Notes on “Dependence of Earths Thermal Radiation on Five Most Abundant Greenhouse,” W. A. van Wijngaarden and W. Happer. This was referenced in S. Koonin’s book “Unsettled.”

Looking at Table 2, I wondered why the paper doesn’t sum up the values at ½ today’s concentrations, and at 2X today’s concentrations.[1] Half a minute reflection reaches the conclusion there is no point in summing them, since that would assume each individual concentration will increase together in lockstep beyond $F_{sd}^{(i)}(z)$. In other words, if for example CO_2 doubles in concentration, there is a very small chance all the others will double at the same instance. So a sum is irrelevant.

	$F_{sd}^{\{i\}}(z)$		$\Delta F^{\{i\}}(z,0)$		$\Delta F^{\{i\}}(z,1/2)$		$\Delta F^{\{i\}}(z,2)$	
$i \setminus z$	z_{tp}	z_{mp}	z_{tp}	z_{mp}	z_{tp}	z_{mp}	z_{tp}	z_{mp}
H_2O	81.6	71.6	-72.6	-62.2	-10.4	-7.8	11.2	8.1
CO_2	52.4	38.9	-44.6	-30.2	-5.3	-3.0	5.5	3.0
O_3	6.1	10.5	-4.7	-8.1	-1.8	-2.2	2.5	2.5
N_2O	4.4	4.7	-2.2	-2.2	-0.8	-0.8	1.2	1.1
CH_4	4.2	4.4	-2.1	-2.1	-0.6	-0.6	0.8	0.7
$\sum_i$	148.7	130.1	-126.2	-104.8				
$F_{sd}(z)$	137	117	137	117				

Table 2: Partial forcings $F_{sd}^{\{i\}}(z)$ of (48) and partial forcing increments $\Delta F^{\{i\}}(z,f)$ of (50), all in units of W m^{-2}, at the altitudes $z_{tp} = 11$ km of the tropopause and $z_{mp} = 86$ km of the mesopause. The last row contains the forcings $F_{sd}(z)$ of (47), shown in Fig. 7, when all greenhouse molecules are present simultaneously at their standard column densities $\hat{N}_{sd}^{\{i\}}$. Because of the overlapping absorption bands, $\sum_i F_{sd}^{\{i\}}(z) > F_{sd}(z)$, and $-\sum_i \Delta F^{\{i\}}(z,0) < F_{sd}(z)$.

(A quick reference to the equations, tables, and graphs cited here is at the end of this document.)

Table 1							-1		$\Delta F^{\{i\}}(z,f)$ of (50).		
			$F_{sd}^{\{i\}}(z)$		$\Delta F^{\{i\}}(z,0)$		$\Delta F^{\{i\}}(z,1/2)$		$\Delta F^{\{i\}}(z,2)$		
	i		z_{tp}	z_{mp}	z_{tp}	z_{mp}	z_{tp}	z_{mp}	z_{tp}	z_{mp}	
	1	H_2O	81.6	71.6	-72.6	-62.2	-10.4	-7.8	11.2	8.1	
	2	CO_2	52.4	38.9	-44.6	-30.2	-5.3	-3	5.5	3	
	3	O_3	6.1	10.5	-4.7	-8.1	-1.8	-2.2	2.5	2.5	
	4	N_2O	4.4	4.7	-2.2	-2.2	-0.8	-0.8	1.2	1.1	
	5	CH_4	4.2	4.4	-2.1	-2.1	-0.6	-0.6	0.8	0.7	
		total	148.7	130.1	-126.2	-104.8					
std densities		$F_{sd}(z)$	137	117	137	117					

Here are the totals:

overlap er	7.9%	10.1%	-8.6%	-11.6%	7.9%	10.1%
		multiples	0		1	
		total forcing	274.9	234.9	148.7	130.1

[1] *Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases*, W. A. van Wijngaarden and W. Happer, June 8, 2020, arXiv:2006.03098v1 [physics.ao-ph] 4 Jun 2020

As there is overlap of the spectra that causes the total of the individual gases to be more than than the actual total, it makes sense to adjust the individual gases to *effective* values:

Table 1, adj.										
adj. for overlapping absorption bar										
for visualization			$F_{\mathrm{sd}}^{\{i\}}(z)$		$\Delta F^{\{i\}}(z,0)$		$\Delta F^{\{i\}}(z,1/2)$		$\Delta F^{\{i\}}(z,2)$	
	i		z_{tp}	z_{mp}	z_{tp}	z_{mp}	z_{tp}	z_{mp}	z_{tp}	z_{mp}
	1	H2O	75.2	64.4	-78.8	-69.4	-9.5	-7.0	10.3	7.2
	2	CO2	48.3	35.0	-48.4	-33.7	-4.9	-2.7	5.0	2.7
	3	O3	5.6	9.4	-5.1	-9.0	-1.7	-2.0	2.3	2.2
	4	N2O	4.1	4.2	-2.4	-2.5	-0.7	-0.7	1.1	1.0
	5	CH4	3.9	4.0	-2.3	-2.3	-0.6	-0.5	0.7	0.6
		total	137	117	-137.0	-117.0				
			137	117	137	117				
				multiples	0		1			
					tp	mp	tp	mp		
				total forcing	274.0	234.0	137.0	117.0		

The smaller the number (W/m^2) the less released to the universe, so the more heat is retained in the insulating boundary (troposphere and mesosphere). So the 274.0 represents what is released at zero greenhouse gas, which is close to the amount the earth receives on average. Under those conditions, the Earth's average temperature is estimated at 0°F, from radiation considerations only. The multiples are what correspond to the CO_2 concentrations of 0, 200, 400 (the current), and 800 ppm.

