NOTES AND CORRESPONDENCE

The Effect of Changing CO_2 Concentration on Radiative Heating Rates: Further Comments[1]

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ABSTRACT

Changes in radiative heating and cooling rates due to both the near infrared and 15μ bands of CO_2 are computed for changes in CO_2 concentration from 320 to 600 and 1000 ppmv. An increase in CO_2 concentration leads to a smaller net cooling rate in the troposphere, little net change at the tropopause, and increased cooling in the stratosphere. The 15μ and near infrared effects act in the same sense in the tropopause but tend to compensate in the stratosphere, although the near infrared contribution is generally small when compared with that due to the 15μ band. Possible effects of the changes on the generation of zonal available potential energy are suggested.

Recently (Newell and Dopplick, 1970) we considered the change in the calculated thermal cooling rate of the atmosphere when the CO_2 concentration was increased from 320 to 400 ppmv (parts per million by volume). This note compares changes in the thermal cooling rates with changes in the near infrared heating rates due to an increase in CO_2 and points out their possible influence on the generation of zonal available potential energy.

In addition to the computations for CO_2 concentrations of 400 ppmv, discussed previously, several sets of radiative heating rate calculations have been made at concentrations of 600 and 1000 ppmv. As in our previous paper the heating rates were computed from a numerical integration of the radiative transfer equation, the absorptance data for the 15 μ band being taken from Rodgers and Walshaw (1966). The calculations were performed at 10° latitude intervals. Cloud conditions, ozone and water vapor concentrations, and temperature profiles have been kept constant.

The near infrared bands of CO_2 included in the calculations are those at 1.4, 1.6, 2.0, 2.7, 4.3, 4.8 and 5.2 μ. The values of near infrared heating which are discussed also include a contribution due to absorption by H_2O and O_2. The overlap between CO_2 and H_2O is taken into account.

Table 1 gives the 15 μ CO_2 cooling rates for concentrations of 320, 600 and 1000 ppmv, to show the progressive change, and the near infrared (NIR) heating rates for concentrations of 320 and 1000 ppmv. The data are given at the equator and at 60N for January.

At the equator the change in heating rates is dominated by that due to the 15 μ band except in the upper troposphere and lower stratosphere. In the lower troposphere there is less cooling due to the 15 μ band and more heating in the near infrared as the CO_2 concentration increases. The two components act in the same direction and the result, all other things being equal, is a net decrease in cooling. In the middle stratosphere there is more cooling due to the 15 μ band and more heating in the near infrared; there is thus a tendency toward compensation as Gebhart (1967) pointed out although at 30 mb and above there is a clear net increase in cooling. The effect of the 15 μ band also generally dominates at 60N in January where the solar effect is diminished. In summer at high latitudes there is again some reinforcement of the terms in the troposphere and compensation in the stratosphere.

Fig. 1 gives the latitude-height distribution of the changes in Q, the radiative heating rate, for January

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Table 1. Changes in radiative heating rates (°C per day) accompanying CO_2 concentration changes for January.*

	Radiative heating rates					Changes in heating rates				
	Equator					Equator			60N	
Layer		15μ		Near infrared (NIR)		15 μ	NIR	Net	15μ	NIR
(mb)	1	2	3	4	5	6	7	8	9	10
2– 5	−4.246	−5.392	−6.311	0.573	0.694	−2.065	0.121	−1.944	−1.140	0.021
5– 20	−2.145	−2.819	−3.423	0.356	0.435	−1.278	0.079	−1.199	−0.778	0.016
20– 30	−1.231	−1.381	−1.418	0.288	0.359	−0.187	0.071	−0.116	−0.279	0.008
30– 50	−0.763	−0.808	−0.873	0.264	0.321	−0.110	0.057	−0.053	−0.186	0.005
50– 70	−0.239	−0.263	−0.266	0.245	0.277	−0.027	0.032	0.005	−0.074	0.004
70– 100	0.078	0.090	0.093	0.225	0.244	0.015	0.019	0.034	−0.043	0.004
100– 150	0.067	0.067	0.071	0.207	0.225	0.004	0.018	0.022	−0.020	0.003
150– 200	−0.005	−0.014	−0.022	0.322	0.300	−0.017	−0.022	−0.039	−0.004	0.004
200– 300	−0.189	−0.189	−0.188	0.541	0.558	0.001	0.017	0.018	0.003	0.003
300– 500	−0.345	−0.324	−0.305	0.894	0.925	0.040	0.031	0.071	−0.001	0.002
500– 700	−0.327	−0.287	−0.254	0.998	1.014	0.073	0.016	0.089	0.027	0.002
700– 850	−0.286	−0.230	−0.186	0.803	0.805	0.100	0.002	0.102	0.037	0.003
850–1000	−0.228	−0.174	−0.132	0.453	0.463	0.096	0.010	0.106	0.036	0.001

