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LONG-TERM TEMPERATURE TRENDS IN THE STRATOSPHERE : POSSIBLE INFLUENCE OF ANTHROPOGENIC GASES

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Abstract. Analysis of northern hemisphere mid-latitude temperature data at 30 mbar over the last 20 years suggests a long-term negative trend of about - 0.24 K/decade when all observations between 10°N and 90°N are considered. This stratospheric cooling which could tentatively be attributed to the increase of the carbon dioxide amount in the stratosphere is in qualitative agreement at 30 mbar with a model calculation of the historical evolution of temperature and chemical composition in the middle atmosphere.

Introduction

The continuous increase of the CO_2 content in the atmosphere as well as the release of several other gases produced by human activities, with the subsequent change in the ozone amount, is expected to infer significant climatic changes. Numerical models (e.g. Wuebbles et al., 1983; Brasseur et al., 1985; Brühl and Crutzen, 1985) have predicted quantitative variations in the atmospheric composition as well as in the temperature. These models indicate that ozone and temperature changes should be very pronounced in the upper stratosphere, but that noticeable effects should be present as low as the level of 10 to 30 mbar. Data obtained in the past, especially observed temperatures which have been consistently reported, should provide some indications about the possible response of the atmosphere to man-made perturbations. Parker (1985) for example, using selected stations, finds that there is no clear indication of a cooling in the lower stratosphere but derives a significant cooling at the 50 mbar level in summer if only the more reliable US weather Bureau radiosonde data are used.

The purpose of this paper is to report long-term observational data and to show that they are consistent with a calculated temperature decrease over the last 20-30 years in the middle stratosphere.

Observed Temperature Variations on a Hemispheric Scale

Based on daily radiosonde observations (approximately two times 450 soundings per day, i.e. at 00 and 12 GMT), height and temperature fields for several stratospheric pressure levels are analyzed for each day; (Meteorologische Abhandlungen, Freie Universität Berlin, since 1958). These analyses are a research product, analyzed subjectively after all data have been received. The analyses are built up hydrostatically from the 50-mbar level, giving much weight to the vector and thermal winds, assuming geostrophic conditions. Consistency in time and space is attempted. We assume this procedure to be superior to the use of single, selected stations (Parker, 1985). The daily charts are digitized on a 10 by 10 deg. latitude-longitude grid and monthly means of zonal mean temperatures are derived. Over middle latitudes, each monthly mean value of a zonal mean temperature is thus based on approximately 3000 observations. This implies an extremely small error bar. Furthermore, a 39 point filter is used to eliminate the high frequency variations, in particular the annual cycle and the quasi-biennal oscillation. Figure 1 shows the resulting filtered zonal mean temperature as a function of time. It can be seen that, when the high frequency fluctuations have been removed, significant long-term variations remain, whose origin cannot be clearly and entirely explained. For example, Naujokat (1981) showed that no convincing statistical evidence exists between temperature behavior and the sunspot number. At high latitudes, however, the variations appear to be connected with the occurence of intense mid-winter warmings. Furthermore, the temperature enhancement detected since 1980 in the tropics and at mid-latitude (as far as 70°N) can probably be attributed to the increased aerosol load after the volcanic eruptions of Mt St Helens and El Chichon (Labitzke et al., 1983).

From least-square fits of the data, made for each latitudinal band over the period February 1966 - April 1980 (prior to the 2 volcanic eruptions), one derives long-term trends of - 0.03 K/decade at 80°N, - 0.56 at 70°N, - 0.63 at 60°N, - 0.70 at 50°N, - 0.48 at 40°N, - 0.22 at 30°N and + 0.03 at 20° N. A trend of about - 0.6 K/decade is thus clearly visible at 30 mbar between 50 and 60°N before the appearance of the rapid temperature increase in 1980, probably related to the volcanic eruptions. At lower latitudes (30°N), the temperature variation appears to be smaller and is even reversed in the tropics as a positive trend of + 0.24 K/decade is derived at 10°N. The resulting area weighted averaged trend for the 1966 - 1980 period is - 0.24 K/decade when all observations (between 10 and 90°N) are considered and - 0.34 K/decade, when the noisy data at 10°, 80° and 90° N are omitted. This cooling could be related to the observed increase in carbon dioxide, with the related enhanced infrared emission to space, and to the expected ozone depletion in the upper