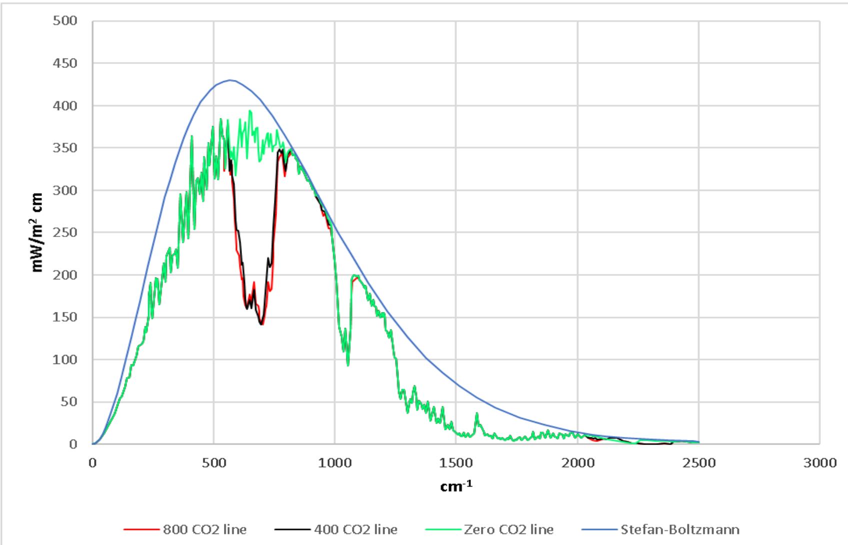
Here are the gases under consideration, from Table 1. Notice these densities are per *area*, not volume:

i	Molecule	$\hat{N}_{\mathrm{sd}}^{\{i\}}$ (cm^{-2})
1	H_2O	4.67×10^{22}
2	CO_2	8.61×10^{21}
3	O_3	9.22×10^{18}
4	N_2O	6.61×10^{18}
5	CH_4	3.76×10^{19}

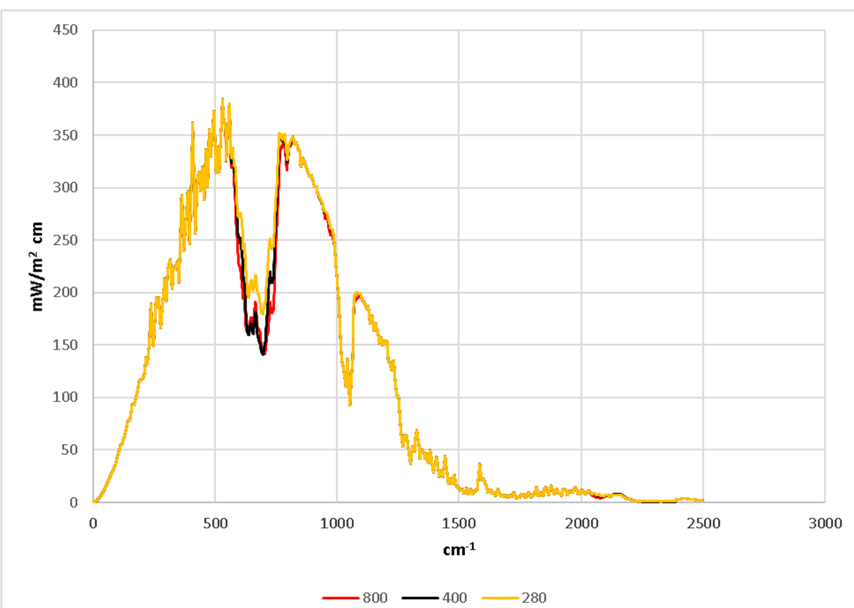
Table 1: Column densities, $\hat{N}_{\mathrm{sd}}^{\{i\}}$, of the 5 most abundant greenhouse gases obtained using the standard altitudinal profiles [18] of Fig. [1].

The column density is a method used a lot in astronomy, that identifies the number of molecules in a column over an area of 1 cm^2. Being able to count molecules helps quantify the theoretical flux, based on each type of molecules characteristics (vibrational modes figured with quantum physics).

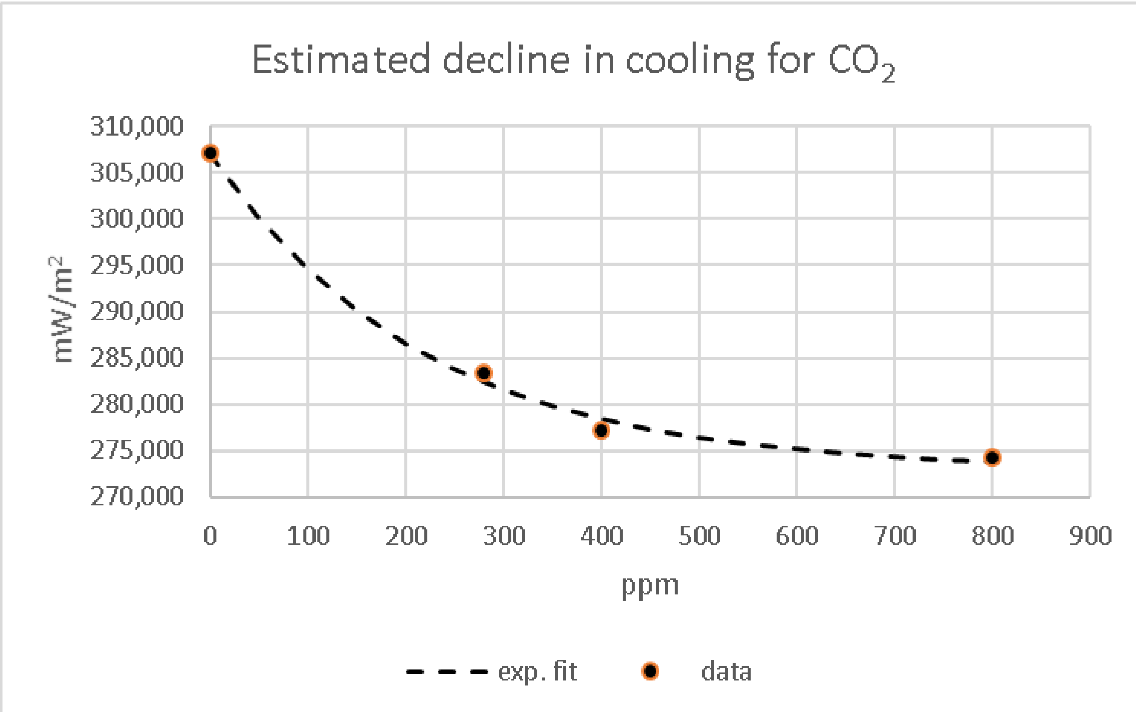
There is an interesting graph in this paper (Figure 4) that shows the theoretical results of all the vibrational modes effect on absorption and emission, as individual forcings. The area under the curve is the spectral flux from a surface at average earth temperature of 288 K, at 86km (mesopause). This is "cooling", or flux from the earth's surface. So the bigger the area, the more the cooling (or the less the heating). The biggest area is under the Stefan Boltzmann curve (no atmosphere) and represents the maximum cooling and no heating, since there is no thermal gradient where there is no atmosphere.