* CO_2 concentration (ppmv): Col. 1, 320; col. 2, 600; col. 3, 1000; col. 4, 320; col. 5, 1000. Increase in CO_2 concentration (ppmv): Cols. 6–10, from 320 to 1000.

which result from increasing the CO_2 concentration from 320 to 1000 ppmv. The cooling rates for the 15 μ band of CO_2 at a concentration of 320 ppmv are given in Fig. 2. The 15 μ CO_2 band clearly contributes to net cooling in the low latitude troposphere and an increase of CO_2 concentration diminishes this cooling as indicated by the positive values in Fig. 1a. This is the dominant change in this region as can be seen from Figs. 1b and 1c. This change is small in comparison with the other components of the radiative heating rate (Dopplick, 1970). It is also small when compared with the other components (latent heat release, boundary layer heating) of the total diabatic heating rate. Such small changes in the heating rate could easily be swamped by the effects of changes in stability and surface temperature on the transports of water vapor and sensible heat into the atmosphere.

Near the tropical tropopause the net change (Fig. 1c) is very small. In view of the extreme sensitivity of stratospheric moisture content to the cold trap

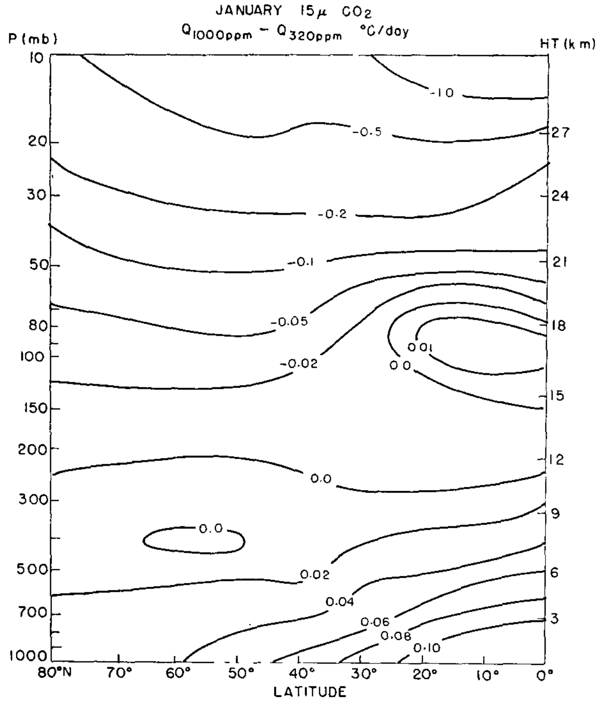

Fig. 1a. The change in the thermal cooling rate of the 15μ CO_2 band due to an increase in the CO_2 concentration from 320 to 1000 ppmv (January).