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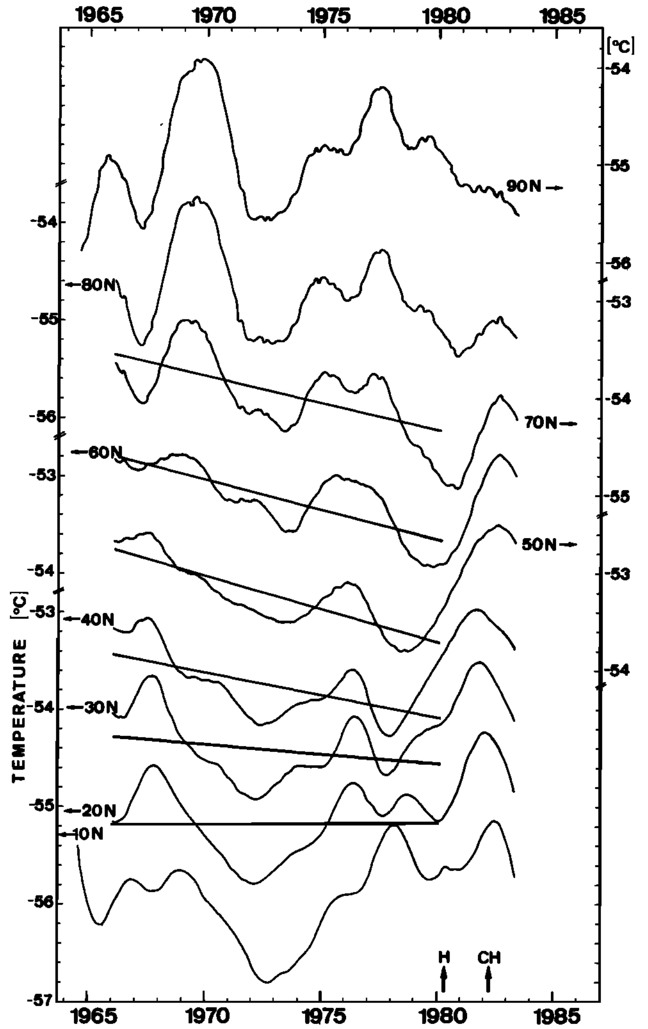

Fig. 1. Zonal means of filtered monthly mean 30-mbar temperatures (°C) at selected latitudes. Straight lines are least square fits for the period February 66 - April 80.

stratosphere due to the release in the atmosphere of chlorofluorocarbons, with the subsequent decrease in the solar ultraviolet absorption. This reduction in upper stratospheric ozone allows the radiation to penetrate more deeply in the atmosphere, to produce ozone below 30 km and to induce a small additional heating in the lower stratosphere. The smaller trend of the temperature with decreasing latitude may thus be explained by this self healing effect of ozone, which is largest near the equator.

Model Simulation and Comparison with Data

In order to test the consistency of the long-term temperature trend inferred from the data at mid-latitude, a calculation of the chemical and thermal evolution of the middle atmosphere has been performed using a one-dimensional model with coupled chemical and radiative schemes. This model considers a number of species belonging to the O_x, HO_x, NO_x, ClO_x and CO_x families (Brasseur et al., 1982). The chemical rate constants are taken from the JPL publication (1983) and the solar irradiance from Brasseur and Simon (1981). The vertical profiles of the long-lived species are calculated from continuity equations in which the vertical flux is parameterized by a prescribed eddy diffusion coefficient. The temperature is calculated self-consistently by considering explicitely the absorption of the solar UV radiation by O_3 and O_2 and by using the radiative model of Morcrette (private communication, 1983) for calculating the radiative transfer of terrestrial and atmospheric radiation in the infrared bands of CO_2, O_3 and H_2O (see also Brasseur et al., 1985 for a description of the radiative model). The direct radiative contribution of N_2O, CH_4 and the chlorofluorocarbons is ignored but their chemical effects on ozone are considered explicitely.

The simulation is started in 1940 and performed until year 1985. It is based on the historical increase in the CO_2, N_2O and CH_4 mixing ratio suggested by Wuebbles et al. (1984) and shown in Figure 2.a for the period 1960-1985. The adopted emission of CFC-11 and 12 is based on figures provided by the Chemical Manufacturers Association (private communication) and the release of CCl_4 and CH_3CCl_3 is taken from Simmonds et al. (1983) and Prinn et al. (1983), respectively. The emission values for these chlorine species are shown in Figure 2.b.