The green line is with an atmosphere with all the greenhouse gases, except for CO_2. Water is the predominant greenhouse gase. The black line is all the greenhouse gases, including CO_2 at 400ppm (present). The red line is double that, at 800ppm CO_2, the rest at current levels. For some reason, the authors of this paper did not include 280ppm, the so-called baseline that was disturbed by human activities the last 100 years or so. Presumably it is somewhere between the zero line and the 400ppm line, so I interpolated with a polynomial to place it at an estimated location:



Each curve can be integrated to get to the total loss of cooling (area under the curve). This leads to a relationship that fits well with the "painted window" analogy, where if you keep piling on layers of paint on a window, the incremental effectiveness of each layer decreases asymptotically (shown with an exponential decline here):



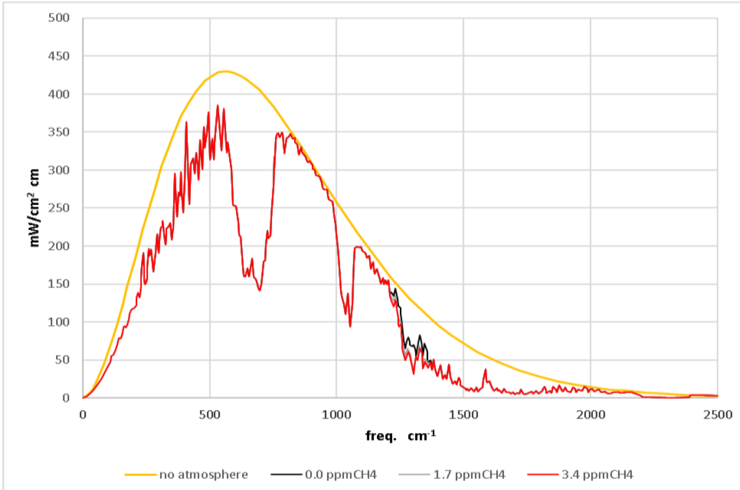
The relative loss of cooling is summarized in this table:

cooling decline, CO_2

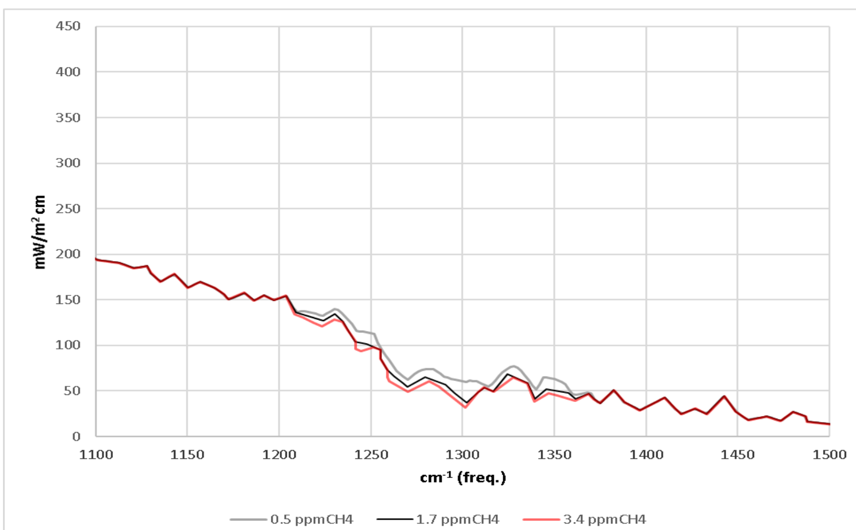
	0 - 280	280 - 400	400 - 800	0 - 400
mW/m^2	23,689	6,132	3,015	29,821
W/m^2	23.7	6.1	3.0	29.8
	7.72%	2.16%	1.09%	9.71%

This suggests the doubling of the current CO_2 in the atmosphere won't have near the effect as going from 280 to current levels did. That's not saying it is a good thing, but a fact that should be understood.

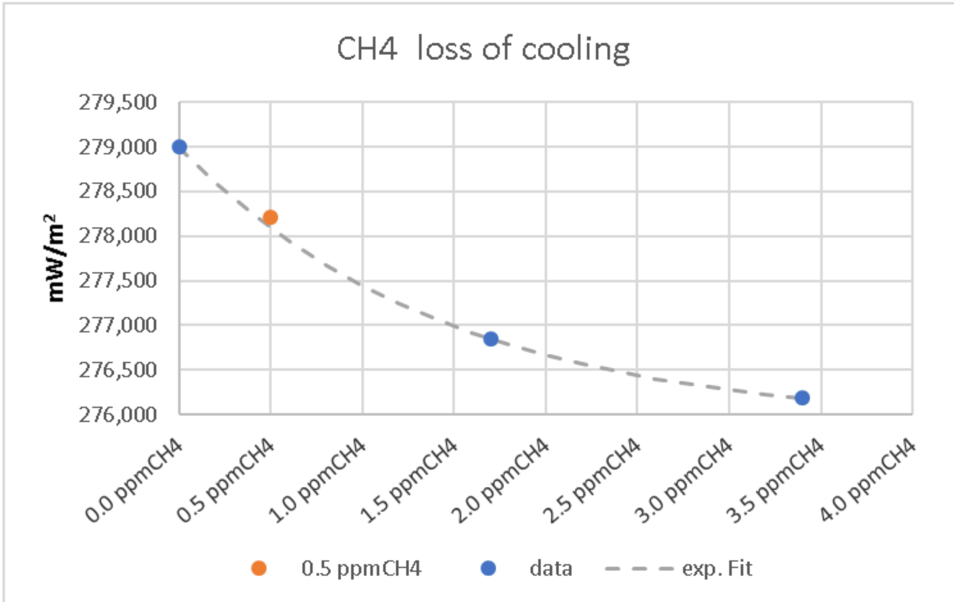
Something similar happens with methane (and the other gases). Here is methane, whose baseline concentration was about 0.5 ppm for hundreds of thousands of years, but now is around 1.7 ppm. It is a powerful greenhouse gas, and unlike CO_2, does not have a constant concentration with altitude.



Like CO_2, the concern is the area under each curve, which can be calculated through integration. A 0.5 line has been interpolated, and notice methane only has effect in a narrow frequency range. This is based on the current concentrations of greenhouse gases, with CH_4 varied from zero to double today's value.



