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RADIATIVE FORCING PERTURBATION DUE TO OBSERVED INCREASES IN TROPOSPHERIC OZONE AT HOHENPEISSENBERG

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1. Introduction

The effect on surface temperature due to changes in atmospheric O_3 depends highly on the altitude where the change occurs. Previous sensitivity calculations indicate that ozone changes in the upper troposphere and lower stratosphere are more effective in causing surface temperature change (Wang et al., 1980). Long term ground-based observations show that tropospheric ozone, especially at the tropopause region, has been increasing at middle and high latitudes in the Northern Hemisphere (NATO, 1988; Quadrennial Ozone Symposium, 1992). These increases will enhance the greenhouse effect and increase the radiative forcing to the troposphere-surface system, which is opposite to the negative radiative forcing calculated from the observed stratospheric ozone depletion recently reported in WMO (1992).

We used more than two thousands regularly measured ozonesondes providing reliable vertical O_3 distribution at Hohenpeissenberg (47N; 11E) for the 1967-1990 to study the instantaneous solar and longwave radiative forcing during the two decades 1971-1990 and compare the forcing with those caused by increasing CO_2, CH_4, N_2O, and CFCs. Calculations are also made to compare the O_3 radiative forcing between stratospheric depletion and tropospheric increase. Results indicate that the O_3 changes will induce a positive radiative forcing dominated by tropospheric O_3 increase and the magnitude of the forcing is comparable to that due to CO_2 increases during the two decades. The significant implications of the tropospheric O_3 increase to the global climate are discussed.

2. Ozone Variations

Variations of the O_3 concentration in the stratosphere and troposphere are shown in Fig. 1. Note that the tropopause is assumed to be ~200 and 300 mb for summer and winter, respectively, and ~250 mb for spring and fall. The data indicate that, during this period, O_3 decreases in the stratosphere for all seasons and the decrease is particularly large in winter and spring. On the other hand, tropospheric O_3 has been steadily increasing and the increases are larger in spring and summer. Figure 2 shows the changes of the January and July O_3 vertical distribution between two decades, 1971-80 and 1981-90. On the decadal time scale, the stratospheric O_3 decreases 10-12% around 13-18 km in January while tropospheric O_3 increases 20-30% between 5-8 km for both months. Note that since the tropospheric O_3 amount is about 7-13% of the total column (see Fig. 1), the trend of the total O_3 at Hohenpeissenberg over the whole period show a decline by 2.3%/decade [WMO, 1992].

3. Radiative Forcing

To carry out the solar and longwave radiation calculations, we used (a) the January and July climatological temperature and moisture, (b) incoming solar radiation based on the middle of January and July with corresponding surface albedo 0.4 and 0.2, respectively. For the results shown below, we used clear sky condition.

The effects on the solar and longwave radiative fluxes to the troposphere-surface climate system due to changes in atmospheric O_3 will depend on the altitudes where O_3 changes. For example, a decrease in stratospheric O_3 is to provide: (a) a warming effect due to increased available solar radiation for absorption and (b) a cooling effect due to decreased downward longwave radiation; the net effect will depend on the location and time of the year. On the other hand, an increase in tropospheric O_3 can warm the troposphere-surface system through increased in absorption of both the solar radiation and longwave radiation. Table 1 shows the calculated solar and longwave radiative forcing due to observed O_3 changes at Hohenpeissenberg. To examine the relative importance of the vertical O_3 changes, we include the calculations of the radiative forcing due to changes in the individual stratosphere and troposphere. Note that in January the total radiative forcing 0.13 Wm^{-2} is dominated by the longwave radiative forcing. On the other hand, in July, the total forcing of 0.62 Wm^{-2} contributed almost equally from the solar and longwave radiative forcing. Note also that the total longwave radiative forcing is contributed mainly from tropospheric O_3 changes while stratospheric O_3 plays minor role.

Comparison of the radiative forcing between O_3 changes and increases of greenhouse gases CO_2, CH_4, N_2O, and CFCs between the two decades are shown in Table 2. The total radiative forcing is calculated to be 0.5 and 1.1 Wm^{-2} respectively for January and July. In January, CO_2 accounts for about 46% of the total forcing while the effect of O_3 is to contribute 26% of the forcing. On the other hand, O_3's effect in July dominates and accounts for over half of the total forcing.

4. Conclusions and Discussion

It appears that the observed decrease in stratospheric O_3 and increase in tropospheric O_3 during the last two decades at Hohenpeissenberg can contribute substantially to a warming of the local troposphere-surface climate system. The calculations indicate that O_3 changes can account to 26% and 56% respectively of the total January and July radiative forcing of all the greenhouse gases. In addition, the O_3 radiative forcing is dominated by the increases of the tropospheric O_3 while

Table 1 Radiative forcing (Wm^{-2}) for the troposphere-surface system due to O_3 changes between the 1971-80 and 1981-90.

Month	Stratosphere		Troposphere		Total	
	SW	LW	SW	LW	SW	LW
January	0.006	0.007	0.001	0.125	0.007	0.130
July	0.213	-0.036	0.110	0.338	0.324	0.302

SW and LW refer to solar and longwave radiation respectively; The tropopause is 300 mb for January and 200 mb for July.

Table 2 Changes of the total radiative forcing (Wm^{-2}; SW+LW) for the troposphere-surface system due to O_3 changes and increasing other gases CO_2, CH_4, N_2O, and CFCs between 1971-80 and 1981-90.