The resulting change in temperature at selected heights, relative to year 1960, is displayed up to 1985 in Figure 3.a. This graph shows that the sensitivity of the temperature to changes in the atmospheric composition increases with altitude but is already apparent at 30 mbar. During the course of the integration from 1940 to 1985, the CO_2 mixing ratio has increased from 308 to 345 ppmv. For the same period, the concentration of total odd chlorine in the upper stratosphere has been multiplied by a factor 2.2 leading to an ozone depletion in 1983 of 4% at 50 km, 12.5% at 40 km, 0.2% at 30 km. A small increase (Figure 3.b) of about 1% is predicted at 20 km and at 24 km (30 mbar) in good agreement with the model of Wuebbles (1985). The calculated change in the ozone concentration at 30 mbar is thus very small and the long-term decrease in the temperature at this level should not be attributed to changes in the local ozone density but more probably to the CO_2 increase. Furthermore, the cooling due to the enhanced infrared emission in the 15 μm band should be somewhat counterbalanced by the heating resulting from larger solar ultraviolet penetration due to significant ozone depletion in the upper stratosphere. The model predicts a 0.2K temperature reduction at 30 mbar in the last 10 years. This amount, which should be regarded as a global value, is significantly smaller than the trend inferred from the data between 40 and 70°N but in good agreement with the data analysis if the apparently smaller long-term trends at lower latitude are taken into account to determine a global hemispheric temperature trend.

Long-term stratospheric temperature changes at higher altitude are not yet well established. In a recent study (Johnson and Gelman, 1984) the western hemisphere rocketsonde network reports have been used for the period 1965 to 1983, with careful quality procedures to the data. The authors conclude that the change in rocketsonde

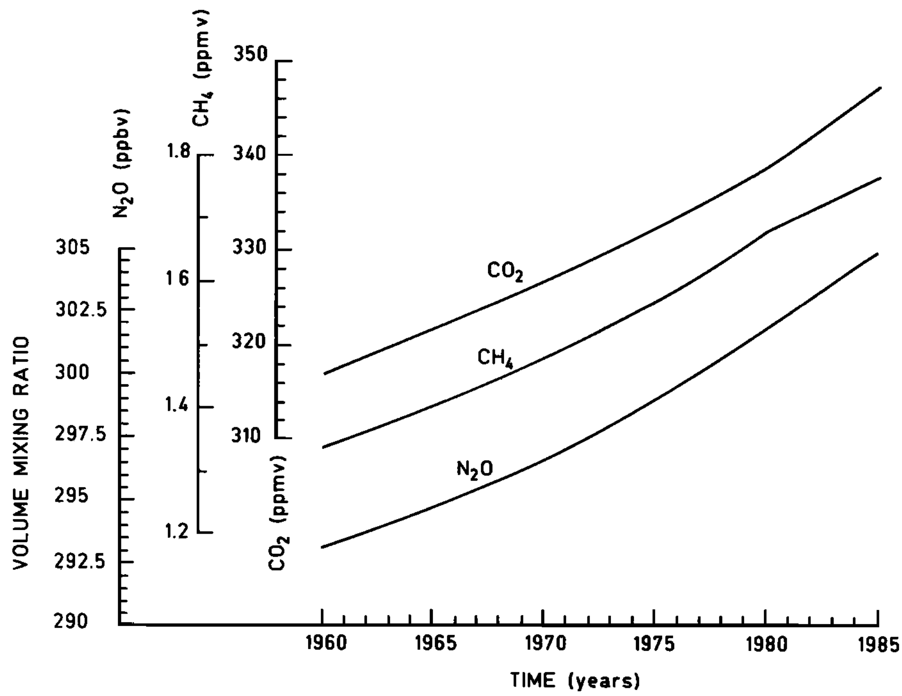

Fig. 2a. Increase in the tropospheric CO_2, CH_4 and N_2O mixing ratio between 1960 and 1985 adopted in the model as input data.

temperatures in the early 1970's, as derived from the data, simply reflects a previously uncompensated change in the rocketsonde temperature measurement system. They have tried to determine