This is another example of the painted window effect; a curve fit of various concentrations is made, to show the change in forcing likely reduces exponentially as the concentration is doubled from today's value (the curve fit is an exponential), and the estimate from 0.5 ppm interpolation also shown:

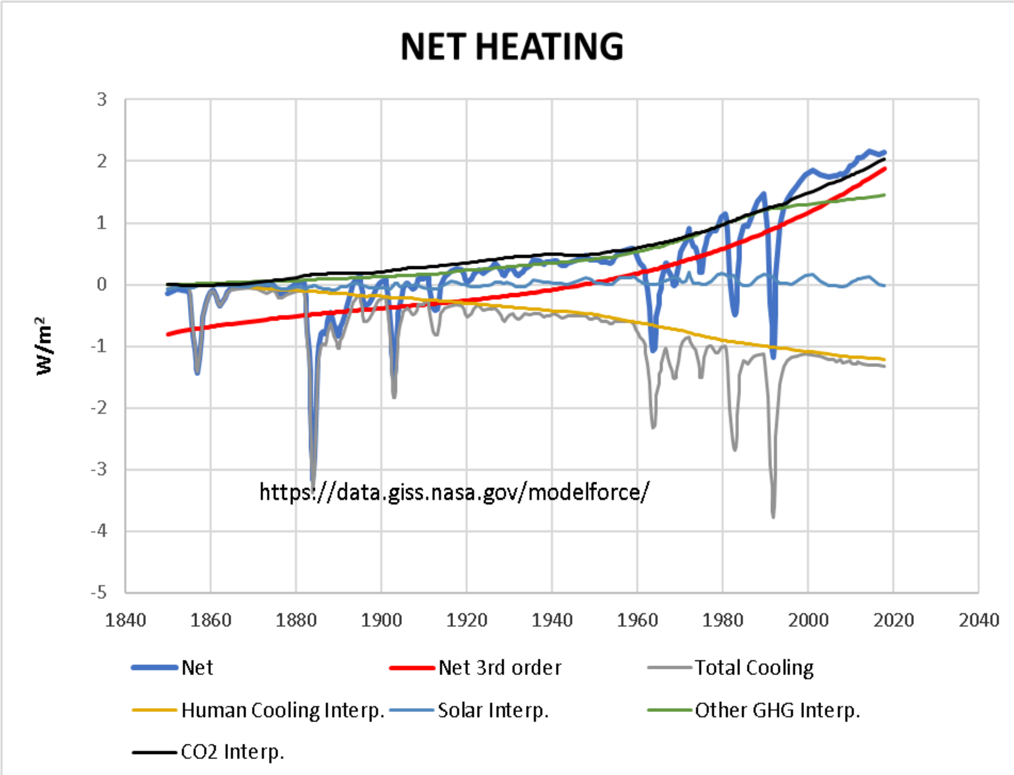


cooling decline, CH_4

	0 - 0.5	0.5 - 1.7	1.7 - 3.4	0 - 1.7
mW/m^2	786	1,363	667	2,149
W/m^2	0.8	1.4	0.7	2.1
	0.28%	0.49%	0.24%	0.77%

Similar to CO_2, from 0.5 to 1.7 ppm represents the bulk of the loss of cooling. Make no mistake, methane is a powerful greenhouse gas.

Another interesting piece is the following graph, from another source:



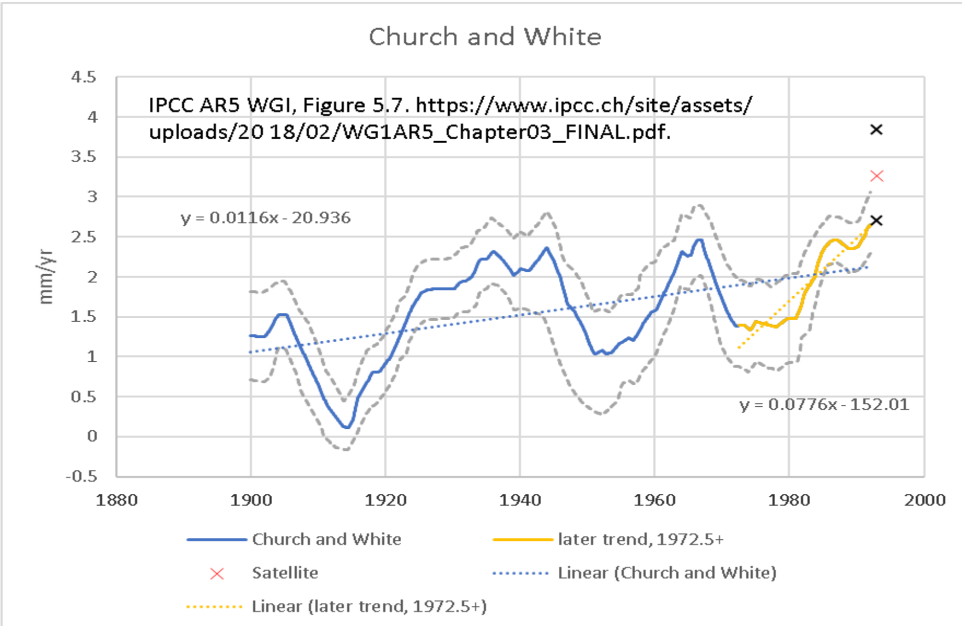
It bears a bit of study, since it combines individual forcings with net forcings. The two thicker lines (blue and red) are *net* effect, the red being a curve fit of the blue. The solar variability is present, but obviously is a very minor contributor, but does not include here major energy spikes up or down. The total cooling has some big spikes, mostly from volcanic eruptions that puts debris in the air. However, it has a trend that is gradually rising from zero, so the trend is from aerosols produced from human activities. The surprising conclusion would be if humans clean up their pollution, the warming from greenhouse gases will have even a stronger effect!

Finally, CO_2 by itself is visible as the black line. There is a lot of uncertainty when you combine these, which rivals the magnitude of the predicted warming itself, it should be pointed out.

A lot of people like to think the fact that CO_2 being a tiny fraction of the earth's atmosphere, it's not significant. Or, they like to think humanity's contribution being so small compared to the natural amounts in the cycle, it's not significant. The point that is missed is carbon circulation is in quasi-equilibrium, so what we produce can tilt it out of equilibrium, even though it's a small part of what is circulating.

It's also worth mentioning that there is energy conservation, so what gets absorbed by the earth eventually gets re-emitted by the earth. The problem with changing the insulating layer is that will change the thermal gradient from the surface to the end of the atmosphere in space, as the earth adjusts to a new energy equilibrium. The new thermal gradient is known to us as climate change.

