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TRENDS IN OZONE AND TEMPERATURE STRUCTURE: COMPARISON OF THEORY AND MEASUREMENTS

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Summary

Comparison of model calculated trends in ozone and temperature due to inferred variations in trace gas concentrations and solar flux, are made with available analyses of observations. In general, the calculated trends in total ozone and the vertical ozone distribution agree well with the measured trends. However, there are too many remaining theoretical and sampling uncertainties to establish causality. Although qualitatively in agreement, the observed temperature decrease in the upper stratosphere is significantly larger than that calculated. Theoretical results suggest a significant influence on stratospheric ozone from solar flux variations, but observational evidence is at best inconclusive. Overall, the trend comparisons tend to be consistent with the hypothesis that several different anthropogenic influences are affecting the present global atmosphere.

1. Introduction

The detectability of changes in ozone and temperature, and the underlying causes of observed changes, are of particular interest because of potential anthropogenic influences. In this study, trends in ozone and temperature calculated in the LLNL one-dimensional model of the troposphere and stratosphere are compared with available analyses of observed trends. The purpose is to examine whether substantial discrepancies exist between current theoretical results and observed trends. Because of the limited availability of data, primary emphasis is on the comparison of measurements with model-calculated trends in ozone and temperatures during the decades of the 1960s and 1970s, and the beginning of the 1980s.

Theoretical calculations suggest that changing concentrations of a number of anthropogenically influenced trace gases may presently be altering the global atmospheric ozone distribution and temperature structure. Concentrations and/or emissions of gases such as CO_2, CH_4, N_2O, several chlorocarbons (CℓCs), and NO_x from aircraft and nuclear tests are varied historically based on consideration of recent emissions evaluations and atmospheric measured trends (1). A variety of natural processes and phenomena are also known to affect the stratosphere. Variations in the solar ultraviolet flux over the 11-year sunspot cycle are included in this study (case a) based on the solar emissions model of Lean et al. (2). Because of uncertainties, a second case considered only half the solar flux variation at wavelengths greater than 180 nm (case b).

2. Trends in Total Ozone

Table 1 shows calculated changes in total ozone over recent decades for several of the scenarios examined. Cases I and II suggest that total ozone should have increased at a slow but steady rate throughout the 1960s and 1970s due to the influence of trace gas emissions. This increase in ozone is primarily due to increasing concentrations of CO_2 and CH_4, with a significant influence from aircraft emissions when included. A small decrease is derived in the total ozone trend when only chlorocarbons are considered.

TABLE 1. Calculated trends in total ozone (%/time period) for periods 1960-1970, 1970-1980, and 1980-1983.

	Case	1960-70	1970-80	1980-83
I	($C\ell C$ + CO_2 + N_2O + CH_4)	+0.30	+0.30	+0.09
II	(I + NO_x)[2]	+0.42	+0.60	+0.20
VI	$C\ell C$ only	-0.03	-0.12	-0.07
VIII	I + solar variability (a)	+1.29	+0.71	-2.69
IX	I + solar variability (b)	+0.74	+0.49	-1.19

In evaluating the trend in total ozone during the 1960s, it is necessary to consider the NO_x produced by nuclear tests of the late 1950s and early 1960s. Several data analyses suggest that a decrease in total ozone may have occurred at the time of the nuclear test series. Figure 1 shows that the calculated effect of the nuclear tests is a maximum total ozone decrease of 2.5%. These results are consistent with the upper limits (< 4%) estimated by the analyses of total ozone data. However, as seen from Fig. 1, a minimum in total ozone is also calculated for the early 1960s when considering the influence of solar cycle variations.