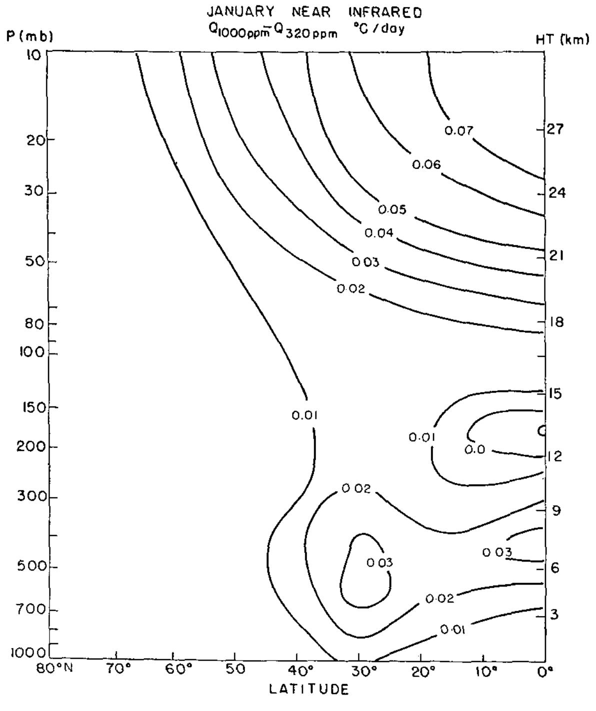

Fig. 1b. The change in the NIR hearing rate due to an increase in the CO_2 concentration from 320 to 1000 ppmv. The effect of the overlapping water vapor bands is also included (January).

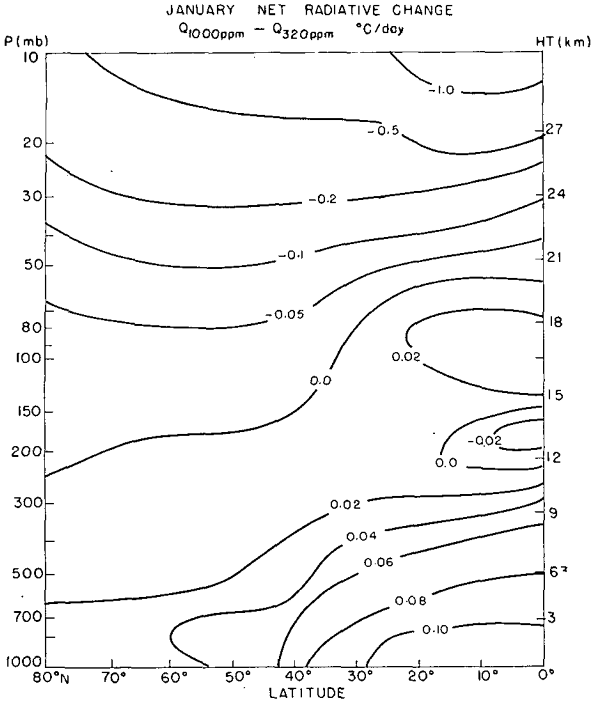

FIG. 1c. The net change in the atmospheric cooling rate due to an increased CO$_2$ concentration (January).

temperature there, this finding may be viewed with relief.

Above 30 mb there seems to be no question that increased CO$_2$ concentrations will lead to increased cooling rates and therefore to lower temperatures. The net change in heating rate represents a large fraction of the original rate due to CO$_2$ which in turn represents a significant portion of the total heating rate due to all diabatic processes. A net temperature decrease would of course be accompanied by diminished cooling rates as demonstrated by Manabe and Wetherald (1967) in their calculations of radiative-convective equilibrium temperatures. A complete knowledge of the effects of increased CO$_2$ concentration on temperatures must await complex modeling calculations which include the interrelated effects of the three-dimensional motion field of the atmosphere with a complete specification of the thermodynamics.