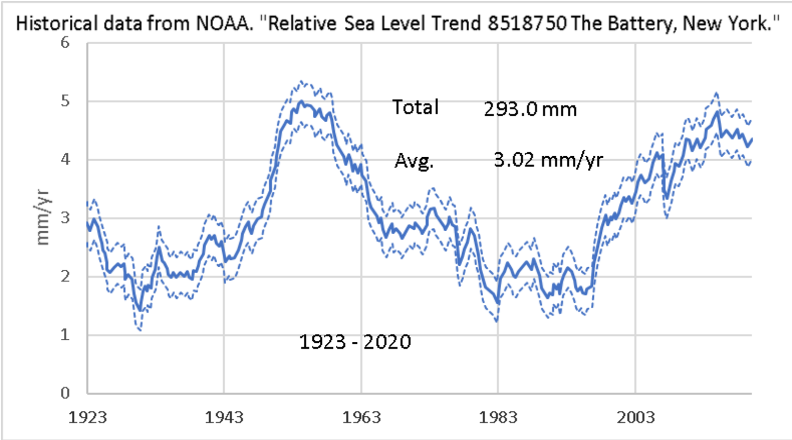
Some things get trended out of context. The following shows some sea level readings taken from 1900 to 1992.[2] It's mostly agreed sea level rises about 3mm a year, or 300mm for this century, which is about 12 inches. But it has a lot of variability, so some pretty outrageous estimates are thrown around by the media, since it gets the heart racing:

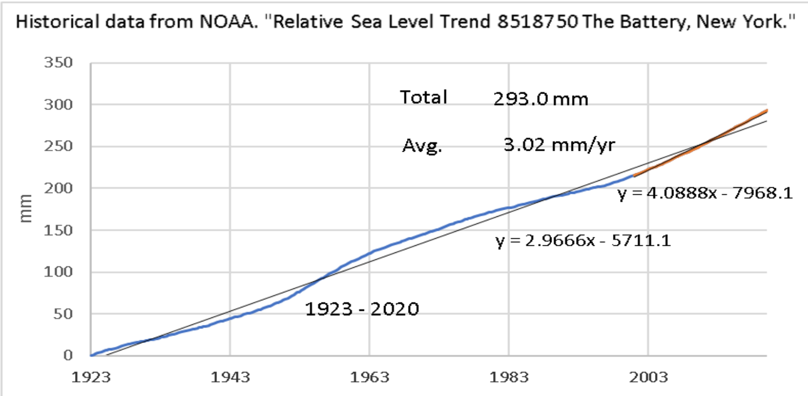


The source for this graphic can be found in IPCC's site.[3] The single satellite reading is 3.3mm/yr. Integrating the blue line results in 293mm (11.5 in) over 92 years. But the change varies, depending on location. It can be seen the overall average is 1.6/yr per year and trending to 2.2mm/yr at present, but choosing an origin in 1972 to base a trend instead results in 5.2mm/yr per year by 2100. The rate of rise around 1940 is nearly as much as this site recorded in 1992. If the 92 year trend in rate per year is extended out to 2100, the total change in level from 1992 is 302mm (11.9 in). If mis-trended at the erroneous rate growth (0.0776 rate growth per year) starting at 1972, the total change from 1992 to 2100 is 730mm, or 28.7in!

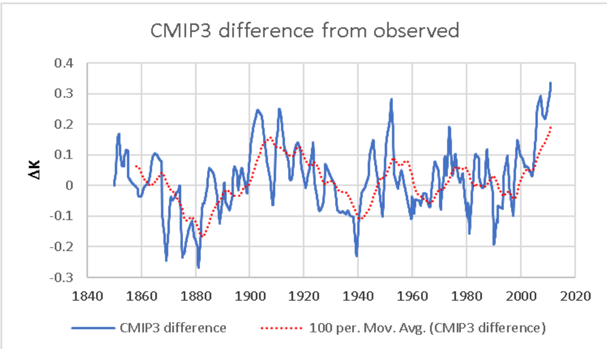
Another dataset records sea level rise rate at the Battery, NYC. The one below is a thirty year *backwards* average, unlike the previous graph. Similar results, but it's worth noting nowhere does the rate of rise become zero or go negative; always rising is the trend. If sea level rising is a climate change indicator, it appears from these data that climate change was happening back in 1940, before most people started ascribing it to human activities. Notice the difference in slopes in the curve fits in the second graph derived from the first, depending on where you start and finish the fits.

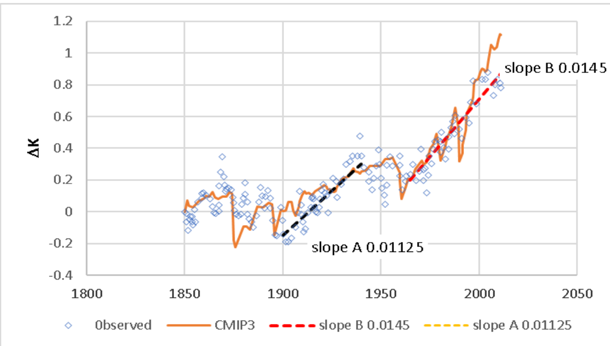
[2] Rolling average for following 18 years. So, 1992 data is average for 1992 through 2010, for example.
[3] https://www.ipcc.ch/report/ar5/wg1/observations-ocean/





Temperature considerations. The models just keep rolling out, CMIP3, CMIP5, and then CMIP6. The first two are history matched to 1850, the last to 1900, for some reason I haven't figured out yet. Why not do them at the same origin?[4]

