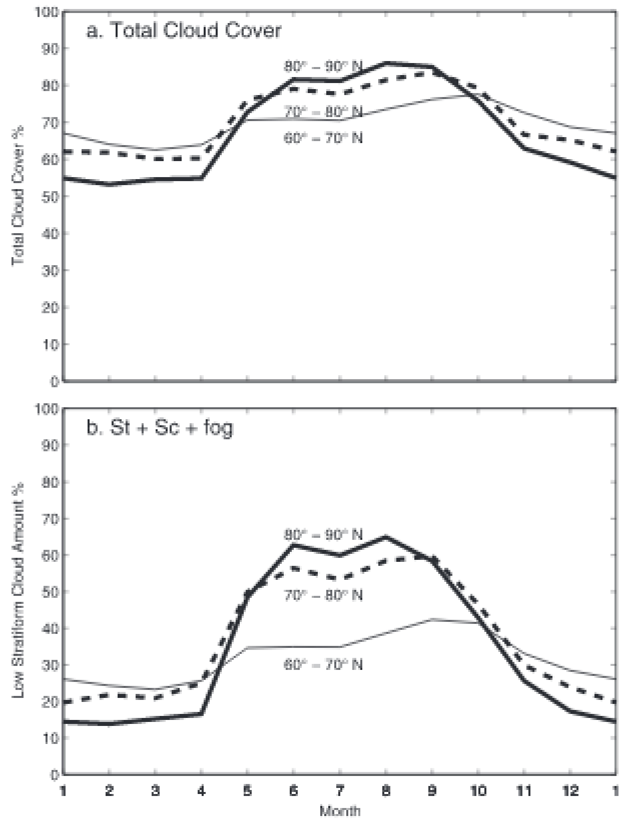
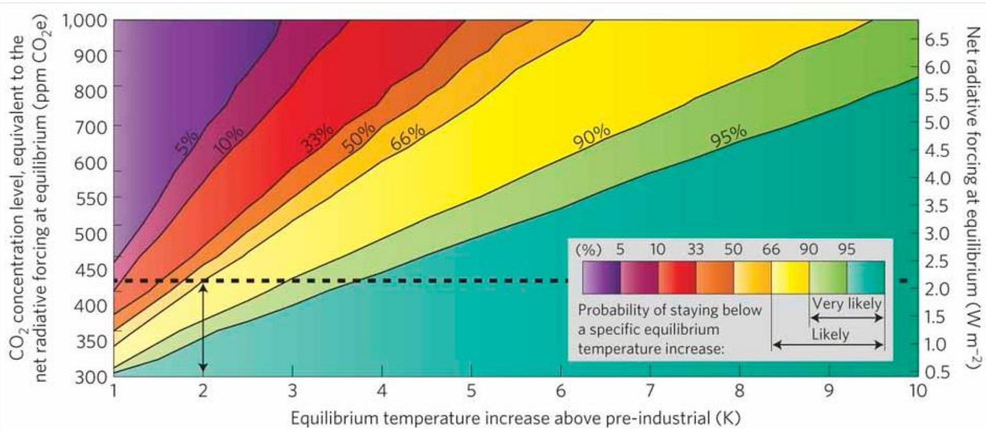
Interannual Variations of Arctic Cloud Types in Relation to Sea Ice
RYAN E ASTMAN AND
STEPHENG. WARREN</td><td>

FIG. 3. (a) The annual cycles of total cloud cover within 10° latitude bands in the Arctic. (b) Annual cycles of stratiform cloud cover within the same latitude bands.</td></tr>
<tr><td>4</td><td colspan="2">https://en.wikipedia.org/wiki/Radiative_forcing</td></tr>
<tr><td>5</td><td>Based on the formula in Table 1 (above), the atmospheric concentration was calculated for several radiative forcing values and these are very close to the values obtained from the chart at the right
<table>
<tr><th>RF</th><th>Equiv. PPM</th><th>From Chart</th></tr>
<tr><td>2.0</td><td>403.0</td><td>403</td></tr>
<tr><td>2.5</td><td>442.5</td><td>443</td></tr>
<tr><td>3.0</td><td>485.8</td><td>487</td></tr>
<tr><td>3.5</td><td>533.4</td><td>535</td></tr>
<tr><td>4.0</td><td>585.6</td><td>587</td></tr>
</table></td><td>

Note that the left scale indicates the CO_2 concentration level, equivalent to the net radiative forcing at equilibrium resulting from all forcing agents. It includes both the contributions of short- (for example, soot and aerosols) and long-lived (for example, CO_2) forcing agents. The right scale directly shows the equivalent net radiative forcing. The arrow illustrates that to limit global temperature increase to below 2°C with a 'likely' (greater than 66%) probability, equivalent CO_2 concentrations at equilibrium should be lower than 415 ppm CO_2e or the net radiative forcing at equilibrium below about 2.1 Wm^{-2}.

http://www.nature.com/nclimate/journal/v2/n4/full/nclimate1385.html</td></tr>
<tr><td>6</td><td>XLSX for calculations</td><td>http://ccdatacenter.org/documents/AlbedoCO2TempCalcs.xlxs</td></tr>
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