Month	O_3	CFCs	CO_2	CH_4	N_2O	Total
January	0.137 (26.3)	0.066 (12.7)	0.238 (45.7)	0.064 (12.2)	0.016 (3.1)	0.521
July	0.610 (56.1)	0.105 (9.7)	0.270* (24.8)	0.083 (7.6)	0.019 (1.8)	1.087

Values in parenthesis are percentage of the total.
*The results include a radiative forcing -0.016 Wm^{-2} due to changes of SW by CO_2 increases.

stratospheric O_3 decrease plays a minor role. This finding will have broad climate implications since the other ground ozonesonde stations located in middle and high latitudes of the Northern Hemisphere all show an increases of the tropospheric O_3.

References

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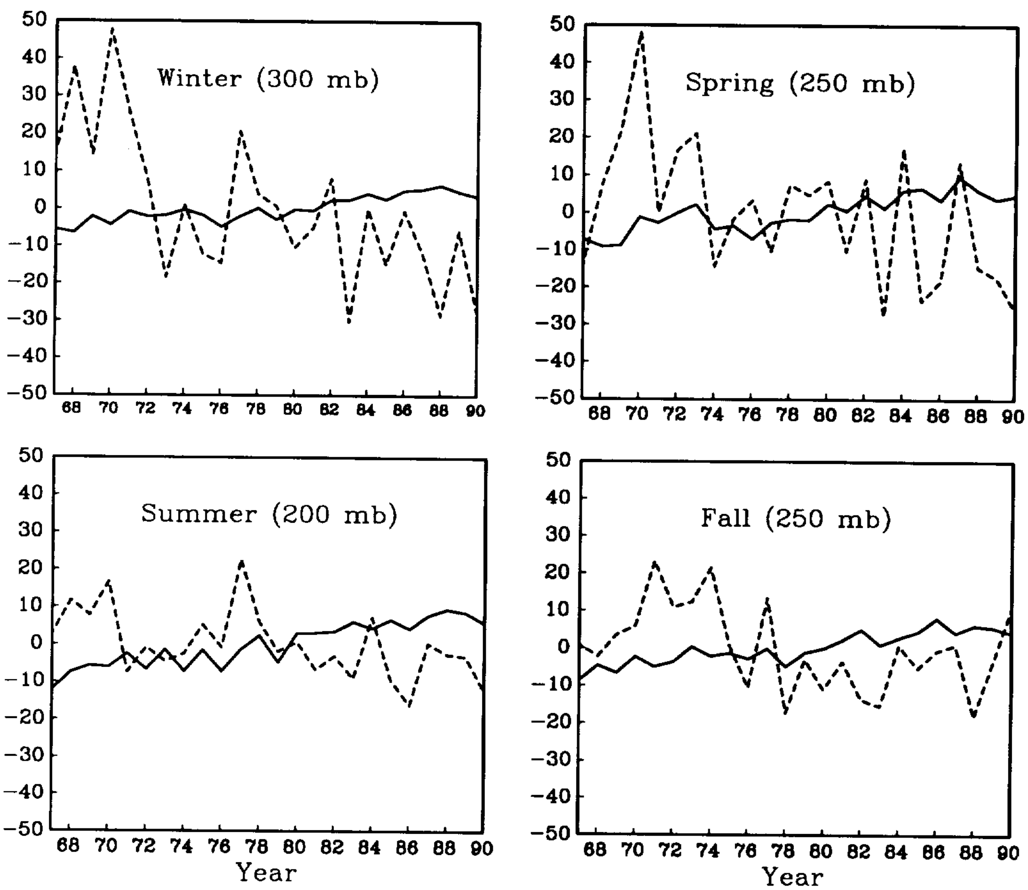

Figure 1: Seasonal variations of O_3 (DU) in the stratosphere (dashed line) and troposphere (solid line) at Hohenpeissenberg for the period 1967-1990. The first number inside the parenthesis is the mean value for the troposphere while the second number is for the stratosphere). The four seasons are winter (December-January-February), spring (March-April-May), summer (June-July-August) and fall (September-October-November). The tropopause is ~200 mb for summer, ~250 mb for spring and fall, and ~300 mb for winter.

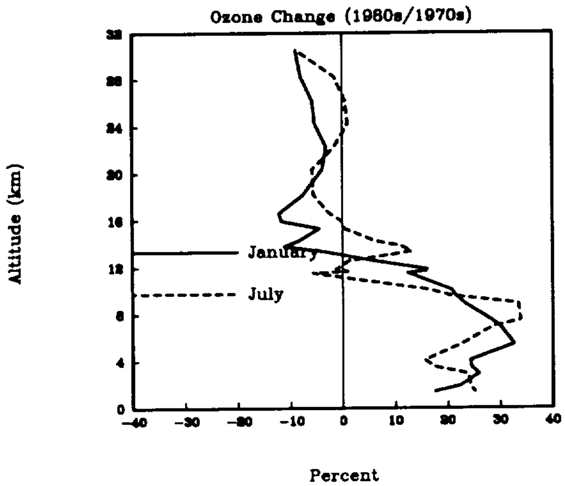

Figure 2: Vertical distribution of change in mean O_3 (%) between the 1971-80 and 1981-1990 at Hohenpeissenberg.