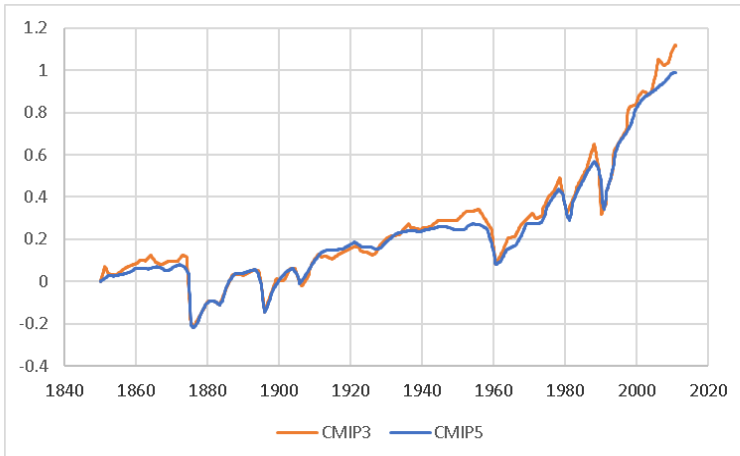




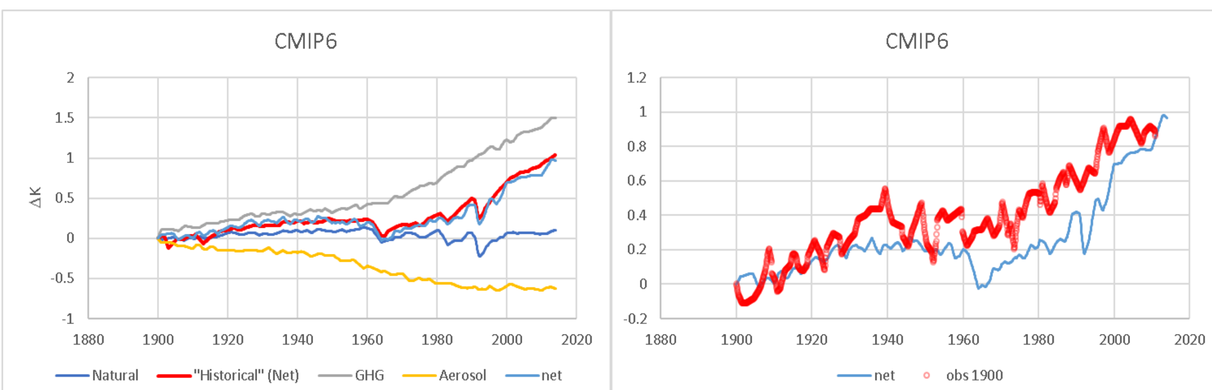
[4] From IPCC Fifth Assessment Report (AR5), WGI (The Physical Science Basis), Figure 10.1.

Interesting the change from origin (1850) from 1900 to around 1940 was almost as steep as the part from the early 60's to the end of the data, but neither model reflected it. Was climate change occurring from 1900 to 1940? Or better put, was it *human-induced*; obviously something was changing pretty quickly. The difference of the model result from what was observed has a pretty regular pattern of discrepancy.

Here are the two models, fairly close to each other:



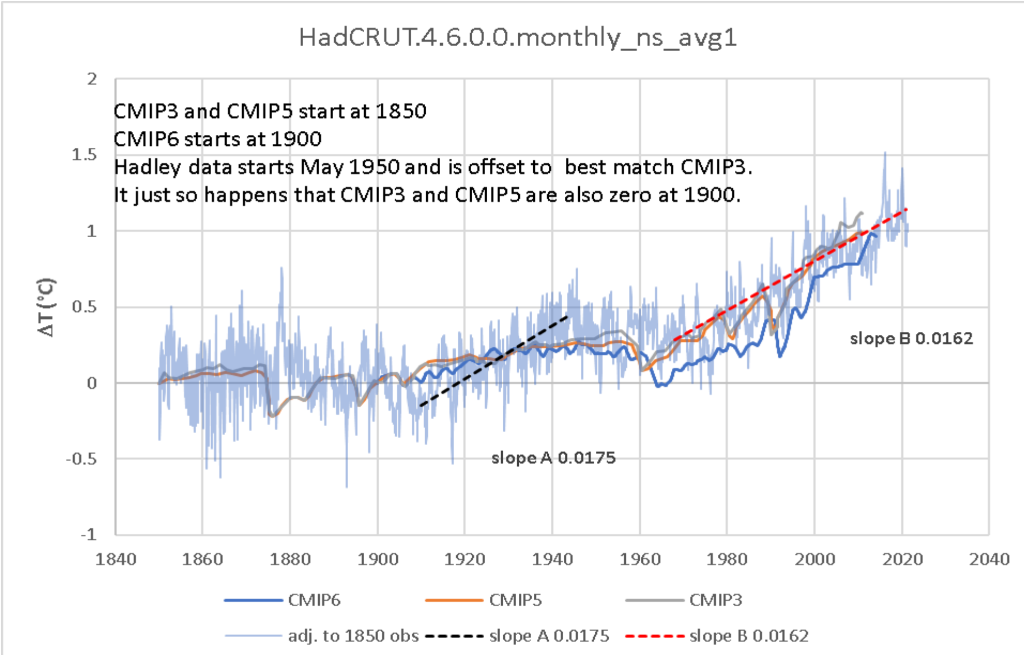
CMIP6 actually looks a little worse.[5] I zeroed the observed data from the previous data to 1900, since this model graphic starts at 1900.



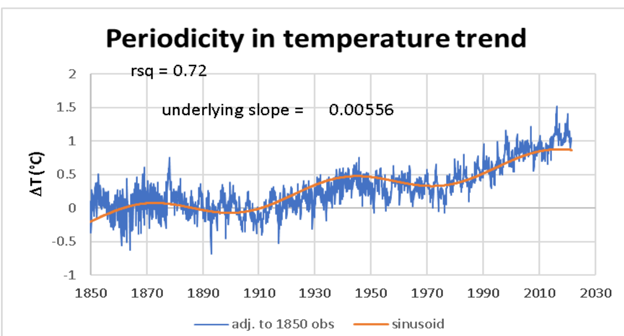
It doesn't seem to match the observed data too well. The graphic on the left has a label "Historical" but it's not really. It is the net sum of the other curves, which are all model results. It's interesting to see how much the aerosol contributes to cooling, offsetting the greenhouse gas (GHG) effect.

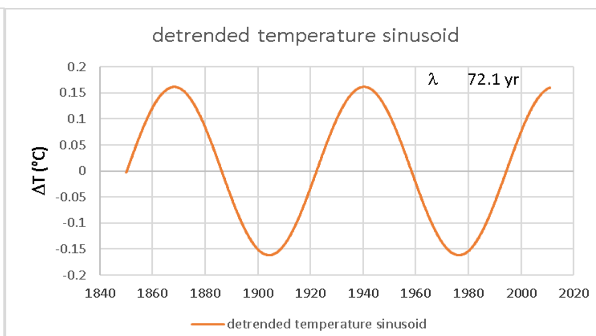
[5] From Tokarska, Katarzyna B., Martin B. Stolpe, Sebastian Sippel, Erich M. Fischer, Christopher J. Smith, Flavio Lehner, and Reto Knutti. "Past Warming Trend Constrains Future Warming in CMIP6 Models." Science Advances 6 (2020): eaaz9549. https://advances.sciencemag.org/content/6/12/eaazg9549

The HadleyCRUT database provides some more global data.[6] It doesn't differ a lot from the above, but see the following:



The scientists and quants who do this stuff seem to have a difficulty picking a common reference point, you can notice. The slopes are trends in the observed data, in two obvious upticking trends. The latest, CMIP6, seems to have difficulty matching the this observed data. Periodicity also visible:





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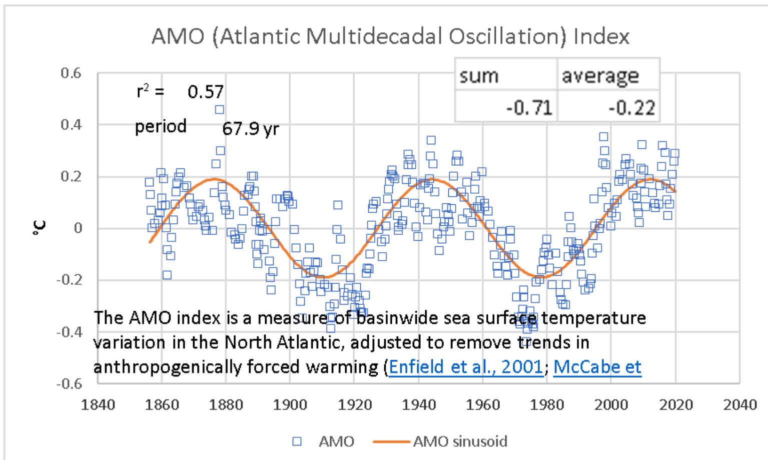
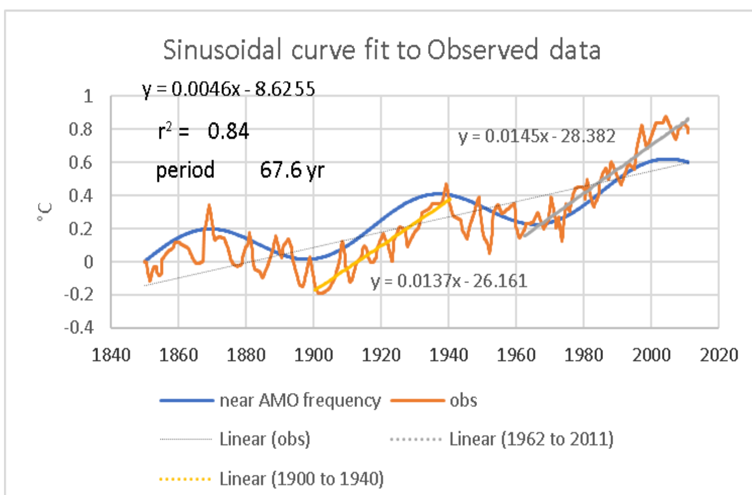
[6] https://www.metoffice.gov.uk/hadobs/hadcrut4/data/current/download.html#regional_series

There is another feature oceanographers and meteorologists watch, and that is the Atlantic Multidecadal Oscillation (AMO), which is related to the Pacific one known as El Niño (ENSO). It has a period of about 68 years.[7] Notice that this graph is de-trended, so offers no information on progressive warming.[8] It's an index, but still carries units of temperature, since it is an index made from a reference temperature. See paper for details.

AMO oscillation (notice the quote from the source shown on the graph implicitly credits any warming trend to human activity):



Interestingly enough, if a sinusoid is curve fit to the temperature deviation observation data shown earlier[9], you get the same period, pretty much. Remember, temperature deviation magnitude is affected by whatever base date is picked.



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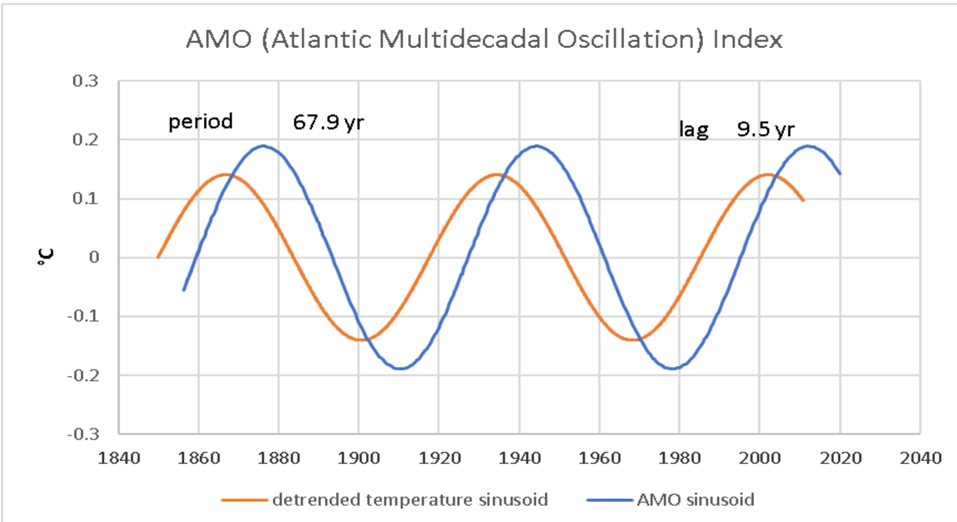
[7] https://www.psl.noaa.gov/data/timeseries/AMO/
GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 10, PAGES 2077-2080, MAY 15, 2001
The Atlantic multidecadal oscillation and its relation torainfall and river flows in the continental U.S.
Enfield, Estes-Muñez, et al.

[8] The SST data from *https://www.metoffice.gov.uk/hadobs/hadisst/data/download.html* does show trends in subsurface temperatures.

[9] From IPCC Fifth Assessment Report (AR5), WGI (The Physical Science Basis), Figure 10.1.

That might suggest the most recent “hockey stick”, with a slope of 0.0145 degrees per year may be related to the AMO, and a more realistic slope might be the overall trend of 0.0046 degrees per year (0.46 °C in 100 years) of the observed data. That’s an order of magnitude less than the latest “hockey stick” slope. This could be an explanation for the 1900 to 1940 model “miss” mentioned earlier: the deviation was in its upward oscillation.

Finally, plot the AMO sinusoidal fit, and the Observed (detrended) temperature fit, and you can see they are also almost in phase. Both amplitudes are fairly close to each other, too. If that’s a correlation, it could mean other factors are affecting both:



The atmospheric temperature could lead the AMO temperature because of the greater thermal inertia of the Atlantic ocean. Or it’s all an artifact; Michael Mann (the original “hockey stick” guy) in a recent article in *Science* questions whether the AMO is even real.

Examining graphs like these reminds me of taking stock market trends and reading all sorts of patterns into them, hoping to get rich. The other thing not really covered in these comments is the associated uncertainty. For example, the Net in the CMIP6 is a sum of components, all with their own uncertainty. If the uncertainty is the same magnitude as what’s being measured, I sure hope we are not about to dump modern civilization on that basis. Modern civilization was built on fossil fuels, and there is no guarantee it will continue without them, at least at the current level of technology. It’s also true fossil fuels are not renewable, either. We could be in for some really hard times.