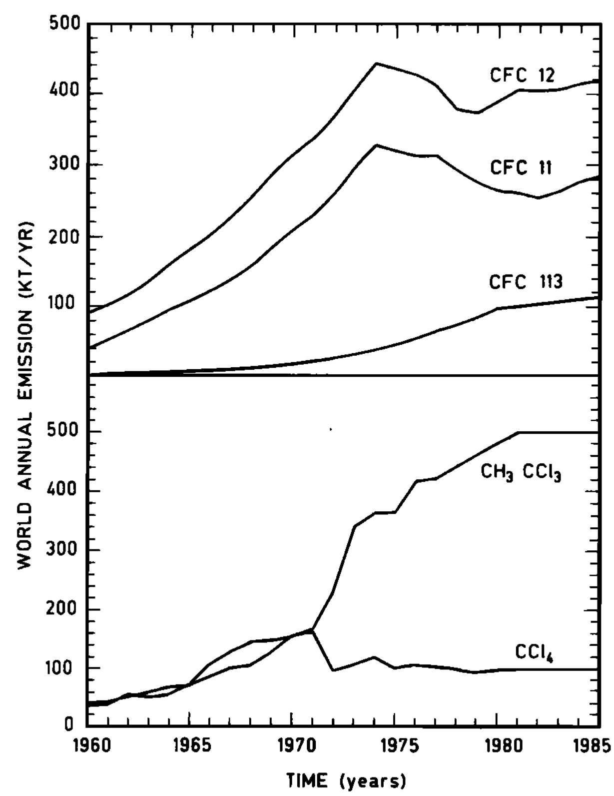

Fig. 2b. Same as in figure 2a but for the world annual emission of chlorocarbons 11, 12 and 113 and of carbon tetrachloride and methyl chloroform.

a trend in the 40-45 km temperature data (only for June) for the limited period 1973-1983 which is after the instrument transition. The results indicate a negative trend of - 0.75K/decade with a standard error of 0.34K/decade. (Personal communication by A.J. Miller, NOAA). This decrease is somewhat smaller than the trend predicted by Wuebbles (1985) (- 1.2 to - 1.7 K/decade) and by our model calculation (- 0.4K at 30 km, - 1.5K at 40 km, - 2.0K at 50 km between 1970 and 1980).

Conclusions

Temperature data at the 30 mbar level in the last 20 years, especially at mid-latitude, where the fluctuations are smaller than in the tropical and polar regions, show a negative trend until the end of the 70's, when the background tempera-

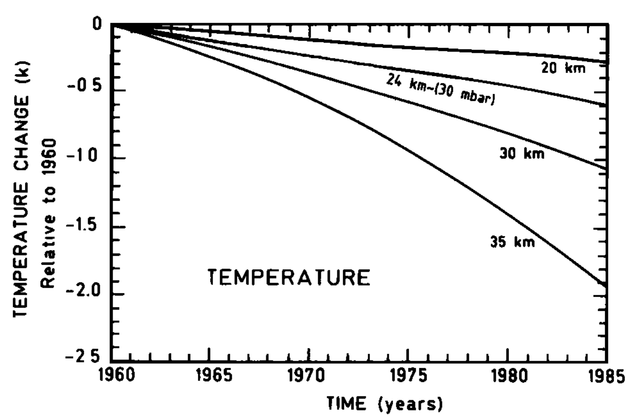

Fig. 3a. Calculated change in the stratospheric temperature at selected altitudes, between 1960 and 1985.

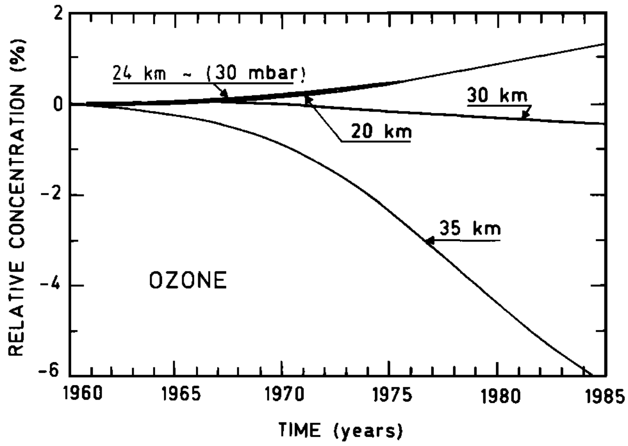

Fig. 3b. Relative change in the ozone concentration calculated at selected altitudes between 1960 and 1985.

ture becomes disturbed by the effects of volcanic explosions. This long-term cooling, which is believed to be due - at least partly - to the changes in atmospheric composition, especially the the increase in the CO_2 amount, is more pronounced at mid- and high latitudes (40-70°N) than in the tropics. This negative trend averaged over the Northern hemisphere (- 0.24 K/decade between 1966 and 1980) is in qualitative agreement at 30 mbar with numerical modeling predictions (- 0.2 K/decade) when the historical increases in the mixing ratio and in the atmospheric release of source gases are considered.

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