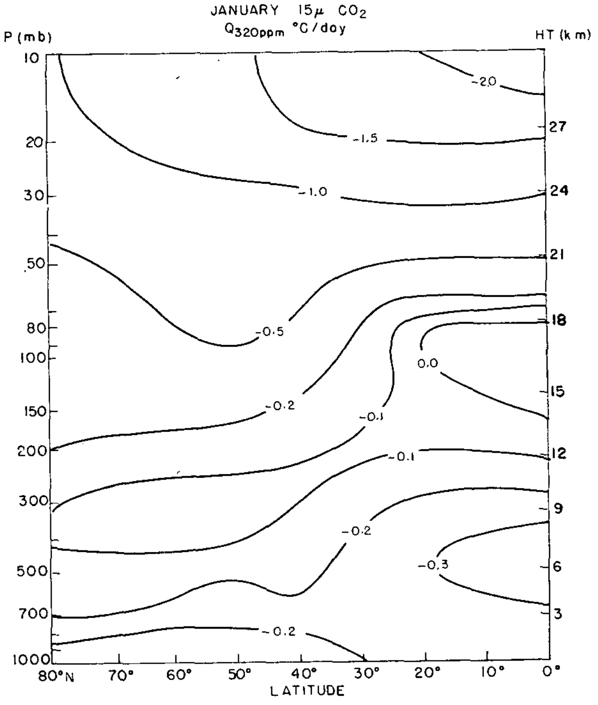

FIG. 2. Cooling due to the 15μ CO$_2$ band for a concentration of 320 ppmv (January).

The presence of CO$_2$ in the atmosphere results in the generation and destruction of available potential energy through radiative effects. Some of the consequences of a change in CO$_2$ concentration can be inferred from Fig. 2 and a meridional cross section of temperature. Generation of available potential energy occurs when warm regions are heated and cold regions are cooled (Lorenz, 1955). The total cooling rate due to CO$_2$ in the middle and lower troposphere is closely approximated by the values shown in Fig. 2 since the dominant near infrared contribution in this region is due to water vapor and not to CO$_2$. The effect of CO$_2$ is clearly to destroy available potential energy, as there is cooling in the tropical troposphere where the air is warm and less cooling at higher latitudes where the temperatures are lower. This tropospheric effect of CO$_2$ cooling is rather small compared to that due to the other components of the total radiative heating rate and the effect of an increase in CO$_2$ concentration is generally to lessen the rate of destruction of available potential energy. As we have mentioned, the effects of other diabatic heating processes could easily swamp this effect.

In the stratosphere, above about 30 mb, the presence of CO$_2$ results in radiative cooling rates which clearly dominate the heating due to the near infrared absorption and, as can be seen from Fig. 2, the result is to destroy available potential energy as maximum cooling is associated with the warmest temperatures and vice versa. The effect of an increase in CO$_2$ concentration would be to accentuate this destruction although the expected change in temperature due to the increased cooling would tend to offset this effect. As the effect of the CO$_2$ cooling is an appreciable fraction of the net heating rate due to all constituents in this region, the effect on the available potential energy could in turn be appreciable.

While the computations here have used CO$_2$ concentrations up to 1000 ppmv for illustrative purposes, the peak values to be expected are unknown. The concentration is presently increasing at about 0.7 ppmv per year, while the rate at which man burns fossil fuels is also increasing; in fact, it seems that most of the world's accessible oil will be used in the next 35–50 years and most of the coal within 300 years, so that peak CO_2 concentrations may be expected in this relatively short span of time. Dr. C. D. Keeling, in discussing the problem with us at the Williamstown Study of Critical Environmental Problems (SCEP, 1970), suggested that we take values up to 1500 ppmv in our computations. On the other hand it is known that the ocean holds many times the atmospheric CO_2 content in solution and MacIntyre (1970) argues that most of the extra CO_2 will be taken up by the ocean so that maximum concentrations may reach only 480 ppmv before the end of the century. It is also of interest to reverse the changes in Fig. 1 and argue that at some time in the past, when there was less CO_2 in the atmosphere, cooling rates in the tropical troposphere were larger while those in the middle stratosphere were smaller. The tendency would have been for lower tropospheric temperatures, higher stratospheric temperatures, and an increase in static stability. These changes may be worthy of consideration in explanations of the climate of the past.

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