Notes from the paper referenced:

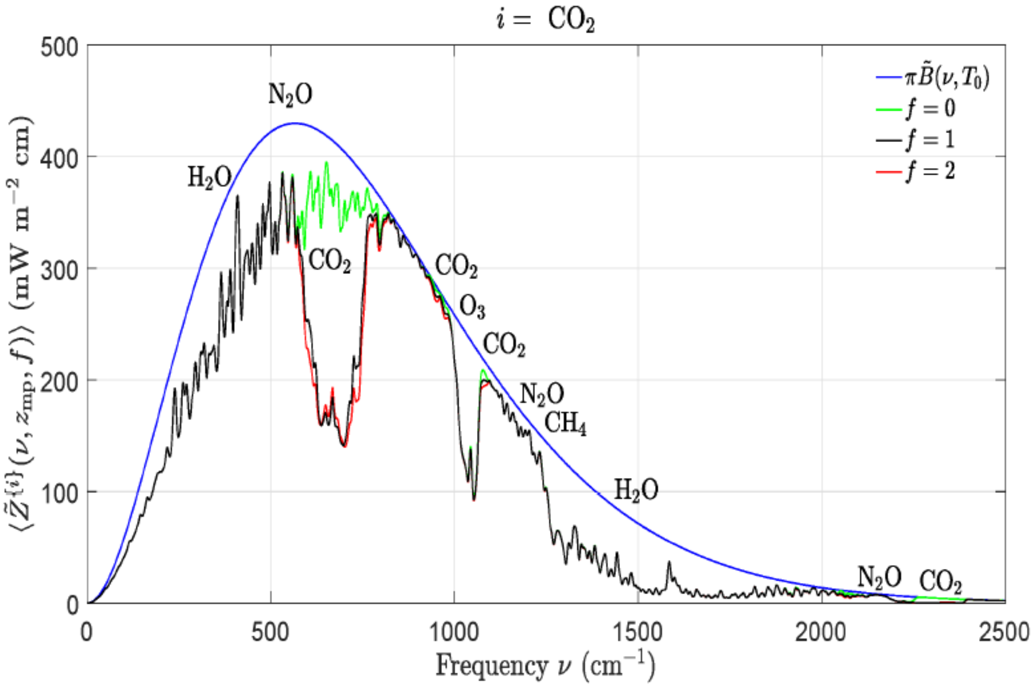


Figure 4: Effects of changing concentrations of carbon dioxide, CO_2 on the filtered spectral flux $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, f)\rangle$ of (44) at the mesopause altitude, $z_{mp} = 86$ km. The width of the filter (43) was $\Delta\nu = 3$ cm^{-1}. The smooth blue line is the spectral flux, $\tilde{Z} = \pi\tilde{B}(\nu, T_0)$ from a surface at the temperature $T_0 = 288.7$ K for a transparent atmosphere with no greenhouse gases. The green line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, 0)\rangle$ with the CO_2 removed but with all the other greenhouse gases at their standard concentrations. The black line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, 1)\rangle$ with all greenhouse gases at their standard concentrations. The red line is $\langle \tilde{Z}^{\{i\}}(\nu, z_{mp}, 2)\rangle$ for twice the standard concentration of CO_2 but with all the other greenhouse gases at their standard concentrations. Doubling the standard concentration of CO_2 (from 400 to 800 ppm) would cause a forcing increase (the area between the black and red lines) of $\Delta F^{\{i\}} = 3.0$ W m^{-2}, as shown in Table 2.

The standard concentrations for the ith greenhouse gas, $C^{\{i\}}_{\rm sd}$, based on observations[18], are shown as functions of altitude on the right of Fig. 1. The sea level concentrations are 7,750 ppm of H_2O, 1.8 ppm of CH_4 and 0.32 ppm of N_2O. The O_3 concentration peaks at 7.8 ppm at an altitude of 35 km, and the CO_2 concentration was 400 ppm at all altitudes. Integrating the concentrations over an atmospheric column having a cross sectional area of 1 cm^2 yields the column number density of the ith type of molecule $\hat{N}^{\{i\}}_{\rm sd}$ which are listed in Table 1.

The frequency integrals of the flux (30) and the forcing (34) are

$$Z = \int_0^\infty d\nu\,\tilde{Z}, \tag{35}$$

$$F = \int_0^\infty d\nu\,\tilde{F} = \sigma_{\rm SB}T_0^4 - Z, \tag{36}$$

where σ_{SB} is the Stefan Boltzmann constant.

The effects on radiative transfer of changing the column density of the ith greenhouse gas to some multiple f of the standard value, $\hat{N}^{\{i\}}_{\rm sd}$, can be displayed with filtered spectral fluxes

$$\langle \tilde{Z}^{\{i\}}(\nu,z,f)\rangle = \langle \tilde{Z}(\nu,z,\hat{N}^{\{1\}}_{\rm sd},\ldots,\hat{N}^{\{i-1\}}_{\rm sd},f\hat{N}^{\{i\}}_{\rm sd},\hat{N}^{\{i+1\}}_{\rm sd},\ldots,\hat{N}^{\{n\}}_{\rm sd})\rangle. \tag{44}$$

The frequency integrated forcing, F, of (36) depends on the altitude z and on the column densities of the five greenhouse gases given in Table 1.

$$F = F(z,\hat{N}^{\{1\}},\ldots,\hat{N}^{\{5\}}). \tag{46}$$

We assume the temperature T and densities $N^{\{i\}}$ have the same altitude profiles as in the midlatitude example of Fig. 1. An important special case of (46) is the forcing, $F_{\rm sd}$, when

each greenhouse gas i is present at its standard column density $\hat{N}^{\{i\}}_{\rm sd}$ of Table 1,

$$F_{\rm sd}(z) = F(z,\hat{N}^{\{1\}}_{\rm sd},\ldots,\hat{N}^{\{5\}}_{\rm sd}). \tag{47}$$

A second special case of (46) is the hypothetical, per molecule standard forcing, $F^{\{i\}}_{\rm sd}$, when the atmosphere contains only molecules of type i at their standard column density, $\hat{N}^{\{i\}} = \hat{N}^{\{i\}}_{\rm sd}$, and the concentrations of the other greenhouse vanish, $\hat{N}^{\{j\}} = 0$ if $j \neq i$,

$$F^{\{i\}}_{\rm sd}(z) = F(z,0,\ldots,0,\hat{N}^{\{i\}}_{\rm sd},0,\ldots,0). \tag{48}$$

We define a finite forcing increment for the ith type of greenhouse molecule as

$$\Delta F^{\{i\}}(z,f) = F(z,\hat{N}^{\{1\}}_{\rm sd},\ldots,\hat{N}^{\{i-1\}}_{\rm sd},f\hat{N}^{\{i\}}_{\rm sd},\hat{N}^{\{i+1\}}_{\rm sd},\ldots,\hat{N}^{\{n\}}_{\rm sd}) - F_{\rm sd}. \tag{50}$$