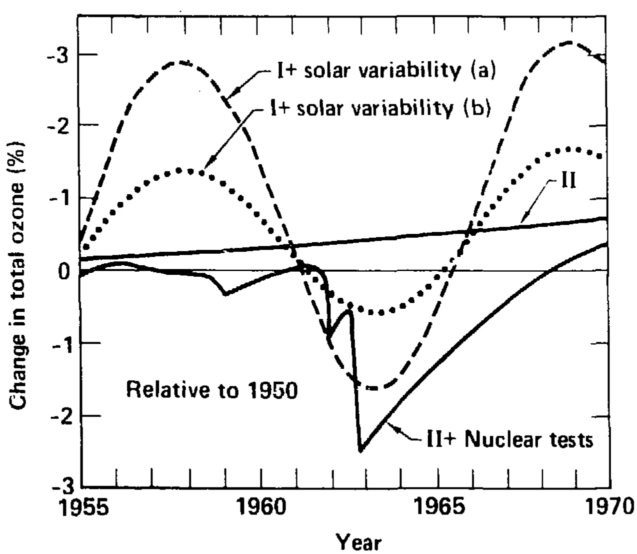

Figure 1. Calculated change in total ozone for the 1960s.

The cases which consider the possible effects of solar cycle variations calculate a change in total ozone of approximately 2.1% (case b) to 4.4% (case a) from solar minimum to solar maximum. Solar cycle variations could make detection of trends in total ozone due to anthropogenic influences more difficult. Observational evidence of a relationship between total ozone and solar activity is at best inconclusive. Larger than normal total ozone amounts were observed in the years of the solar maximums (3). However, a minimum in total ozone calculated to occur in 1975 is not obviously evident in the observations.

Assuming Cases I and II correspond approximately to the conditions for the Southern and Northern Hemispheres, respectively, then the results shown in Table 2 suggest a global trend of +0.45% from 1970-1980 due to the effects of trace gases. Reinsel (4), using time series statistical analysis derived the global ozone change from 1970-1980 based on Dobson total ozone column measurements to be 0.49(±1.35)%. The measured trends from this and other similar analyses are in excellent agreement with the calculated global change when all anthropogenic emissions are considered. Unfortunately, no definitive analysis is available of the measured difference in the trends of total ozone between hemispheres.

TABLE 2. Summary of comparison between calculated and observed trends during the 1970s.

	Calculated	Observed	Reference
Total ozone	+0.45%	+0.49±1.35%	(4)
Ozone distribution			
2-8 km	+6%	+7%	(3)
8-16 km	+3%	some +	(3)
16-31 km	+1%	little change	(3)
Umkehr level 5	+0.9%	-0.40±1.39%	(9)
6	-0.04%	-0.01±1.07%	(9)
7	-2.2%	-2.23±1.69%	(9)
8	-4.1%	-3.03±1.64%	(9)
9	-2.4%	-2.87±3.94%	(9)
Stratospheric temperatures			
26-35 km	-0.2 to -0.6K	-1.5 to -3K	(7)
38-45 km	-1.2 to -1.7K	-2.5 to -3.5K	(7)
48-55 km	-1.4 to -1.5K	-3.5 to -5K	(7)

3. Trends in the Ozone Vertical Distribution

The change in ozone with pressure level is shown in Fig. 2 for Case II at selected times relative to 1950. Tropospheric and stratospheric ozone are calculated to have changed significantly during the 1970s and 1980s (to 1983). The growing calculated decrease in upper stratospheric ozone results primarily from chlorocarbon emissions. The increase in the middle stratosphere results from increasing CO_2 and CH_4 concentrations as well as the ozone recovery mechanism. The increase in the troposphere and lower stratosphere results from the assumed aircraft NO_x emissions and increasing CH_4 concentrations. A maximum decrease over the 1970s of 4.4% is calculated in the upper stratosphere (at 3.5 mb). A maximum ozone increase of 6.7% is calculated in Case II in the upper troposphere. A much smaller increase (~2% at the surface and <1% in upper troposphere) is determined for the Southern Hemisphere (Case I) troposphere, which does not include aircraft emissions.

