SHORTER CONTRIBUTION

Carbon dioxide concentration in the upper troposphere and lower stratosphere. III

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ABSTRACT

Investigations of the atmospheric CO_2 content have shown that marked differences between samples collected in the troposphere and stratosphere exist (Bischof, 1965; Bischof & Bolin, 1966; Bischof, 1971). Using all data available from flights during 1963–68, a significant change in amplitude and phase of the annual cycle was found when comparing the variations at 12 km with those at lower levels (Bolin & Bischof, 1970). A separation between tropospheric and stratospheric samples was, however, not undertaken, because the data was not adequate. If including samples from the years 1969–71, a data separation clearly shows the change in amplitude and phase between upper troposphere and lower stratosphere. The results are presented below and compared with data obtained at Scripps Institution of Oceanography. The data also show that the annual increase of CO_2 in the atmosphere is increasing by about 0.09 ppm/year^2.

Data presentation

Samples from height levels above 7 km were separated and classified as tropospheric or stratospheric, as will be described in more detail by Bischof (1972). Mean values for each flight were calculated and plotted as a function of the time of the year. With due regard to the annual cycle, an annual mean value was computed and the annual increase from one year to the next was thereby obtained. The results are shown in Figs. 1–3.

In Fig. 1, the mean annual cycles for the upper troposphere and lower stratosphere are presented, the average annual increase having been eliminated. The mean annual cycles for Mauna Loa and South Pole station have also been plotted according to Keeling et al. (1972).

To demonstrate the difference in the CO_2 concentration between troposphere and stratosphere at different times of the year, differences as calculated from each flight are shown in Fig. 2.

Fig. 3 shows the annual increase between successive years. For a comparison, the data as obtained by Keeling and Bainbridge (1971) for Mauna Loa and smoothed data as presented by Keeling et al. (1972) for the South Pole are also shown.

Discussion

The marked shift in phase and amplitude of the seasonal CO_2 variation is somewhat stronger between troposphere and stratosphere than between data from the 10 and 12 km levels. This deviation can be explained by the fact that the height of the tropopause changes by season and also during a single flight. The data at the two latter levels, therefore, most certainly include both tropospheric and stratospheric samples, as well as samples collected within the transition layer at the tropopause. The difference in amplitude of the two curves in Fig. 2 can be explained in the same way. However, by calculating an annual average, a difference of about −1 ppm occurs for the stratospheric data. Obviously, the 1971 data dominate somewhat in this calculation during the last part of the season. Since the 1971 data

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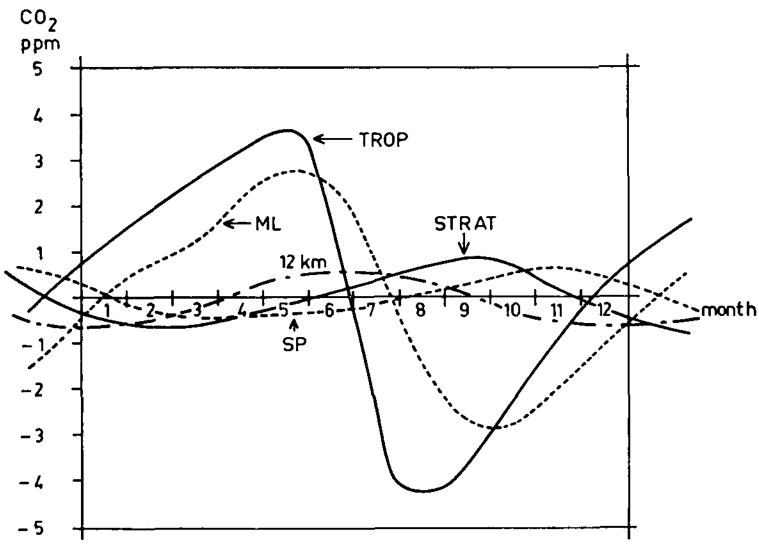

Fig. 1. CO_2 seasonal variation. Aircraft data, 50°–70° N: upper troposphere (TROP), lower stratosphere (STRAT), constant 12 km altitude (12 km). Scripps data: Mauna Loa (ML), Hawaii, 20° N, South Pole (SP).

show considerable deviation in the annual cycle compared with other years, the results in Fig. 2 include some uncertainty in this aspect.

The reported aircraft data were obtained between 50° and 70° N, where airmasses are affected by the CO_2 sources and sinks at the ground. Although samples were primarily collected over the North Atlantic, the influence of such processes are still clearly observed at the tropopause level. Compared with Mauna Loa, 20° N at 3 km elevation (Fig. 1) the aircraft data show a somewhat larger amplitude.

Between Mauna Loa and South Pole, a shift occurs in phase of about 5 months and a

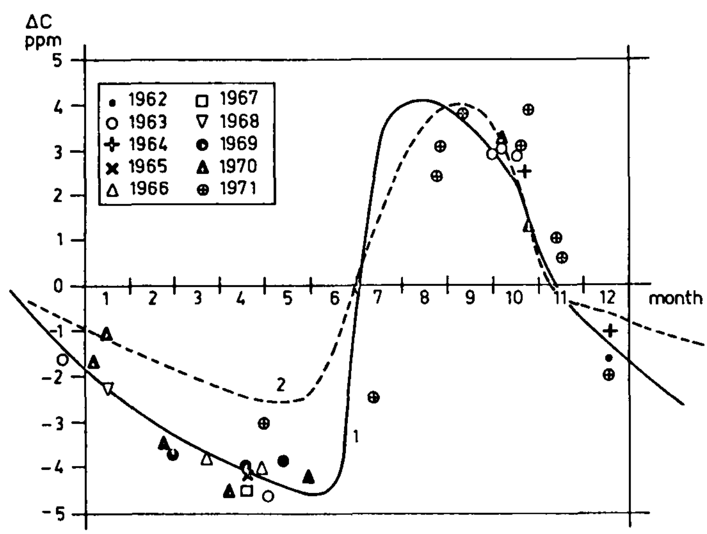

Fig. 2. CO_2 concentration differences ΔC between samples collected in the troposphere and stratosphere (symbols). Curve 1 is the difference between the average seasonal variation in the upper troposphere and lower stratosphere see Fig. 1. As a comparison curve 2 shows the difference between the 12 and 10 km height level.

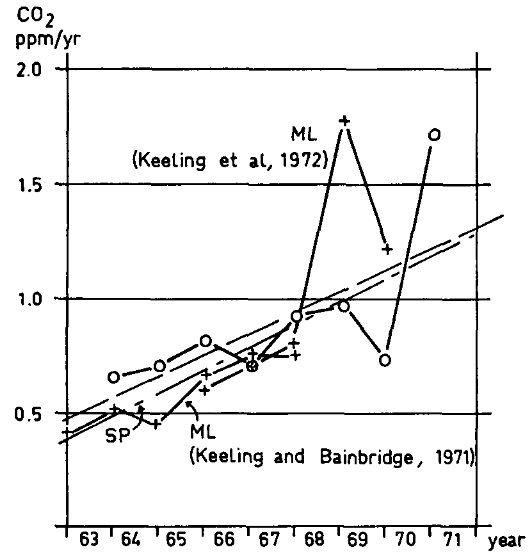

Fig. 3. CO_2 annual increase rate. Circles are mean values from the aircraft data (troposphere and stratosphere). *ML* and *SP* denote Mauna Loa and South Pole respectively. The dashed line is the mean increase trend for the aircraft data.

change in amplitude of about 2 ppm. A similar phase and amplitude shift is observed between troposphere and stratosphere; i.e. the stratospheric cycle is very close to that of the South Pole. Since no significant sources and sinks for CO_2 which vary with the season are present in the Southern Hemisphere, phase and amplitude shift are presumably the result of mixing and transport processes between the hemispheres (Bolin and Keeling 1963). Since the stratospheric cycle is not affected by sources and sinks in the stratosphere, the phase and amplitude shift in the aircraft data will also have to be explained as a result of mixing and transport processes.

The circulation model developed by Dobson and Brewer has been applied by several investigators to study the transport of water vapor, ozone and radioactive tracers. The model, in principle, includes equatorward transport in the troposphere and upward flux within the tropical tropopause region into the stratosphere, mixing and poleward transport within the stratopshere of both hemispheres, (Reed and Vlcek 1969, Manabe et al. 1965, Mastenbrook 1971). Brewer, (1949), calculated a transport time of the order of 100–200 days from the equator to about 50° N within the stratosphere. Burton and Steward (1960), using long-lived natural radioactive tracers, estimated a circulation time of air entering the stratosphere from the troposphere above the U.K. and found a circulation time of about six months. This number is an agreement with our aircraft data, if we assume that the phase delay shown in Fig. 1 is an indicator of the transport time, as was assumed for the South Pole data. The annual increase rate as given in Fig. 3, shows considerable scatter towards the end of the period. An increasing trend is, however, obvious. For the aircraft data, the average of this increase for the whole period is 0.09 ppm/year^2, with an average scatter of ± 0.26 ppm/year^2; close to the South Pole the corresponding value is 0.10 ppm/year^2. A considerable larger trend exists, however, in the Mauna Loa data, according to Keeling and Bainbridge (1971). The somewhat modified data recently reported by Keeling et al. (1972) do not, in general, change the increase trend for the period investigated here. However, it should be pointed out that the annual increase rate for Mauna Loa as well as for the South Pole station was much less during 1962–1964, i.e. at the beginning of the period investigated here.

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КОНЦЕНТРАЦИИ ДВУОКИСИ В ВЕРХНЕЙ ТРОПОСФЕРЕ И НИЖНЕЙ СТРАТОСФЕРЕ. III

Исследования содержания CO_2 в атмосфере показали, что существует заметная разница между результатами проб, взятых в тропосфере и в стратосфере (Бишоф, 1965, Бишов и Болин, 1966, Бишоф, 1971). С помощью всех доступных данных полетов в течение 1963–68 гг. найдено, что существует значительное изменение в амплитуде и фазе годовых циклов вариаций концентрации на уровне 12 *км* по сравнению с более низкими уровнями (Болин и Бишоф, 1970). Однако вследствие недостаточности данных не было сделано различие между тропосферными и стратосферными пробами. Если учесть данные проб 1969–71 гг., то такое различие может быть проведено и оно ясно показывает, что амплитуды и фазы разные в верхней тропосфере и нижней стратосфере. Результаты представлены ниже и они сравниваются с данными, полученными в Скрипповском океанографическом институте. Данные также показывают, что годовое увеличение концентрации CO_2 в атмосфере растет примерно на $9 \cdot 10^{-8}$ год$^{-2}$.