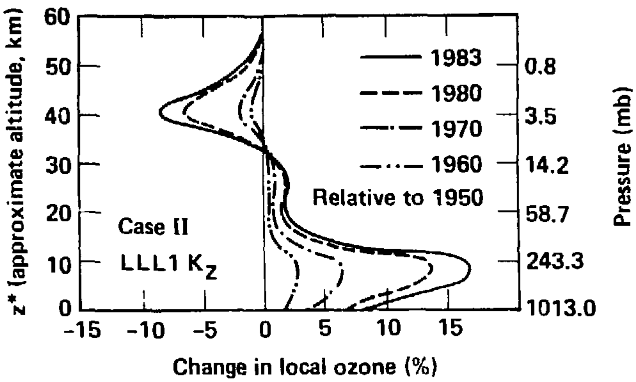

Figure 2. Calculated percentage change in ozone for Case II at selected times relative to 1950.

By comparison, ozonesonde measurements in the tropospheric layer from 2-8 km in northern temperate latitudes suggest nearly a 7% ozone increase during the last decade (3,5). Little change was found in Southern Hemisphere data. The limited amount of data makes interpretation of these analyses highly uncertain. Some ozone increase in Northern Hemisphere data is also indicated for the 8-16 km layer with little change in ozone from 16 to 32 km (3). Umkehr data for upper stratospheric ozone have recently been reanalyzed to correct for potential errors, such as those due to atmospheric aerosols and changes in instrumentation (6). Calculated trends are within the observation confidence limits at all levels (see Table 2).

4. Trends in Upper Air Temperatures

Figure 3 shows the calculated change in stratospheric temperatures at selected times from January 1950 to January 1983. The stratosphere is calculated to cool throughout this period, primarily due to the increasing CO_2 concentrations, but also due to decreasing ozone amounts in the upper stratosphere. The largest cooling occurs at approximately 2.4 mb (~42.5 km). Radiosonde data (7) at 16-24 km suggest a small decrease in temperature of approximately 0.2-0.4 K during the 1960s, in good general agreement with the calculated results. Measured trends at higher altitudes during the 1960s were not available for comparison. From January 1970 to January 1980, the maximum calculated temperature change of -1.7 K occurred in both Cases I and II at 2.4 mb. Similar upper air temperature changes are calculated for both the Northern and Southern Hemispheres. The calculations agree qualitatively with the analysis of rocketsonde data (7) of a surface and tropospheric warming and stratospheric cooling during the past decade. However, the data suggest larger changes in stratospheric temperatures during the 1970s than are calculated (see Table 2). Such a large change in temperature, if real and not due to sampling errors, requires additional theoretical analysis as to its cause. It is difficult to develop a mechanism for explaining the large observed decrease in temperature. A larger cooling than that calculated would add to the calculated increase in total ozone over the decade and reduce the magnitude of the calculated decreases in upper stratosphere ozone.

5. Discussion

Table 2 summarizes the comparisons of calculated and observed global trends in ozone and temperature for the 1970s. Although the model calculated trends in ozone and temperature for the 1960s and 1970s are generally

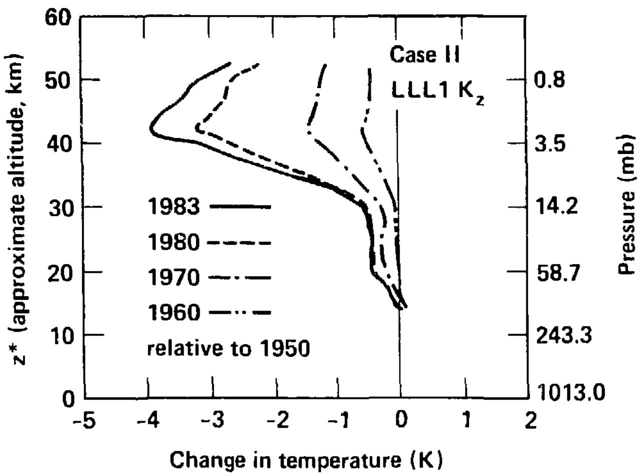

Figure 3. Calculated changes in stratospheric temperatures for Case II at selected times relative to January 1950.

in agreement with the measured trends, there are too many remaining theoretical and sampling uncertainties for causality to be established. Overall, the trend comparisons tend to be consistent with the hypothesis that several different anthropogenic influences are affecting the present global atmosphere.

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